*Applied Numerical Modeling in Geomechanics – 2020 – Billaux, Hazzard, Nelson & Schöpfer (eds.) Paper: 16-06*
 *ISBN 978-0-9767577-5-7*

# Three-dimensional numerical modelling of geocell reinforced foundation beds

Rajagopal Karpurapu & Ramesh Gedela
*Department of Civil Engineering, Indian Institute of Technology Madras, Chennai, India, 600036*

## 1 INTRODUCTION

The geocells, three-dimensional form of geosynthetics, are commonly used for construction over soft soils. The geocells consist of several interconnected pockets in the same manner as a honeycomb. The geocell layers are able to support large loads due to their flexural rigidity and ability to spread the loads over large areas.

The laboratory studies carried out by Dash et al. (2003, 2007), Sitharam et al. (2005), Latha et al. (2008, 2009), Sireesh et al. (2009), Han et al. (2010), Hegde & Sitharam (2013), etc. have demonstrated significant benefits of geocell layers. Generally, the geocell pockets attain honeycomb shape and modelling of this complex shape involves difficulties in the various numerical packages. Hence, many researchers in the previous studies have used Equivalent Composite Approach (ECA) for modelling of geocell reinforced foundation beds in both 2-dimensional and 3-dimensional analyses (Abusharar & Han 2011, Zhang et al. 2014, Latha & Rajagopal 2007 and Latha et al. 2008). Some other studies have modeled the geocell pockets using simplified shapes of square, diamond, circular and hexagon for modelling geocell reinforced foundation beds (Saride et al. 2009, Leshchinsky & Ling 2013, Yang et al. 2010, Hegde & Sitharam 2015a, Biabani et al. 2016).

The main focus of the present study is to understand the advantage of modelling the geocell pockets accurately in 3-dmensional numerical analyses. All the numerical analyses were performed using finite difference code Fast Lagrangian Analysis of Continua in Three-Dimensions (*FLAC3D*, Itasca 2017). The results of the numerical models were compared with experimental results obtained from laboratory tests performed in a large test tank having plan dimensions of 1.8 m × 1.8 m and height 1.5 m.

## 2 TEST SET UP AND MATERIALS

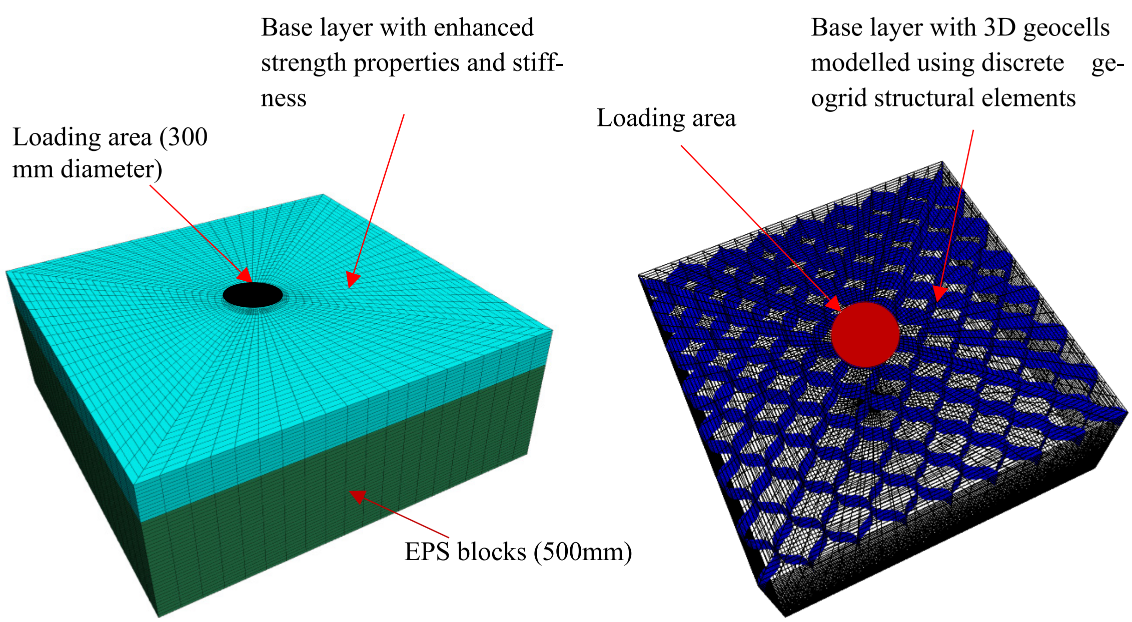
The test bed consists of 500 mm thick soft subgrade material (Expanded polystyrene block having density of 20 kg/m$^3$) and base layer of 150 mm thick. The base layer consisted of unreinforced soil layer or 150 mm high geocell layer with soil filled within the pockets. The load was applied through a 300 mm diameter rigid circular plate at the center of the tank using servo-controlled hydraulic loading system. A cover soil of 20 mm was provided above the geocell layer to prevent direct contact of geocell walls with the rigid loading plate. The average CBR value of the EPS block ranged between 1.5 and 2 thus acting as a soft subgrade layer. A locally available river sand was used as infill material. The peak and critical state friction angles of the sand was 44° and 33° respectively. The difference between the peak and critical friction angles was considered as dilation angle. The geocells used in this study were made of HDPE sheets ultrasonically welded at distances of 356 mm. The equivalent diameter of the expanded geocell pocket is approximately 192 mm.

