Potential for the Use of Environmentally Friendly Geotextiles for Ground Strengthening

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ABSTRACT

Built environment protection is important because construction represents a major contribution to climate change, resource depletion and pollution at a global level. Global strategy for more sustainable construction is a significant step towards a more successful, socially and environmental friendly atmosphere making a strong contribution to the better quality of life signaled by sustainable development strategy. The brightest sustainable strategy in ground engineering is the /consideration of substituting the use of biodegradable materials as substitute to the non-biodegradable (man-made materials) in situation where there is requirement for short-term ground improvement. The most important properties of biodegradable geotextiles such as Vegetable Fibres for soil reinforcement are their high initial tensile strength. Widespread use of biodegradable fabrics in ground engineering has not happened due to the limited service life of these fabrics and availability of chemical fibres, which are superior to vegetable fibres. The overall aim of this paper demonstrates the potential for the use of sustainable biodegradable vegetable fibres over man-made polymeric materials in ground improvement

Keywords: Vegetable fibres, soft soil reinforcement, embankments, biodegradable geotextiles

1. INTRODUCTION

Low-cost roads, whether bound or unbound, reinforced or unreinforced are exposed to both short-term and long-term repeated, high and focused loads which can cause premature failure. The major applications of reinforcement during road construction are to strengthen the pavement ,provide an increased working life , reduce deflections, reduce rutting and fatigue cracking, reduce the amount of base materials. A wide range of ground conditions, require a wide range of reinforcement products as well as the duration of which reinforcement are required during the life cycle of either bound or unbound roads. The question on whether reinforcement are required for short term or long term should be addressed during the design period since one style of geotextiles will not be optimal for all ground types. The potential to reduce construction materials in these roads saves on the export and import of materials from site, by using sustainable materials such as Limited Life Geotextiles manufactured using Vegetable Fibre especially in developing countries where vegetable fibres are abundant .

Environment protection is important because construction represents a major contribution to climate change, resource depletion and pollution at a global level. This Strategy for more sustainable construction is a significant step towards a more successful, socially and environmental friendly atmosphere making a strong contribution to the better quality of life signaled by our sustainable development strategy.

Consumption of plastics by the building and construction sector in Western Europe is predicted to rise by more than 60%, to almost 8 million tonnes in 2010. Construction is already the second largest market for plastics after packaging, accounting for 20% (4.89 million tonnes) of total plastics consumption in 1995 (http://dioxin.abag.ca.gov/pilot_projs/PVC_FAQ.pdf 2007 cited 2008). High consumption of plastics in construction industry has critical environmental effects since 47 chemical plants ranked highest in carcinogenic emissions by the Environmental Protection Agency (EPA), 35 are involved in plastic production. Plastics such as polyvinyl chloride (PVC), used for indoor and outdoor construction works are potential sources of highly toxic dioxins (Sarsby 2007). Other polymeric materials used in construction such as polystyrene products are often made with chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs), both of which are ozone-destroying chemicals.

There are many other disadvantages associated with the use of polymeric materials in construction industry such as:

- The polymeric materials are manufactured using petroleum products which are expensive especially for the developing countries;
- Polymeric materials are usually non-renewable resource;
- Polymeric materials can create environmental pollutants;
- As litter it defiles private and public land and poses a serious threat to domestic and wildlife often causing death through suffocation or entanglement.

UNCTAD [3] identified two approaches to reduce harmful environmental impacts namely:

- Reduce the consumption in the developed countries, whilst concomitantly avoiding replication in developing countries of the consumption patterns of the developed ones.
- Reduce the environmental impact of consumption by identifying environmentally preferable products with less harmful environmental impacts during their life cycles, improve the awareness of consumers and industries about the existence of such alternatives, improve the competitiveness of these products, and shift demand towards them.

2. APPLICATIONS OF VEGETABLE FIBRES FOR GROUND ENGINEERING

The biobased geotextiles research project have been conducted by several Institutions in United Kingdom by Ali (1992), Sarsby (1992, 1994), Pritchard (1999), Booth *at. el.* (2005) in USA by USDA (United States Department of Agriculture) Forest services, Forest Products laboratory (FPL) (English 1993). Today most biodegradable geotextiles are used in erosion control where they serve to stabilize the soil surface while natural vegetation is established.

