Numerical modelling of geocell reinforced foundation beds

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ABSTRACT: Geocell has three-dimensional (3D) honeycomb structure. Unlike planar reinforcements like geogrid and geotextile it offers 3D confinement to the infill soil. Modelling of complex honeycomb structure is very difficult. Instead of modelling exact shape, simplified shape of geocell gives the unrealistic results when compared with the experimental data. This paper mainly concentrates on the development of an exact model considering the honeycomb shape of geocell in plan. All the numerical analyses were performed using the 3D software FLAC (Fast Lagrangian Analysis of Continua). Mohr-Coulomb constitutive model is used for the subgrade material and the infill material and the geocell is modelled using the inbuilt geogrid structural elements using the linear-elastic constitutive model. The geogrid element can support only tensile forces and not compressive forces. The results from the numerical study show good agreement when compared to the experimental results. From the results it is observed that the stress magnitude below the geocell is 30% of applied stress on the geocell surface. A plate load test is conducted in the laboratory to compare the numerical results with experimental data. Pressure-settlement responses predicted from numerical model follow closely with the experimental measurements.

Keywords: Geocell, FLAC3D, numerical modelling, soft soils, EPS

1 INTRODUCTION

Construction of any Civil Engineering structure over a problematic soil is challenging task to geotechnical engineer. The problematic soil can be improved by using various ground improvement methods. Out of all the existing methods, soil reinforcement is one of the best solutions for improving the poor subgrade soil performance. From the past few decades, it has been observed that usage of geocell in the field drastically increased. Recently, the geocell reinforcement is used in wide range of applications in the field such as embankments, pavements, foundation beds, canal lining, retaining walls etc., due to its better performance, easiness in the installation, cost-effectiveness and speed of construction when compared to other ground improvement methods. The usage of geocell is more effective when it is used in the poor subgrade soil because geocell membrane action starts at larger deformations. When the geocell used in good subgrade soils sufficient deformation may not occur to mobilize the membrane action of geocell. This effect is observed by many researchers in the past (Bathurst et al 1998, Latha et al. 2001, Dash et al. 2001, Sitharam et al. 2005, Dash et al. 2007, Sireesh et al. 2009, Dash and Bora 2013, Hegde and Sitharam 2013, Leshchinsky et al. 2013, Neto et al. 2013, Hegde and Sitharam 2014, Indraratna et al. 2014, Hegde and Sitharam 2016, Hegde 2017). Significant benefits of geocell was extremely investigated using 1g laboratory model studies by many researchers.

Numerical modelling is one of the best tools to study the performance of geocell and it overcomes the limitations existing in the laboratory and field studies. Generally, the geocell is having 3D complex honeycomb shape. Modelling of this complex honeycomb shape involves a lot of difficulty in the various numerical packages. Due to this reason, it has modelled by several researchers using the equivalent composite approach (ECA) or 3D simplified shape of geocell in commercially available softwares. In

ECA method, the geocell with infill material is considered as a soil layer with enhanced stiffness. The improvement in stiffness is provided by the additional confinement offered by the geocell (Bathrust and Karpurapu 1993, Rajagopal et al. 1999, Madhavi Latha et al. 2000, Rajagopal et al. 2001, Madhavi Latha and Rajagopal 2007). Hedge and Sitharam (2013) used ECA method to investigate the effect of geocell reinforcement. The paper concludes that numerical model results have a deviation from the experimental data and hence, ECA is an approximate method. Table 1 summarizes the details of the research carried out using ECA method.

Modelling of 3D geocell shape for reinforced soil bed is more accurate and reliable than ECA method. Very limited literature is available on 3D geocell modelling. Many researchers assumed various geocell shape viz. square, circular, diamond, approximated honeycomb of equivalent area due to the complexity in modelling the exact geocell shape. Table 2 depicts the geocell shape adopted by various researchers for their studies.

