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Thinking outside the box: The time dependent behaviour of a reinforced embankment on soft soil

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ABSTRACT

Applications of eco-friendly geotextiles are gaining a preference over traditional polymeric geotextiles as measures to reinforce earth embankments. Understanding the behaviour of these eco-friendly geotextiles sometimes known as limited life geotextiles (LLG) is in its infancy. This paper explains the behaviour of an embankment reinforced with Sisal fibre geotextiles constructed within a box. The diminishing need for geotextile is represented by an external load 'outside the box' which can be manually controlled depending on the rate of increasing foundation shear strength. The excess pore water pressure was observed 'outside the box' from the end of the construction of the embankment to the end of the consolidation by monitoring the height of the water in pipes 'outside the box'.

1. Introduction

The feasibility of using limited life geotextiles (LLG) has been demonstrated by the construction and testing of reinforced soil retaining walls reinforced with vegetable fibre ropes [1]. Authors such as [2–4,6] have demonstrated analytically that vegetable fibres can be used to reinforce an embankment on soft soil. It is now necessary to consider how the tensile strength of the vegetable fibres will change with time once they have been surrounded by different types of foundation and fill materials. Unfortunately this problem of the durability of natural fibres is complex and contradictory examples of both very fast decay and remarkable stability are cited. In the 1920s and 1930s an extensive investigation was undertaken by the then imperial institute of tropical agriculture into the suitability of Sisal for the manufacture of marine ropes. Numerous samples of Sisal rope were subjected to cyclic wetting (with sea-water) and drying over a period of 12 months at the imperial institute of tropical agriculture [7]. The data collected showed that the ropes exhibited much higher rates of tensile strength loss with immersion time than that permitted if any of the back-calculated design time-strength envelopes were to be satisfied economically as was demonstrated by Mwasha [4].

The diminishing need over time, for geotextiles for the reinforcement of an embankment on soft soil has been demonstrated using the professional computer software GEO 5 [8] by Mwasha [5,6]. However the lack of substantial empirical data has hindered the progress of using limited life geotextiles. Physical models could be used to ascertain the concept of limited life geotextiles.

The possibilities and problems associated with the use of physical models to determine the tensile strength of geotextiles has been reported by Sego [9], who demonstrated that the increase in tensile–strain within the geotextiles has a direct response to both horizontal and vertical deformation in the embankment soil due to the development of compression and extension within the soil at the ground level and variation of the tensile strength within the reinforced soil. However, Chew et al. [10] demonstrated that by attaching tensile–strain gauges to geotextiles, poses a challenge as geotextiles are soft and have a fibrous surface. A common method of geotextile tensile–strain measurement is by attaching strain gauges directly to the geotextile with an adhesive agent and mounting electronic sensors by means of two end plates fixed to the geotextiles. This method forms both a localized area of the geotextile due to the introduction of the adhesive agent, at the same time however the sensors are large, bulky and expensive. In this latter method it is assumed that the geotextile's tensile–strain has its maximum at the mid-point of an embankment [11]. Another assumption is that the tensile strength decreases linearly away from the mid-point to zero at the toe of an embankment [12]. Based on these assumptions a new tensile–strain gauging method is proposed which is intended to minimize or eliminate the limitations of the present tensile–strain measurement methods. This new method makes use of the idea of attaching gauges (externally) 'outside the box' to a high strength steel wire connected via a proof ring to the geotextile via *T* shaped rods. The geotextiles held by the *T* rod support the loading from an embankment as well as the outward directed lateral force caused by the horizon-

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tal stress in the fill acting on the foundation surface. The advantage of this method over the traditional method is that the role for the reinforcement to support the outward shear stress, which relieves the foundation of critical loading, is represented by the process of diminishing need of tensile strength from the geotextiles. The properties of interaction between vegetable fibre geotextiles and soil are needed for the proper design of these types of geotextiles in any specific environment. In order to explain the interaction between sisal geotextiles and the soil, pullout tests were conducted. Different granular soils of different grain sizes were spread on the geotextiles to simulate a free drained embankment. The results of this experiment showed that the local rounded Guanapo sand had a higher coefficient of adhesion as compared to the more angular limestone sand. The opening size of mesh relative to the soil grain size could have influenced the pullout interaction between soil and geotextile. It was also found that the coefficient of adhesion increased during the consolidation process. Since the strain in the soil is considered to be negligible and the coefficient of adhesion is almost one [1], therefore the strain deformation of geotextiles will not be considered in this paper.