There are other numerous ground engineering situations where the critical period for stability is immediately, or very shortly, after construction, e.g. any form of 'foundation loading' of free-draining or slow-draining soils. In such situations it is common practice to incorporate geosynthetic basal reinforcement to provide an additional stabilizing force. If the foundation soil is slow-draining then loading of the ground will create pore pressure excess within the foundation. Subsequently, with time, pore water in the foundation will migrate from beneath the loaded area and the shear strength of the foundation will increase. Hence the stability of the system will improve in time and so the stabilizing force, which needs to be provided by the geosynthectic, will diminish. After a certain time (typically between a few months and a few years) the whole system will be stable with little or no assistance from the geosynthetic – in many cases the geosynthetic becomes totally redundant. It is the Authors' contention that, in such a situation, the use of a non-conventional geosynthetic, which has a limited, but predictable working life, is sound engineering practice this is the concept of Limited Life Geotextiles (Mwasha 2005, Sarsby 2006).

For the foregoing situation the variation of required tensile strength of the reinforcing geosynthetic with time has been designated as the design Time-Strength Envelope for the geosynthetic, i.e. it defines the minimum tensile strength that the geosynthetic must have at any time in its design life. Vegetable fibres are an ideal 'raw material' for the manufacture of Limited Life Geotextiles (LLGs). Such materials certainly degrade with time, but there is a huge range of natural fibers available and these exhibit very different strength and durability characteristics as illustrated in Figure 1:

- Some fibres have very high initial tensile strength – for instance a Sisal fibre is almost as strong as the equivalent polyester fibre which itself would be about three times the strength of the corresponding Coir fibre.
- Some fibres exhibit very slow, progressive loss of tensile strength with time – a Coir fibre subjected to cycles of wetting and drying would only lose around 8% of its strength after 6 months, 20% after 12 months and 30% after 2 years, whereas with Flax the corresponding strength losses would be 45%, 60% and 90% respectively (Pritchard, 1999).

3. BASAL REINFORCEMENT OF AN EMBANKMENT BUILT ON SOFT CLAY

In order to investigate the potential for the use of Vegetable Fibres Geotextiles (VFGs) in ground engineering a parametric study was undertaken of the time-dependent basal reinforcement requirements of an embankment built on a normally-consolidated, saturated, soft, clay layer. Typical 3 m high embankment was analyzed. On the basis of published data, typical values were assigned to geotechnical parameters relating to foundation soil and the embankment.

3.1 PARAMETRIC STUDY

For an embankment constructed on the soft ground, the shear strength of the foundation soil is increasing with time. To show how this increase in shear strength will affect the stability of slopes, the parameters study was conducted. The parameters for embankment, foundation soil are shown in Table 1.

Table 1: Typical value of the relevant parameters for the parametric study

Embankment	**Typical slopes (V: H)**	**Slope range chosen for analysis V: H**
	1v:1h to 1v:5h	1v:2h to1v:5h
	Typical shear strength parameters	**Selected shear strength parameters**
	$c' = 0(kN/m^2)$, $\phi' = 35^o$ to 41^o	$c'(kN/m^2) = 0$, $\phi' = 35^o$ and 41^o
	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**
	$c' = 0$, $\phi' = 14^o$ to 26^o	$c' = 0$, $\phi' = 14^o$ to 26^o
	Range of bulk unit weight	**Selected bulk unit weight**
	15 to 20(kN/m^3)	15 to 22(kN/m^3)

In order to specify the number of analyses to be undertaken the factors, which affect the behaviour of embankment, were prioritized. The highest priority factors were embankment slope, and effective friction angle of the foundation soil (15; 20; 23; 26 degrees) as illustrated in Table 1. For this preliminary investigation the embankment was assumed to be composed of free-draining fill and a range of typical embankment face slopes (from 1 vertical : 2 horizontal to 1v : 5 h) was analyzed. It was assumed that the embankment fill was placed instantaneously, i.e. there was no consolidation during construction. Post-construction consolidation of the foundation soil was accounted for by using one-dimensional consolidation theory. A rotational stability analysis was used to back-calculate the reinforcement force required to achieve a particular Factor of Safety at any given time after completion of construction using computer program GEO5