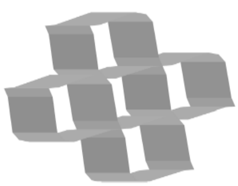
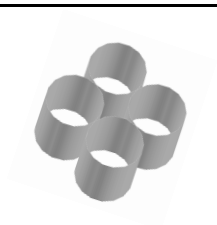
The installed geocell pocket shape in the field trials and laboratory experiments are different from the 3D geocell shape created for the numerical analysis. Hence, there exists an ambiguity in the previous study results even though they have maintained the same pocket area. This paper's major focus is to model the exact shape of geocell by considering the exact curvature. The smooth curvature action aids to distribute the stresses to the surrounding pockets and thereby minimizes the stress concentration at the junctions.

Table 1. Summary of the studies carried out using ECA method (Hegde, A. 2017)

Type of study	**Software package**	**Researcher**
The performance of geocell reinforced cover over the large span of conduits	GEOFEM	Bathurst and Knight (1998)
Performance of geocell reinforced sand beds	GEOFEM	Latha et al. (2001)
Modelling of reinforced embankments	PLAXIS	Bergado et al. (2003)
The analysis of geocell supported embankments	GEOFEM	Latha and Rajagopal (2007)
Effect of planar reinforcement and geocell reinforcement	FLAC3D	Latha et al. (2008)
The geocell reinforced slopes.	FLAC2D	Mehdipour et al. (2013)
The effect of geocell reinforcement in sand and clay beds.	FLAC2D	Hedge and Sitharam (2013)

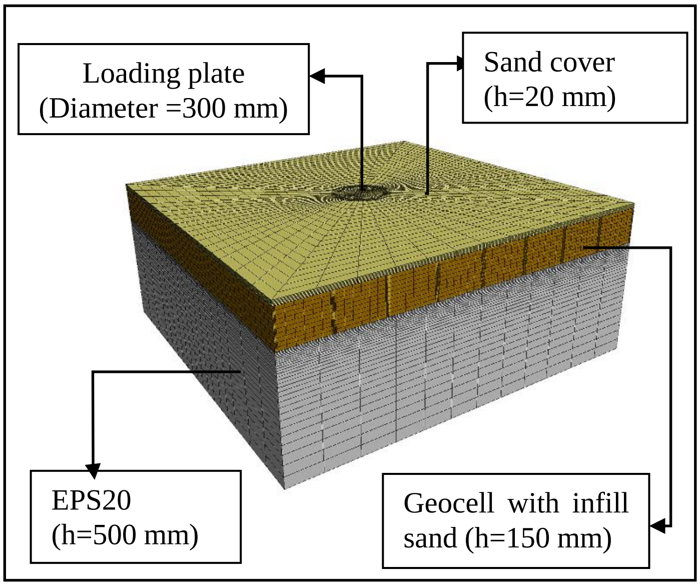
Table 2. Summary of numerical modelling of 3D geocell shape used in the past studies

Square Han et al. (2008)	**Multiple square pockets** Siride et al. (2008) Leshchinsky and Ling. (2013)	**Approximated honeycomb (single pocket)** Yang et al. (2010)	**Single Circular pockets** Hegde and Sitharam. (2015)
			

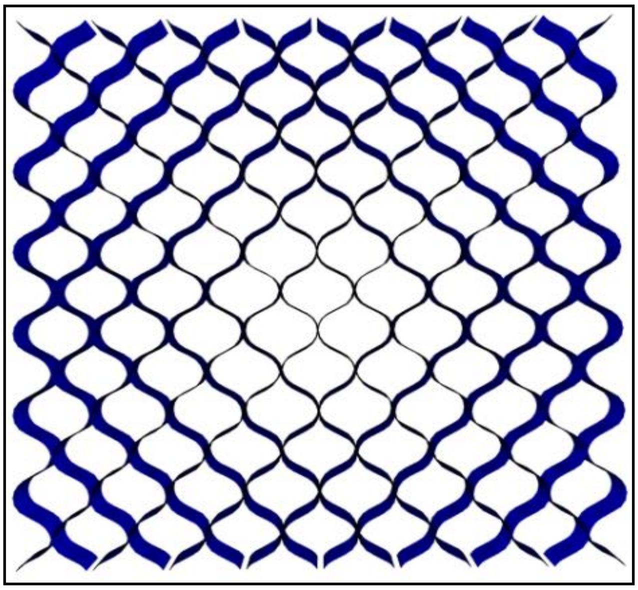
Approximated honeycomb (multiple pockets) Hedge and Sitharam. (2015)	**Multiple circular pockets** Dutta and Mandal (2016)	**Multiple hexagonal pockets** Biabani et al. (2016)
		