## 3 MODEL GENERATION USING *FLAC3D*

The modelling of geocell reinforced foundation bed was done in the following two ways,

i. Equivalent Composite Analysis (ECA) method
ii. Discrete method in which the geocell pockets were modeled exactly

In the ECA method, the geocell with infill material is considered as an equivalent homogeneous soil layer with enhanced stiffness and strength properties. The relations to express the strength and stiffness properties are reported by Latha & Rajagopal (2007), Latha et al. (2008), Abusharar & Han 2011, and Zhang et al. 2014. On the other hand, in the case of discrete model, the exact shape of geocell pockets was developed using extrusion technique with the help of digital image of plan view of geocell mat imported into Auto CAD and digitized coordinates. The walls of the geocells were modelled using inbuilt geogrid structural elements which can support only tensile forces. These elements do not support any compressive or bending forces. The dimensions and the boundary conditions used in the numerical models correspond to those of the laboratory set up. Figure 1 illustrates the full-scale model developed in *FLAC3D* using ECA and 3D discrete modelling of reinforcement elements. Two other simplified opening shapes of square and diamond were considered in the analyses.




a. Equivalent composite model b. Discrete model with geocell pockets

Figure 1. Numerical models of geocell reinforced foundation bed.

The material properties for the numerical study were obtained from independent laboratory tests on different materials used in the tests. The geocell walls are modelled as linear-elastic material. The constitutive behavior of the soil and the EPS block was simulated using Mohr-Coulomb constitutive model. The properties of the interface between the infill soil and geocell walls were determined from modified direct shear tests. The numerical analyses were carried out with small incremental vertical displacement to induce 120 mm settlement over 7500 number of analysis steps. The displacement field was applied on the nodes corresponding to the loading plate (within the red color shaded region in Fig. 1).

## 4 RESULTS AND DISCUSSIONS

Figure 2 shows the comparison between the pressure settlement responses obtained from laboratory tests and the different numerical models. The numerical models are able to reasonably predict the influence of geocell layer on the footing response. The geocell contribution goes on increasing with deformations as evident from the constant slope of pressure-settlement response even after large deformations. The numerical predictions using the ECA model matched well initially but was unable to predict the increasing pressure with settlements. The ECA model is unable to capture the interaction between the geocell pockets and the infill soil thus failing abruptly. On the other hand, the discrete numerical model with explicit geocell pockets is able to predict the trends correctly.

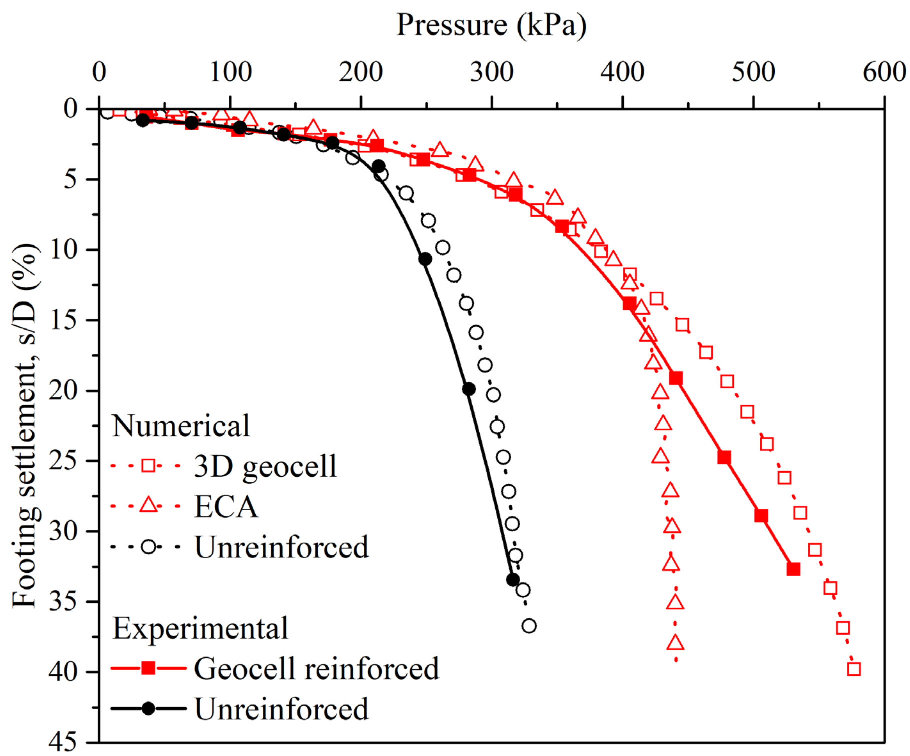



Figure 2. Pressure settlement response of both reinforced and unreinforced sections.