2. Materials and apparatus

2.1. Foundation soil

2.1.1. Caroni Swamp soil

The foundation soil was extracted from the Caroni Swamp an extraordinarily important wetland. The Caroni Swamp is located near Port of Spain the capital of Trinidad and Tobago occupying approximately (8398 ha, 10°34′N 61°27′W). The properties of the samples were average moisture content 119% bulk unit weights between 20 and 21 kN/m^3 and internal angle of friction less than or equal to 25°. The surface bearing strength range between 0 and 40 kPa, therefore in most cases the process of reclamation of any such land should be accompanied with soil reinforcement.

2.2. Embankment

The quartzite sand used for erecting the embankment was from Guanapo, Valencia, in Trinidad. These aggregates are mostly located in the foothills of the northern range and are normally overlain with 2–3 m of heavy clay. Guanapo quartzite is a relatively pure form of quartz (~99% quartz). The yellow brown colour of the Guanapo is a staining deposit of ferric oxide. This is mainly a surface deposit but it has moved over time into the micro cracks of the crystalline particles and in some cases has become an inter-crystalline impregnation [13]. The properties of the Guanapo quartzite sand used to construct the embankment were as follows. The angle of internal angle of friction = 0°, the effective angle of internal friction 35° and the bulk unit weight was 18 kN/m^3.

2.3. Reinforcement

Sisal fibre geotextiles were used as a basal reinforcement material. Sisal is a native of the Yucatan Peninsula, Mexico [14]. Global production of Sisal fibre in 2007 amounted to 240,000 tonnes of which Brazil, the largest producing country, produced 113,000 tonnes [15]. Tanzania produced approximately 37,000 tonnes, Kenya produced 27,600 tonnes, Venezuela 10,500 tonnes and 9000 tonnes were produced in Madagascar. China contributed 40,000 tonnes with smaller amounts coming from South Africa, Mozambique, Haiti, and Cuba. Sisal occupies sixth place among fibre plants, representing 2% of the world's production of plant fibres (plant fibres provide 65% of the world's fibres). Sisal grows best in a hot climate and may be grown throughout the humid and sub-humid lowland tropics. Sisal is a natural fibre, the actual fibres themselves are quite variable (they have diameters typically in the range 0.1–0.5 mm approximately, with high initial strengths of the order of 400–600 MPa [16]. The Sisal fibre used in this research was donated by METL Tanzania Limited [17], a manufacturer of vegetable fibre textiles including canvas, tents and bags. The properties of Sisal fibre geotextiles were: tensile strength which varied from 90 to 100 kN/m, strain 6–10%, water intake 10–20%, density varied from 1.8 to 2.0 kg/m^3, thickness 4–6 mm and the available sizes are 110 × 70 mm. In 1999 knitted and woven geotextiles were patented by Pritchard et al. [18]. Pritchard et al. [18] identified 13 types of vegetable fibre geotextiles. The major properties of these vegetable fibre geotextiles manufactured using different types of vegetable fibres can be accessed in the handbook of textiles [19] therefore they will not be discussed further in this paper.

2.3.1. Predicting external force required

In order to predict the amount of external load to use in this experiment, it was essential to separate the required force needed from the reinforcement needed to achieve the desired equilibrium in the soil, i.e. the available force and the required forces. It was assumed that the maximum possible resistance should be proportional to the effective vertical stress. The effective stress was assumed to have a direct effect on the expected pullout stress between the soils and the geotextiles as

$$\frac{dT_R}{dL} = 2\gamma z \alpha F \quad (1)$$

where T_R is the pull out resistance, z is the depth of fill above the reinforcement and γ is the bulk unit weight of the embankment material. Pull out resistance factors α and F was adopted from federal highway administration [20]. On transforming Eq. (1) to Eq. (2) it can be found that the length of the embedded reinforcement plays a major role in determining the total resistance force required.

$$T_R = 2\gamma z \alpha F L \quad (2)$$

In this case when the overburden pressure increases from the toe of an embankment the pullout resistance increases. By inputting the author's experimental data into Eq. (3), suggested by Duncan and Wright [20], the variation of pullout resistance is shown in Fig. 1.

$$T_R = 2\tan\beta \alpha F L^2 \quad (3)$$

From Fig. 1 above the external load to be used in this experiment was estimated to be 30 kg.

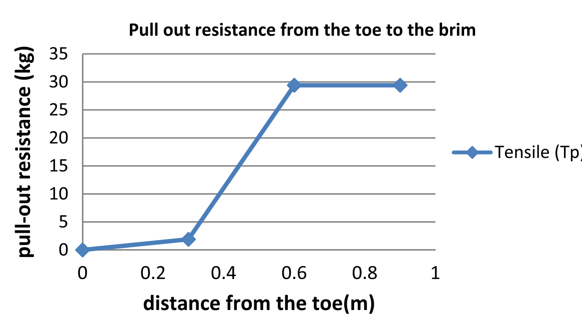

Fig. 1. Results of author's experiment showing variation of pullout resistance with distance from an embankment toe.