Geotextiles and Geomembranes 42 (2014) 339–347

Contents lists available at ScienceDirect

Geotextiles and Geomembranes

journal homepage: www.elsevier.com/locate/geotexmem

A simplified approach for evaluating the bearing performance of encased granular columns

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ARTICLE INFO

Article history:
Received 6 September 2013
Received in revised form
20 May 2014
Accepted 20 May 2014
Available online 11 June 2014

Keywords:
Encased granular columns
Geosynthetics
Simplified approach
Confining pressure increment
Dilation rate
Constant volume

ABSTRACT

Tensile resistant materials used to encase cylindrical granular columns significantly improve column strength. For an encased granular column subjected to axial load, the axial deformation and volumetric expansion causes lateral expansion, which induces circumferential strain and stress in the encasement and provides additional confining pressure to the column.

To make good predictions of column behavior through numerical analysis, elaborate deductive and regressive work is needed to describe the mechanical properties of the filled material. This study analyzes the bearing performance of geosynthetic-encased sand columns using a simplified approach to reduce such laborious deductive efforts. A few equations and calculation steps are also proposed to evaluate the confining pressure increments and deviatoric stress due to encasement extension.

The proposed approach employs an empirical correlation between the dilation rate and deviatoric strain of pure sand to evaluate the volumetric strain of deformed encased granular columns. The approach has also been extended to evaluate the use of the constant volume assumption in predicting the responses of encased granular columns. The relationships between the confining pressure increment and encasement stiffness/column diameter ratio are established through simplified assumptions.

Results obtained from the proposed approach are validated and found to be in good agreement with the experimental measurements and numerically analysis results under rigorous parameter acquisition. The proposed approach provides accurate results without laborious analytical efforts.

1. Introduction

Encasing a granular column with tensile resistant material provides additional confining pressure to the column upon axial loading and column expansion; it therefore enhances the bearing capacity of a granular column. Encapsulating all or part of columns with geosynthetics has been proven to be an adaptable reinforcement practice (Kempfert et al., 1997; Raithel and Kempfert, 2000; Alexiew et al., 2005; Raithel et al., 2005; de Mello et al., 2008; Araujo et al., 2009).

When an embedded reinforced granular column is subjected to increasing axial stress with coincidently increased confining pressure, the interactive axial-confining stresses behavior and the varying confining pressure distribution along the column length complicate the analysis of column behavior. These complications have been overcome in theoretical and numerical analyses by modeling the mechanical properties of the fill material as a function of the monotonously increased confining pressure (Wu et al., 2009; Hong, 2012). The numerical method has advantages over other analytical approaches for analyzing structures with complicated geometric and load conditions, such as columns embedded in areas with limited radial spacing and with non-uniform pressure distributed along the column length. Using a representative single column and its influence boundary, the "unit cell" concept has been added to the numerical method for group column analysis (Shahu et al., 2000; Han and Gabr, 2002; Ambily and Gandhi, 2007; Yoo and Kim, 2009; Lo et al., 2010; Pulko et al., 2011). Homogenization techniques have also been applied to stone-column reinforced foundation analysis (Canetta and Nova, 1989; Lee and Pande, 1998).

The confining pressure of an encased granular column is highly dependent on the volumetric behavior of the column because volumetric strain induces column expansion and radial strain, which in turn increases circumferential stress in the encasing reinforcement and confining pressure provided by the surrounding

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http://dx.doi.org/10.1016/j.geotexmem.2014.05.006
0266-1144/

soil. A numerical model capable of accurately capturing the volumetric strain of the fill material is essential in analyzing reinforced granular column behavior, single or grouped, for columns embedded in soil.

Many constitutive models have been proposed to predict the engineering behavior of soil structures as well as encased granular columns. Of the available models, the elastic-perfectly plastic relation with the Mohr-Coulomb yield criteria has been widely used to determine the stress-strain characteristics and yield condition of soil due to the simplicity of such a combined approach. With simple parameter acquisition, the above model predicts the deviatoric stress of a cylindrical granular column under triaxial load condition accurately. Nevertheless, it cannot capture the expansive behavior of a medium to dense sand prior to soil yield, leading to a significant underestimation of the reinforcing effect of an encasing sleeve.

Based on triaxial test results, Hong (2012) developed rigorous correlations to model soil characteristics, especially the volumetric strain of sand, to produce better predictions for encased granular column behavior. Numerical analysis using rigorous regressive equations predicts both deviatoric stress and volumetric strain in triaxially compressed sand column wells. Moreover, the numerical results using Hong's method, for both the deviatoric stress and volumetric strain of encased sand columns, agree well with the results of experimental laboratory tests. However, numerical modeling of volumetric strain requires elaborate efforts (Hong, 2012).