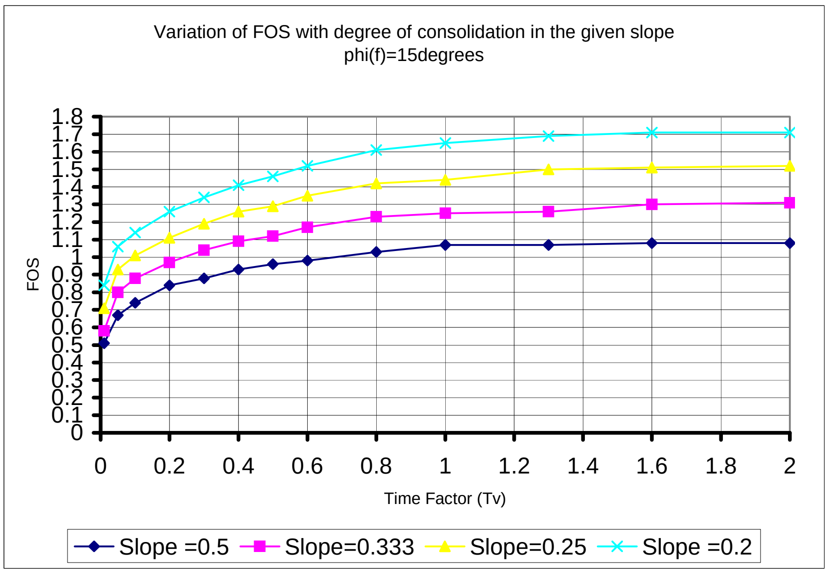

Figure 1: Effect of consolidation on slope stability

The behaviour of an embankment was investigated by observing the change in Factor of Safety (FOS) with time. As the Time Factor (Tv) increases the consolidation increases and the stability of all slopes increase regardless of the slope angle as shown in Figure 1. In fact this increase means that even though all slopes are initially unstable at Tv is zero i.e. all have FOS less than unity, they subsequently acquire FOS in excess of unity, i.e. they become stable when consolidated. Further investigation on the stability of slope was conducted by varying the degree of consolidation (Time factor varying from 0.01 to 2.00). The consolidation effect was registered by varying the Factor of Safety.

