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3-Dimensional numerical modelling of geocell reinforced sand beds

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ABSTRACT

Numerical modelling of the geocell has been always a big challenge due to its complex honeycomb structure. Generally, the equivalent composite approach is adopted to model the geocells. In equivalent composite approach, the geocell-soil composite is treated as the soil layer with improved strength and stiffness values. Though this approach is very simple, it is unrealistic to model geocells as the soil layer. This paper presents a more realistic modelling approach to model geocells in 3-dimensional (3D) framework. Numerical simulations have been carried by forming the actual 3D honeycomb shape of the geocells using the finite difference package FLAC^{3D} (Fast Lagrangian Analysis of Continua in 3D). Geocells are modelled using the geogrid structural element available in the FLAC^{3D} with the inclusion of the interface element. In addition to the modelling of geocells, other two cases, namely, only geogrid and geocell with additional basal geogrid cases were also modelled. It was found that the geocells distribute the load laterally and to a relatively shallow depth as compared to unreinforced case and the geogrid reinforced case. The numerical model was also validated with the experimental studies and the results are found to be in good agreement with each other. The validated numerical model was used to study the influence of various properties of the geocells on the performance of the reinforced foundation beds. The performance of the foundation bed was directly influenced by the modulus and the height of the geocells. Similarly, the pocket size of the geocell inversely affected the performance of the reinforced beds. The geocell with textured surface yielded better performance than the geocell with smooth surface.

1. Introduction

Geocells are 3-dimensional expandable panels made up of high density Polyethylene. Nowadays, geocells are being widely used in geotechnical engineering. General applications of the geocells include foundations, embankments, highways, retaining walls, and slope protections. Geocells can offer faster, cheaper, sustainable, and environmentally friendly solutions to many complex geotechnical problems. Many researchers in the past have demonstrated the beneficial aspects of geocells with the help of experimental and field studies (Sireesh et al., 2009; Tafreshi and Dawson, 2010; Pokharel et al., 2010; Lambert et al., 2011; Yang et al., 2012; Thakur et al., 2012; Tafreshi and Dawson, 2012; Tavakoli Mehrjardi et al., 2012; Tafreshi et al., 2013; Biswas et al., 2013; Sitharam and Hegde, 2013; Tanyu et al., 2013; Dash and Bora, 2013; Leshchinsky and Ling, 2013a; Tafreshi et al., 2014; Hegde and Sitharam, 2014a; Indraratna et al., 2014). However, one cannot always depend on the experimental and field studies for the design and analysis of the complex geotechnical problems. Because, these studies are often time consuming and cumbersome though they produce reliable results. Often, design calculations require quick calculations to understand the effect of the various key parameters in the design. In such situations, numerical modelling is the most favoured technique.

Numerical simulations of the geocells are not so easy due to its complex 3D honeycomb structure. Generally, the equivalent composite approach is used to model the geocells and in which the geocell-soil composite is treated as the soil layer with improved strength and stiffness values (Bathrust and Knight, 1998; Latha and Somwanshi, 2009; Hegde and Sitharam, 2013; Mehdipour et al., 2013). Though this approach is very simple, it is unrealistic to model geocells as the soil layer. Geocell reinforcement is 3-dimensional in nature and hence, 3-dimensional modelling approach should be preferred. Han et al. (2008) modelled single cell geocell using FLAC^{3D}. Due to the difficulties in modelling the actual shape, the cell was modelled as the square box in their study. Similarly, Hegde and Sitharam (2014a) carried out the numerical simulation of the single cell geocell by adopting the circular shaped

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pocket geometry. Saride et al. (2009) modelled the multiple cell geocell in FLAC^{3D} by assigning the square shape to the geometry of the cell pocket. A similar approach was also adopted by Leshchinsky and Ling (2013b) while modelling geocell reinforced ballast system. However, Yang et al. (2010) modelled the actual shape (i.e. 3D honeycomb shape) of the single cell geocell in their study. Contrary to the previous studies, an attempt has been made to model the exact 3D honeycomb shape of the multiple cell geocells.

Literature review suggests that the most of the researchers have either used equivalent composite approach or modelled geocells as the square boxes. Modelling the geocells as square boxes misses one of the key aspects of the geocell i.e. its curvature. If the geocell is modelled as the square box, then the stresses are going to accumulate on the corner edges of the square box. This will lead to inaccurate results. The curvature or the honeycomb structures distribute the stresses uniformly along the periphery of the geocells. That's why the most of the commercial geocells available nowadays have the honeycomb structures. The proposed model takes care of the curvature and hence, increases the precision of the results. In this direction, this work contributes to the advance in the knowledge in the numerical simulations of geocells. The knowledge gained by this study can be used in the numerical simulations of various geotechnical problems involving the geocells.