As the geocell is strained, it develops flexural resistance and membrane stresses in the walls. These membrane stresses in the geocell walls lead to the development of additional confining pressure in the infill soil. The key for the accurate numerical predictions is the ability to simulate both these aspects in the numerical model. When the geocell walls were explicitly modeled, the numerical model is able to capture the real phenomenon.

Some additional numerical analyses were performed by modeling the geocell pocket shape approximately as square and diamond. These approximate models have overestimated the ultimate pressures by more than 25% while the exact model had less than 5% error compared to the experimental values. The reason for this is the over estimation of membrane stresses in the geocell walls and the consequent confining pressures within the infill soil by the approximate models as shown in Tables 1 and 2.

The overestimation of the confining pressures in the soil lead to higher strength and stiffness leading to artificially stronger response in the numerical models.

Table 1. Membrane stresses in geocell walls (at 120 mm footing settlement).

| Pocket shape | Membrane stresses in geocell walls (MPa) |
|---|---|
| Exact honeycomb shape | 14.1 |
| Diamond shape | 17.8 |
| Square shape | 21.2 |

Table 2. Average confining pressure developed within the geocell pockets (kPa).

| Pocket shape | Confining pressure in the infill soil (kPa) |
|---|---|
| Exact honeycomb shape | 105.8 |
| Diamond shape | 159.1 |
| Square shape | 223.6 |

## 5 SUMMARY AND CONCLUSIONS

This paper has discussed the influence of different numerical models on the predicted numerical responses with geocell reinforced foundation beds. The need for accurate modelling of the shape of the geocell pocket is clearly demonstrated by comparing the numerical predictions with the experimental results.

## REFERENCES


Abusharar, S.W. & Han, J. 2011. Two-dimensional deep-seated slope stability analysis of embankments over granular column-improved soft clay. *Engineering Geology*, 120, 103–110.

Bathurst, R.J. & Knight, M.A. 1998. *Analysis of* geocell reinforced soil covers over large span conduits. Comp*uters and Geotechni*cs., 22 (3/4), 205 - 219.

Dash, S.K., Rajagopal, K. & Krishnaswamy, N.R. 2007. Behaviour of geocell-reinforced sand beds under strip loading. *Canadian Geotechnical Journal*., 44(7), 905 - 916.

Dash, S.K., Sireesh, S. & Sitharam, T.G. 2003. Model studies on circular footing supported on geocell reinforced sand underlain by soft clay. *Geotextiles and Geomembranes*., 21, 197 - 219.

Han, J., Yang, X., Leshchinsky, D. & Parsons, R.L. 2008. Behaviour of geocell reinforced sand under a vertical load. *Journal of Transportation Research Board*, 20(45), 95 - 101.

Hegde, A. & Sitharam T.G. 2013. Experimental and numerical studies on footings supported on geocell reinforced sand and clay beds. *International Journal of Geotechnical engineering*, 7 (4), 346 - 354.

Hegde, A. & Sitharam, T.G. 2015a. 3-Dimensional numerical analysis of geocell reinforced soft clay beds by considering the actual geometry of geocell pockets. *Canadian Geotechnical Journal*., 52 (9), 1396 - 1407.

Hegde, A. & Sitharam, T.G. 2015b. 3-dimensional numerical modelling of geocell reinforced sand beds. *Geotextiles and Geomembranes*, 43, 171 - 181.

Itasca Consulting Group, Inc. 2017. *FLAC3D – Fast Lagrangian Analysis of Continua in 3-Dimensions, Ver. 6.00*. Minneapolis: Itasca.

Latha, G.M. & Rajagopal, K. 2007. Parametric finite element analyses of geocell supported embankment. *Canadian Geotechnical Journal*. 44 (8), 917 - 927.

Latha, G.M., Dash, S.K. & Rajagopal, K. 2008. Equivalent continuum simulations of geocell reinforced sand beds supporting strip footings. *Journal of Geotechnical Geological engineering*, 26, 387 - 398.

Rajagopal, K., Krishnaswamy, N.R. & Madhavi Latha, G. 1999. Behaviour of sand confined with single and multiple geocells. *Geotextiles and Geomembranes*, 17, 171 - 181.

Saride, S., Gowrisetti, Sitharam, T.G. & Puppala, A.J. 2009. Numerical simulations of sand and clay. *Ground Improvement*, 162 (GI4), 185 - 198.

Sireesh, S., Sitharam, T.G. & Dash, S.K. 2009. Bearing capacity of circular footing on geocell sand mattress overlying clay bed with void. *Geotextiles and Geomembranes*, 27 (2), 89 - 98.

Yang, X., Han, J., Parsons, L.R. & Leshchinsky, D. 2010. Three-dimensional numerical modelling of single geocell reinforced sand. *Front. Architecture and Civil Engineering journal*, 4 (2), 233 - 240.

Zhang, Z., Han, J. & Ye, G. 2014. Numerical investigation on factors for deep-seated slope stability of stone column-supported embankments over soft clay, *Engineering Geology*, 168, 104-113.