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Mechanical Model to Analyse Multilayer Geosynthetic Reinforced Granular Layer in Column Supported Embankments

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Abstract
The objective of this paper is to develop a mechanical model to predict the behaviour of a multilayer geosynthetic reinforced granular fill soft soil system improved with controlled modulus columns beneath the embankment. Deformation of geosynthetics embedded granular layer due to bending and shear is considered in this study. Therefore, geosynthetic reinforced granular fill has been idealised as a reinforced Timoshenko beam while the columns and the soft soil have been idealised as a layer of linear springs with varied stiffness. Plane strain conditions are considered for the loading and reinforced foundation soil system. Tension developed in the geosynthetics, rotation and settlements of the improved soft ground are predicted using the proposed model. This study shows the effects of multilayer geosynthetics on the settlement response of the granular layer. A notable reduction of the settlement has been observed as a result of the using multilayer weaker geosynthetic reinforcement system when compare to one stronger geosynthetics layer. It is also observed that the top reinforcement layer is subjected to maximum mobilised tension at the column edge whereas bottom reinforcement layer is more effective in controlling the deflection in the middle of two columns.

Keywords: Timoshenko beam, Geosynthetics, Soft soil, Column supported embankments

1 Introduction

Soft soils underneath the embankments are prone to excessive settlement due to the low stiffness, low bearing capacity as well as high shrink-swell potential. The controlled modulus column (CMC) is one of the ground improvement techniques to meet the higher demand for the transport infrastructure particularly near waterways comprising weak soil layers. Introducing geosynthetic reinforcement (GR) within the granular fill materials which is known as load transfer platform (LTP) results in a more

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efficient transfer of load to the columns in the form of an arching mechanism in column-supported embankments. However, the behaviour becomes much more complicated with inclusion of GR. The interaction between the reinforced granular layer, the columns, and the soft soil below the granular layer change their actual behaviour considerably. In recent years many researchers have studied the load-settlement response of such reinforced granular layer (Madhav and Poorooshasb, 1989; Shukla and Chandra, 1995; Yin, 2000).

Most of the models reported in the literature are developed for single-layer reinforced systems without considering columns. Nogami and Yong (2003) investigated the response of a multilayer geosynthetic-reinforced geomedium subjected to structural loading. The governing differential equations for the geomedium were obtained and solved by an iterative finite difference method. However, no significant difference in the response of the reinforced soil was observed for low load intensity. Chandra et al. (2005) proposed a mechanical model to predict the behaviour of a multilayer geosynthetics within the granular fill on soft soil foundation by idealising the granular fill and the soft soil as a Pasternak shear layer and a layer of non-linear springs, respectively. Effect of multilayer geosynthetics was notably observed. However the governing differential equations were solved by an iterative finite difference method. Therefore, currently no closed form solution of the load-settlement response of the reinforced granular layer-soil-column system is available in the literature which considers both the bending and the shear deformation of the multilayer geosynthetic-reinforced granular layer.

In this paper, a mechanical model is proposed for a multilayer geosynthetic reinforced granular layer on column stabilised soft soil, which incorporates the deformation of the granular fill due to both bending and shear. Using the proposed model, the load transfer mechanism in terms of deflection and rotation of the granular layer and tension mobilised in the geosynthetics with one stronger layer of geosynthetics and with two layers of weaker geosynthetics are compared.

2 Analytical Model

A granular layer with multilayer of geosynthetics on CMC improved soft soil system at the base of the embankment is shown in Figure 1a. The behaviour of such a system may be idealised in terms of the proposed mechanical model shown in Figure 1b. In this model, the geosynthetic reinforced granular fill has been idealised as a reinforced Timoshenko beam. The CMCs and the soft soil have been idealised as a layer of linear springs with different stiffness. Two geosynthetic layers are considered in the model. It is assumed that there will be no slippage between the geosynthetic reinforcement layers and granular fill materials. The assumed deformed shape of the LTP and the co-ordinate axes for a unit cell are shown in Figure 2a. The deformation of the column is assumed to remain unchanged over its width. The CMC and the soft soil are loaded with different distributed loading intensities of p_s and p_c, respectively due to soil arching. Since in the field, discrete columns are placed in a square or triangular pattern, the equivalent plane-strain material stiffness is determined by the relationship suggested by Tan et al. (2008) based on matching the column-soil composite stiffness as: $k_{c,pl}a_{r,pl} = k_{c,ax}a_{r,ax} + k_{s,ax}\left(a_{r,pl} - a_{r,ax}\right)$. Subscripts $"pl"$ and $"ax"$ denote plane-strain and axisymmetric conditions, respectively, while a_r is the area replacement ratio. Deformation of the CMC reinforced composite ground can be expressed as:

$$w = \begin{cases} w_{cz} & \text{when } \ 0 \le \xi \le d/2 \\ w_{cz} + w_{sz} & \text{when } \ 0 \le x \le s'/2 \end{cases} \tag{1}$$

where s' is the clear spacing between the CMCs, w_{sz} is the displacement of the LTP on soft soil region at a horizontal distance x, and w_{cz} is the displacement of the LTP over column region at a horizontal distance ξ.