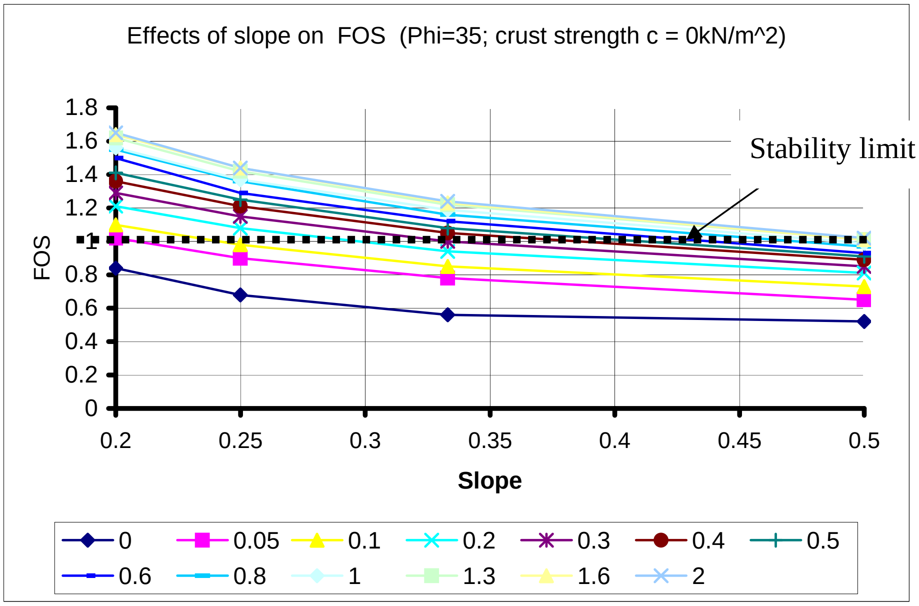

Figure 2: Stability of slopes on varying degree of consolidation

From Figure 2 it is shown that if minimum Factor of Safety is taken as unity then with time the consolidation will increase the resisting moment by enhancing the shearing resistance of soil. Another way to increase the resisting moment is to include soil reinforcement where horizontal force multiplied by the distance from the centre of rotation of the failure surface. If the lever arm is more or less constant with time then as the value of the required added resisting moment decrease then so does the horizontal force provided by the soil reinforcement. On considering the Time Factor then the amount of required reinforcement to stabilize the slope must vary with the slope angle. If the duration of reinforcement that could be required to reinforce slope 1:5 will take 5.4 months to attain stability (FOS=1) for slope V:H= 1:4, 11 months will be required to attain the same stability. Depending on the slope angle limited life geotextiles could be a solution on maintaining stability of these slopes. In this work it is considered that the stability of slope is satisfactory if FOS is not less than 1.2 . In Figure 3 it is clearly shown that in order to maintain FOS= 1.25 for slope 1:3, 7 years are required while just 3 and 1.5 years for slopes 1:4 and 1:5 respectively. In order to maintain FOS=1.4, 7 years are required for slope 1:4 and 3.0 years for slope 1:5. The conclusion to be drawn from this analysis is that reinforcement is needed for limited time.

4. TIME-STRENGTHENING ENVELOP

The slope stability is performed to ensure that the resisting moment are sufficient greater then disturbing moment tending to cause a slope to fail. The calculations usually consist of computing Factor of Safety which is the smallest value of the ratio of the resisting forces Fp to the driving forces F_A(Krynine and Judd 1957). This Factor of safety could be defined with respect to moment and load as shown in expression 1.

$$FOS = \frac{F_P}{F_A} \qquad (1)$$

Global Factor of Safety (F_{GLOBAL}) expression 2 is obtained by directly adding reinforcement strength as passive force in the expression 1 traditional method.

$$F_{GLOBAL} = \frac{\sum F_P + T_R \frac{Y}{R}}{\sum W \sin\alpha} \text{ ---2}$$

Therefore Global Factor of Safety (F_{GLOBAL}) is composed of FOS from soil alone (FOS_{ALONE}) as well as $FOS_{TR..}$ FOS_{TR} is the result of adding resisting force from reinforcement T_R with the active force component in expression 3 Y is lever arm of reinforcement and R is the radius of critical slip circle. T_R is the resulting force in the horizontal direction provided by the reinforcement

$$F_{GLOBAL} = F_{SOIL\ ALONE} + \frac{Y}{R}\frac{T_R}{\sum W \sin\alpha} \text{ --3}$$

By dividing both sides of the equation 4 by F_{GLOBAL} is possible o obtain required mobilized reinforcement strength(T_{MR}) in expression 5 which can be re-written as expression 6 .

$$1 = \frac{F_{SOIL\ ALONE}}{F_{GLOBAL}} + \frac{Y}{R}\left(\frac{T_R}{F_{GLOBAL}}\right)\frac{1}{\sum W \sin\alpha} \text{ --4}$$

$$1 = \frac{F_{SOIL\ ALONE}}{F_{GLOBAL}} + \frac{Y}{R} T_{RM} \frac{1}{\sum W \sin\alpha} \text{ --5}$$