In the present study, the actual shape of the geocell has been modelled considering the real curvature of the expanded geocells. The infill soil and the geocell materials were modelled with two different constitutive models in order to simulate the real case scenario. It is understood that the numerical models need to be validated with experimental results to ascertain the correctness of the results. Hence, in the present study, the laboratory plate load tests were conducted on the geocell reinforced sand beds and the results of the 1-g model tests were used to validate the FLAC^{3D} results. The dimension of the model was kept equal to the dimension of the test bed used in the experiments. The geocell properties similar to the experimental study were used in the modelling. The validated model was further used to study the influence of the various geocell properties on the performance of the reinforced foundation beds. The parameters considered in the present study are geocell modulus, geocell height; pocket size and the interface friction angle. Though this manuscript mainly discusses the numerical simulations of the geocells in detail, the essential details of the experimental study are also presented briefly.

2. Review of the equivalent composite approach

The equivalent composite approach (ECA) is generally used to model the geocells in 2D framework. In this approach, the geocell in-filled with sand is modelled as the composite soil layer with improved strength and stiffness parameters. Many researchers have reported that the geocell confinement of sand induces the apparent cohesion while the friction angle remains constant (Bathrust and Karpurapu, 1993; Rajagopal et al., 1999). The improved apparent cohesion of the geocell-soil composite layer can be calculated using the Eqs. (1) and (2), given by Rajagopal et al. (1999). The Eq. (2) is actually originated from the rubber membrane theory proposed by Henkel and Gilbert (1952) to correct the effects of stiff rubber membrane in triaxial tests. The increase in the confining pressure ($\Delta\sigma_3$) on the soil due to the presence of geocell is given by.

$$\Delta\sigma_3 = \frac{2M}{d_0}\left[\frac{1-\sqrt{1-\xi_a}}{1-\xi_a}\right] \tag{1}$$

where, M is the secant modulus of the geocell material calculated corresponding to the axial strain of ξ_a in the tensile stress-strain response; d_0 is the equivalent diameter of the geocell pocket opening. The increment in the apparent cohesion (C_r) due to the increase in the confining pressure can be given by,

$$C_r = \frac{\Delta\sigma_3}{2}\sqrt{K_p} \tag{2}$$

where, K_p is the coefficient of passive earth pressure. The equivalent stiffness of the geocell-soil composite is related to the stiffness of the unreinforced soil, secant modulus of the geocell material and the interaction parameter, which represents the interaction in case of multiple cells. Latha (2000) proposed a nonlinear equation to express Young's modulus parameter of the geocell-reinforced sand (K_r) in terms of the secant modulus of the geocell material and Young's modulus parameter of the unreinforced sand (K_e) as,

$$K_r = K_e + 200M^{0.16} \tag{3}$$

The Young's modulus parameter (K_e) in the Eq. (3) corresponds to the modulus number in the hyperbolic model proposed by Duncan and Chang (1970). The equivalent initial tangent modulus of the geocell layer is then determined using the equation suggested by Janbu (1963) to relate the stiffness of the soil to the confining pressure as given below.

$$E_i = K_r P_a \left(\frac{\sigma_3}{P_a}\right)^n \tag{4}$$

where E_i is the initial tangent modulus of the geocell layer, σ_3 is the confining pressure acting at the midlevel of the geocell layer, P_a is the atmospheric pressure, K_r is the Young's modulus parameter of geocell layer determined using Eq. (3) and n is the modulus exponent of the unreinforced soil. The sample calculation of the determination of the equivalent strength and stiffness parameters of the geocell-soil composite has been illustrated in Appendix A.

3. Experimental studies

Fig. 1 shows the schematic representation of the test setup. A cast iron test tank of size 900 mm length, 900 mm width and

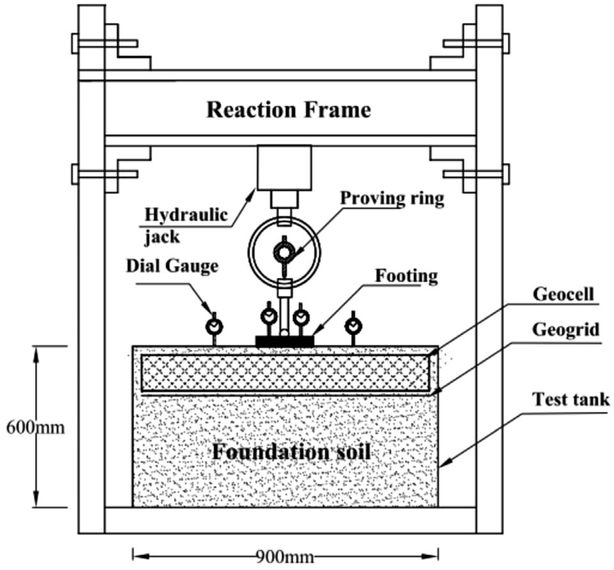

Fig. 1. Schematic view of the test setup.