2 MODEL GEOMETRY

The present study models a geocell reinforced foundation system using the commercially available finite difference software, FLAC3D. The model consists of three layers with a total depth of 0.67 m, the top layer consist of 20 mm sand cover, intermediate layer of 150 mm high geocell layer filled with sand and the bottom layer of 0.5 m expanded polystyrene (EPS) representing the soft subgrade material having CBR less than 2 and with a density of 20 kg/m^3. The load was applied on the test bed using a mild steel (MS) circular plate of 300 mm diameter. The geocell used in this study is having a height of 150 mm with a weld spacing of 356 mm in its unstretched form. The equivalent diameter of geocell pocket after stretching is 178.4 mm. The tank size for the current 1g model study in the laboratory is 1.8 × 1.8 × 1.2 m. The experimental test setup and loading stages were modelled in FLAC3D to compare the numerical outcomes with the experimental results. The load was applied in a strain-controlled manner and the rate of loading was 2.6×10^{-6} m/ step. Schematic view of the model geometry and exact geocell shape (honeycomb) was modelled in the FLAC3D program as shown in Figure 1.



(a)



(b)

Figure 1. (a) Test setup geometry, (b) Honeycomb shaped geocell model in FLAC3D.

3 MATERIAL PROPERTIES

The material properties for the numerical model study are taken from the laboratory test results as well as from the properties reported in the published literature's. The geocell is modelled as linear-elastic material. Mohr-Coulomb constitutive model is assigned to the infill sand of the geocell pockets as well as to the top sand cover. The infill soil is poorly graded dense sand. Geocell reinforcement is effective on poor subgrade material with CBR less than 2, hence to simulate similar properties in the laboratory, the subgrade material is replaced with EPS block of CBR less than that 2. At low strains, the stress-strain curve of EPS material is almost similar to elastoplastic behaviour. The same behaviour is observed by many researchers in the past (Duskov 1997, Hazarika and Hemanta 2006, De et al. 2016, Beju and Mandal 2017). Consequently, Mohr-Coulomb constitutive model is assigned to the EPS material. The material properties used for the modelling are listed in Table 3.

4 RESULTS AND DISCUSSION

Figure 2(a) comprises the pressure-settlement response of both reinforced and unreinforced sections from the experimental and numerical study. In the case of unreinforced sections, the slope of the pressure-settlement curve represents the punching shear failure of subgrade during loading. Meanwhile, in the case of reinforced bed section, no such failure was observed in both experimental and numerical model. The membrane and anchorage friction mechanism of geocell composite layer allows the load dissipation

Table 3. Material properties used in the modelling

Material	**Parameters**	**Values**
Geocell	Modulus of elasticity (MPa)	235
	Poisson ratio	0.45
	Thickness (mm)	1.5
	Interface friction angle	41
	Interface cohesion (kPa)	0
	Coupling stiffness (N/m^3)	2.4×10^6
	Aspect ratio (h/d)	0.842
Expanded polystyrene (EPS20)	Shear modulus (MPa)	1.8
	Bulk modulus (MPa)	1.709
	Poisson's ratio	0.11
	Cohesion (kPa)	37.5
	Friction angle (ϕ)	2.25
	Density (kg/m^3)	20
Sand	Modulus of elasticity (MPa)	35
	Poisson's ratio	0.35
	Cohesion (kPa)	0
	Friction angle (ϕ)	43
	Dilation angle (Ψ)	11
	Density (kg/m^3)	1784

within the layer and thereby improving the bearing capacity of subgrade resulting in local shear failure. From the results, it is observed that up to a settlement ratio of 1.7, only hoop stress action is observed within the geocell. Further increase in settlement ratio results in the mobilization of membrane and anchorage friction mechanism in addition to the geocell's hoop stress. The geocell layer acts as a flexible slab and distributes the load over a larger area. Due to this reason, the stress measured below the geocell layer or exactly above the subgrade layer is around 30% of applied vertical stress over the surface. Figure 2(b) shows the percentage of stress (q/q_s) transferred to subgrade (i.e. stress (q) measured just below the geocell composite layer is normalized with applied pressure at the surface (q_s)) at different s/b ratio. In