$$\text{if } \frac{Y}{R} \frac{1}{\sum W \sin\alpha} = K$$

Therefore expression 5 can be rewritten as

$$1 = \frac{F_{SOIL\ ALONE}}{F_{GLOBAL}} + T_{RM}\ K \text{ --6}$$

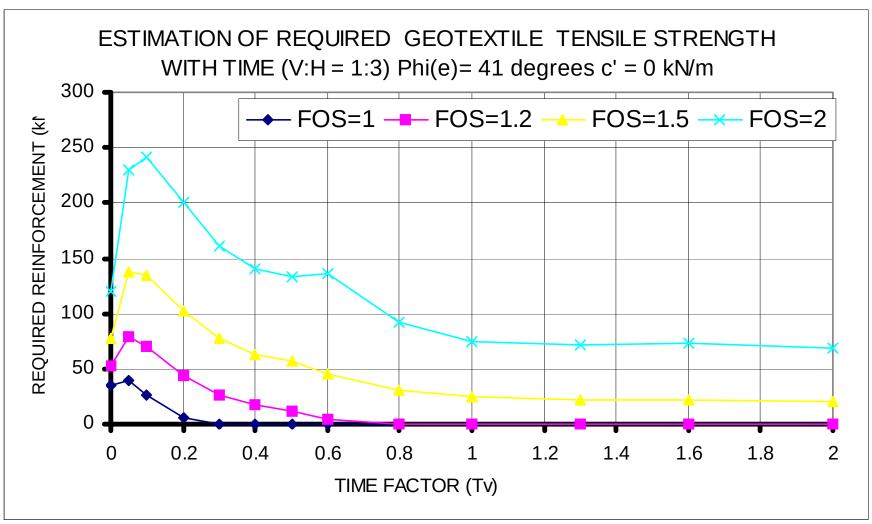

Figure 3: Estimation of required mobilized reinforcement on varying Time Factor

From expression 6 is possible to estimate amount of required mobilized reinforcement on varying the Time Factor as illustrated in Figure 3 where is revealed that immediately after ending of construction (Tv=0.00) in order to maintain FOS=1, the amount of required reinforcement is at maximum and is reduced with time. This phenomenon does not apply when the FOS is more than unity. For FOS= 1.20;1.50 and 2.00 at Tv =0.00 the amount of required reinforcement is lower but rises sharply to when Tv=0.1 and then lowers again. Generally it was found that for slope V:H = 1:3, there was need of reinforcement at Tv=0.3; Tv=0.62 to maintain FOS= 1 and 1.2 respectively. The amount of reinforcement required to maintain stability for FOS 2.00 and 1.5 at the end of consolidation (Tv=2) was reduced by 73% and 86% respectively. The effect of degree of consolidation on the stability of slopes is shown in Figure 6.19. In this case if the degree of consolidation is 25% there is no required reinforcement to maintain stability for slope 1:5. If at the end of construction of slope 1:2 amount of reinforcement required was 75kN/m, there was no need of reinforcement after 85% consolidation of the foundation.

The effect of consolidation can be more illustrated if is demonstrated in real time as shown in Figure. 4. For slope 1:2 after 5.9 years there will be no need of reinforcement to maintain the stability. The numbers of years required for slope 1:3 are 2.7 years, slope 1:4 is 7 months and finally slope 1:5 is only 5 months.

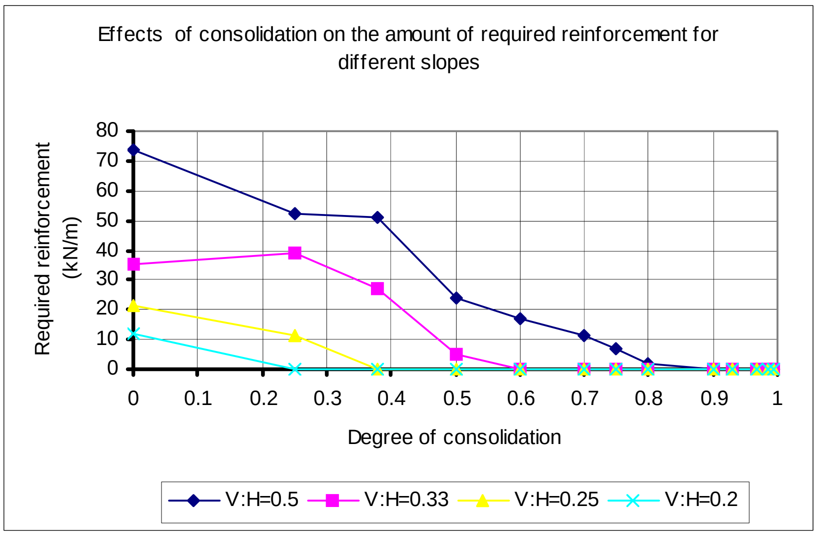

Figure 4: Effects of degree of consolidation on stability of slopes

5. IDENTIFICATION OF SUITABLE VEGETABLE FIBRES AS REINFORCING MATERIALS

The most appropriate method of selecting suitable vegetable fibres for use as geotextile is through eliminating the most unsuitable fibres after doing a literature review of characteristic properties. The main aspects of the production/extraction of vegetable fibres which has influence as the base materials for making textiles are:

- The quantity of fibre obtained from a plant must be adequate to make fibre extraction a viable proposition
- There must be a practical and economical procedure for extracting the fibres, without causing damage to them if they are to be of any value as a geotextile material.
- The pertinent properties of the fibre must be equivalent or superior to the existing chemical fibres.