For engineering purposes, a simplified, yet rational approach to analyzing the bearing performance of encased granular columns would be very useful. Based on empirical correlation, this study develops simple steps to develop such a system. Next, the approach is extended to evaluate the use of the constant volume assumption in predicting the response of encased granular columns. Finally, the proposed approaches are validated through experimental triaxial testing in a laboratory and numerical analyses of encased sand columns under rigorous parameter acquisition.

2. A simplified approach

2.1. The basis of the approach

As a granular column compresses vertically it also undergoes radial or lateral deformation. This lateral deformation causes the sleeve to stretch and develop circumferential tensile stress (hoop stress). The sleeve hoop stress in turn exerts radial confining stress on the encased granular column which helps to mobilize additional compressive strength and resistance to further deformation in an interactive manner until equilibrium is achieved.

For a deformed encased sand column, the confining pressure provided by the encasing sleeve can be expressed as

$$\sigma_f = \frac{T_f}{r_1} \tag{1}$$

where T_f = the circumferential tensile force per unit length of the encasing sleeve, σ_f = the confining pressure acting on the column provided by the expanded sleeve, referred to as "confining pressure increment" hereafter, and r_1 = the radius of the deformed column.

Assuming the encasing material obeys a linear elastic-perfectly plastic load-elongation relation, the circumferential tensile force per unit length of the sleeve in an elastic state is

$$T_f = J\varepsilon_\theta \tag{2}$$

where J = the stiffness of the encasing sleeve and ε_θ = the circumferential strain of the sleeve.

For an encased column with initial and deformed radii of r_0 and r_1, respectively, the encasement circumferential strain is equal to the radial strain of the column

$$\varepsilon_\theta = \frac{2\pi(r_1 - r_0)}{2\pi r_0} = \frac{r_1 - r_0}{r_0} = \varepsilon_r \tag{3}$$

where ε_r = the radial strain of the column.

For a reference granular column length l_0, volumetric strain is

$$\varepsilon_V = \frac{-\Delta V}{V_0} = \frac{-\pi l_0\left[r_1^2(1-\varepsilon_1) - r_0^2\right]}{\pi l_0 r_0^2} = 1 - (1-\varepsilon_1)\left(\frac{r_1}{r_0}\right)^2 \tag{4}$$

where ε_V = the volumetric strain of the granular column, V_0 = the initial volume of the granular column, ΔV = the volume change of the granular column, and ε_1 = the axial strain of the granular column.

The relation among the deformed radius r_1, volumetric strain ε_V, and axial strain ε_1 can then be written as

$$r_1 = r_0\sqrt{\frac{1-\varepsilon_V}{1-\varepsilon_1}} \tag{5}$$

Substituting Eq. (2) and Eq. (5) into Eq. (1) yields the confining pressure increment as

$$\sigma_f = \frac{J\varepsilon_\theta}{r_1} = J\left(\frac{1}{r_0} - \frac{1}{r_1}\right) = \frac{J}{r_0}\left(1 - \frac{1}{\sqrt{\frac{1-\varepsilon_V}{1-\varepsilon_1}}}\right) \tag{6}$$

The above equations demonstrate that the magnitude of the confining pressure increment depends on the circumferential strain of the encasing sleeve, which is related to the diameter and volumetric strain of the sand column and the stiffness of the encasing sleeve. The tensile strength of the encasing sleeve is another factor that influences the confining pressure increment if the column expands to a greater magnitude causing sleeve yield.

Equation (6) reveals that, except for the pre-determined geometric and material properties (i.e. J and r_0), the volumetric response is the only factor influencing the confining pressure increment. Therefore, a simplified rate of dilation-deviatoric strain relation is introduced in this study to simplify volumetric strain evaluation.

2.2. The combination of laboratory tests and the simplified approach

The objective of this study is to develop a simplified approach producing results that are close to experimental results but eliminate the need for elaborate efforts in regression and rigorous mathematical correlations. Laboratory test results performed on cylindrical unreinforced and encased sand columns by Wu and Hong (2009) and Hong (2012) are employed to facilitate the descriptions of the approach. In the experimental works of the above studies, one of two sand types, sub-angular and round-grained shapes, designated as S1 and S2, and one of two geotextile sleeves, designated as GT1 and GT2, were employed to constitute encased sand columns.

The experimental program consists of performing triaxial compression tests on 140 mm high × 70 mm diameter dry sand samples encapsulated in geotextile sleeves. The sub-angular sand S1 has a specific gravity of $G_s = 2.63$, maximum dry unit weight of