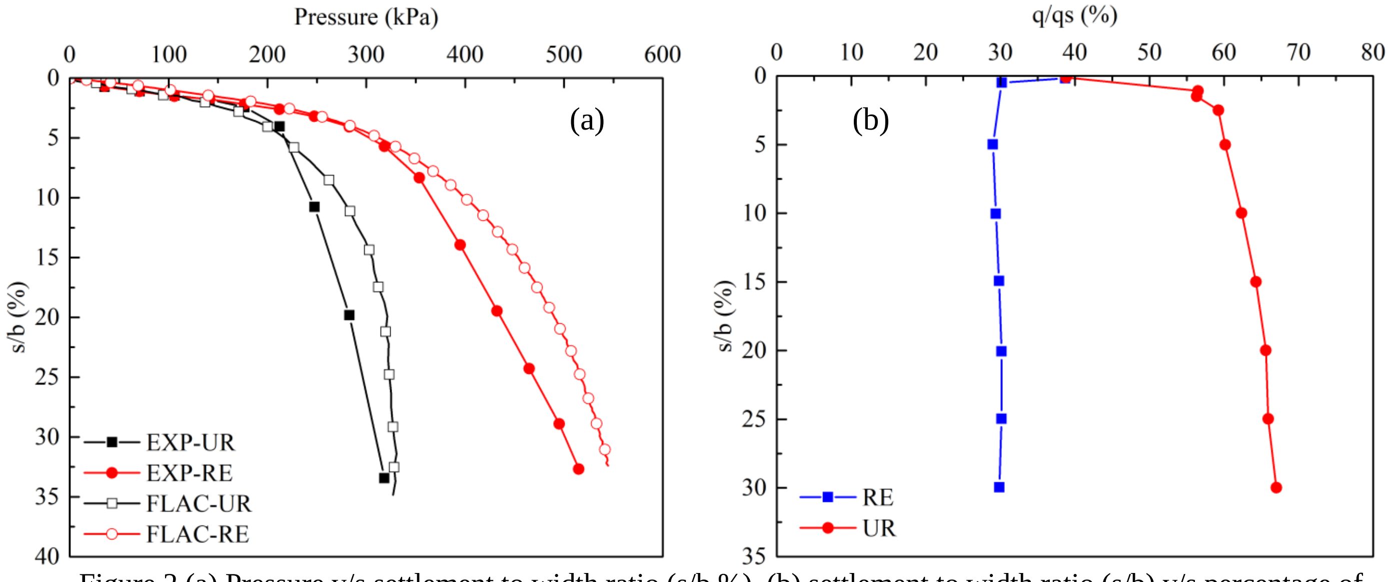


Figure 2 (a) Pressure v/s settlement to width ratio (s/b %), (b) settlement to width ratio (s/b) v/s percentage of stress transferred to subgrade (q/q_s).

the case of unreinforced sections, the stress percentage transferred to the subgrade increases with the settlement. But in the case of reinforced section, the stress percentage transferred to the subgrade decreases till the s/b ratio reaches 5% and further remains constant (q/q_s = 30%). It is one of the evidence to prove that, at larger deformations, geocell composite slab action starts and the load is distributed over a larger area. At s/b = 30%, the stress percentage transferred to the subgrade by the reinforced and unreinforced sections are 30% and 67% respectively.