- The annual yield of the fibre must be repeatable and sufficiently large to sustain the demand for the raw fibres.
- The lack of demand (availability) for the fibre properties on the market.

Table 2: comparing values of physical properties for some important fibres

Physical properties	Polyethylene (PE)	Polypropylene (PP)	Polyester (PET)	Cotton
Strength	2-4	5-9	5-10	3-7
Extensibility (%)	20-40	15-30	10-20	8-10
Moisture absorption %	0	0	0	7.00
Density (g/cm^3)	0.95	0.91	1.38	1.54

On comparing Vegetable Fibre properties with synthetic and other natural fibre the general properties of chemical fibres tend to fall into distinct categories. As shown in Table1 the strength of cotton fibre is higher by 67% but extensibility is lower by 70% when compared to Polyethelene. Synthetic fibres has relatively low moisture uptake.

Pritchard (1999) found that VFGs have superior soil reinforcement properties when compared to mid-range synthetic geotextiles, when considering average tensile strength between 100-200 kN/m at approximately 10% failure strain and frictional resistance (α approximately 1). Pritchard noted that the high degree of frictional resistance of the VFGs was probably developed from both the coarseness of the natural yarns and the novel structure forms.

Table 3: Required and available time –strength envelops

Tensile force required (kN/m) for 1v:2h	Duration after erection of an embankment (years)					
	0	1	2	3	4	5
FOS_G= 1	90	54	32	22	12	8
Plain weave, sisal (warp/weft-2 layers)	135	75	38	25	17	
Knitted, flux grid/weft sisal inlay-2 layers	115	58	32	22	12	

As shown in Table 3 VFGs such as Sisal could be used for short term reinforcement for an embankment erected on the soft soil.

6. DURABILITY OF VEGETABLE FIBRE AS CONSTRUCTION MATERIAL

Durability and mechanical properties of Vegetable fibre i.e. sisal and coir for the reinforcement of ground has been reported by Ghavami Khosrow *et al*. (1999**).** The authors studied the behaviour of composite soil reinforced with natural fibres. They measured the mechanical properties of long and short sisal fibres and compared them with that of coconut fibres. The durability of the fibres were assessed by immersing in drinking water for 30 days intervals for 210 days. All the samples were dried before testing. The results confirmed the superiority of sisal tensile strength when compared with coconut fibres. Mean values of tensile strength of 580Mpa and 150Mpa for sisal and coconut fibres respectively was recorded. The authors investigated the behaviour of soil fibre-composite and they found the failure mode of the specimen made of natural clay soil was very quick and almost without warning. This indicated that the unreinforced soil is relatively more brittle than the reinforced soil.

7. CONCLUSION AND RECOMMENDATIONS

Careful analysis and selection of the materials used and the way they are combined can yield significant improvements in cost effectiveness and energy efficiency in construction industry. Vegetable Fibre Geotextiles provide an invaluable solution to the problem of constructing embankments over soft compressible ground A review of the strengths and weakness of the Vegetable Fibre Geotextiles in relation to the competition is essential for its competitive positioning. It is essentially important to recognize the opportunities that can be taken advantage of the entire shortcoming the product has to face and tackle effectively.

Since the user of geotextiles in civil engineering vary greatly, it is important to develop products as per end user requirement with design and specifications criteria and cost factor should be customized with specified norms. Standardization of the Vegetable Fibre Geotextiles (VFGs) for soil reinforcement with defined specifications are always possible in view of the variation in characteristics of the products required by users depending upon the applications and site parameters.

This paper is based on parametric study with no consideration of particular type of climatic zone including soil salinity and contaminated effects. Future study on these areas in general is recommended to undertake field trial in the countries producing potential fibres for geotextiles such as Trinidad and Tobago so that the biodegradation of VFGs can be controlled with strength gain of the foundation soil in this particular climatic and soil condition.

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