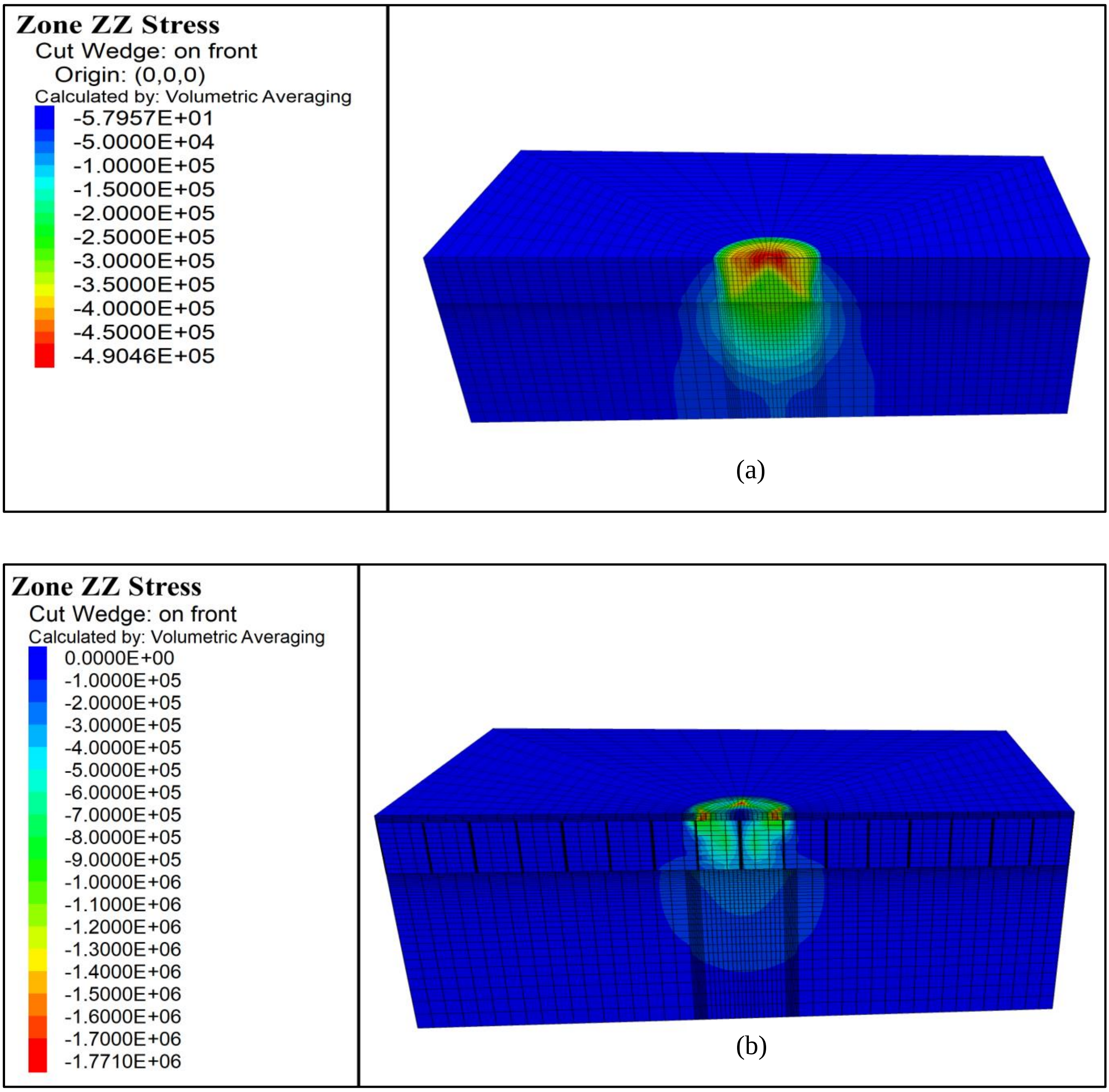


Figure 3 (a) Stress contours of the unreinforced section, (b) Stress contours of reinforced section

5 CONCLUSIONS

Based on the observations from the present study, it can be concluded that use of geocell as a reinforcement for poor subgrade material shows significant effect on the load transfer mechanism. Modelling exact shape of geocell during numerical analysis plays an important role to get the accurate results and to give good agreement with experimental data. It was also found that the average stress transferred to the subgrade soil is nearly 30% of the applied surface stress.

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