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Numerical Modelling of Static Triaxial Behaviour of Geocell Reinforced Sand

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Abstract. Geocells are three-dimensional geosynthetics which consist of interconnected cells filled with soil. Reinforcing the soil with geocells improves the soil properties through friction, interlocking and confinement. Many experimental studies were conducted to quantify the beneficial effects of geocell reinforcement in enhancing the stiffness and strength properties of the soil. However, not many numerical studies are available to understand the behaviour of geocell reinforced sand in triaxial compression. Due to the complexities involved in modelling the actual honeycomb shape of the geocell, most of the previous numerical studies were either conducted using Equivalent Composite Approach (ECA) or by approximating the actual shape of the geocells to simpler shapes like square, diamond or circular shape. FLAC^{3D} was used to carry out numerical analyses in the current study. Triaxial compression tests on a cylindrical sample of unreinforced sand and sand reinforced with honeycomb-shaped geocells are simulated by implementing the actual shape of geocells. The parametric analysis was carried out on the validated numerical model to understand the effects of confining pressure, geocell diameter, modulus of the geocell material on stress-strain response of the geocell reinforced sand.

Keywords: Geocells, triaxial compression, FLAC^{3D}.

1 Introduction

It is well-known that soil is weak in tension and strong in compression. To overcome this, the soil is reinforced with different geosynthetic materials that have higher tensile strength. They are various forms of geosynthetic materials like fibre geosynthetics, planar geosynthetics and three-dimensional geosynthetics. Geocells are the class of geosynthetics that are three-dimensional in nature. They enhance the soil properties through friction, interlocking and confinement. Due to their 3D nature, the improvement of stiffness and strength properties of the soil due to the inclusion of the geocells is superior to that of other forms of geosynthetics [1,2,3].

The comparison of the performance of the geocell-reinforced soil to that of soil reinforced with other forms of geosynthetics was carried out through numerous laboratory element tests and model tests. Though numerous experimental studies have been carried out to study the behaviour of the geocell-reinforced soil, numerical analysis is limited in this area. The modelling of the geocell's honeycomb shape involves complexities. Most of the numerical analyses on soil reinforced with geocell were conducted in 2D using Equivalent Composite Approach (ECA) where the geocell reinforced soil system is represented by soil with higher strength and stiffness properties [4,5]. This is an approximate technique, and it doesn't account for the stresses and strains developed in the geocell. To overcome this, attempts have been made to model the geocell reinforced soil system in 3 dimensions by approximating the actual honeycomb shape of the geocell to simpler shapes like square [6], diamond [7,8], circular [9,10] or hexagonal shapes [11]. The results obtained from these studies are found to overestimate the improvement caused by the inclusion of geocells as compared to that of experimental studies. Of late, attempts have been made to model the geocell by taking the actual honeycomb shape into consideration [12,13,14].

These numerical analyses were carried out to represent the laboratory model tests however the behaviour of the geocell reinforced sand system at the element scale through numerical studies is mostly unexplored. Though attempts have been made by many researchers to understand the fundamentals of the behaviour of geocell reinforced soil subjected to triaxial compression through experimental studies [2,15,16,17], numerical modelling has not been explored. In the current study, the behaviour of the geocell reinforced sand subjected to triaxial compression test by modelling the actual honeycomb shape of the geocell was analyzed.

2 Numerical model

A cylindrical sample of height 200 mm and diameter 100 mm subjected to triaxial compression test was modelled in this study. The axis of the cylindrical sample was along the y-direction. The sample was discretized into 4000 zones. The honeycomb shape of the geocell was obtained by digitizing the image of the geocell to obtain the exact coordinates of the geocell curvature. Each node of the structural element used to form the geocells was moved to the required coordinate to obtain the desired shape of the geocell.

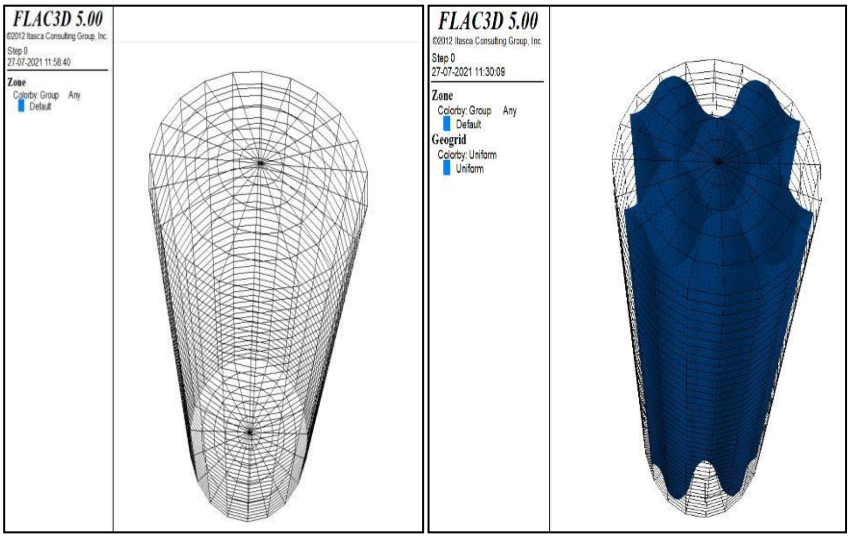

Fig.1 Generated cylindrical sample for unreinforced and geocell reinforced sand

2.1 Material model

The modelling of sand was carried out using the Mohr-Coulomb model. The geocells were modelled using the geogrid structural element which are linear elastic materials with no failure limit. The sand-geocell interface cohesion and interface friction angle were considered to be 0.8 times the sand's cohesion and internal friction angle. Table 1 and Table 2 give the properties of the sand and the geocell used in this study respectively.

Table 1. Properties of the sand

Properties	Value
Poisson's ratio	0.3
Young's modulus (MPa)	7.4
Cohesion (kPa)	0.1
Friction angle (deg.)	40.5
Relative density (%)	55

Table 2. Properties of the geocell

Properties	Value
Poisson's ratio	0.45
Young's modulus (MPa)	173
Interface cohesion (kPa)	0.08
Interface friction angle (deg.)	32
Interface shear modulus (MPa/m)	2.36
Thickness (mm)	0.6

2.2 Boundary conditions and loading

The displacements in normal and radial directions were restrained in the bottom boundary of the cylindrical sample whereas the displacement in the radial directions was restrained in the top boundary of the cylindrical sample. A velocity of 9×10^{-6} m/step was applied along the top boundary in the negative y-direction to represent the loading during the strain-controlled triaxial compression test.

2.3 Validation

The model was validated using the experimental results taken from Rajagopal et al. (1999) [16]. A cylindrical unreinforced sand sample and sand reinforced with four interconnected geocells were considered for the validation. Fig.2 shows the comparison of the deviatoric stress variation with axial strain for both unreinforced and geocell reinforced samples obtained from numerical modelling to that of experimental results. From the plot, it is evident that the results obtained from the numerical modelling are in good agreement with the experimental test results and hence the validated model will be used in further analyses.

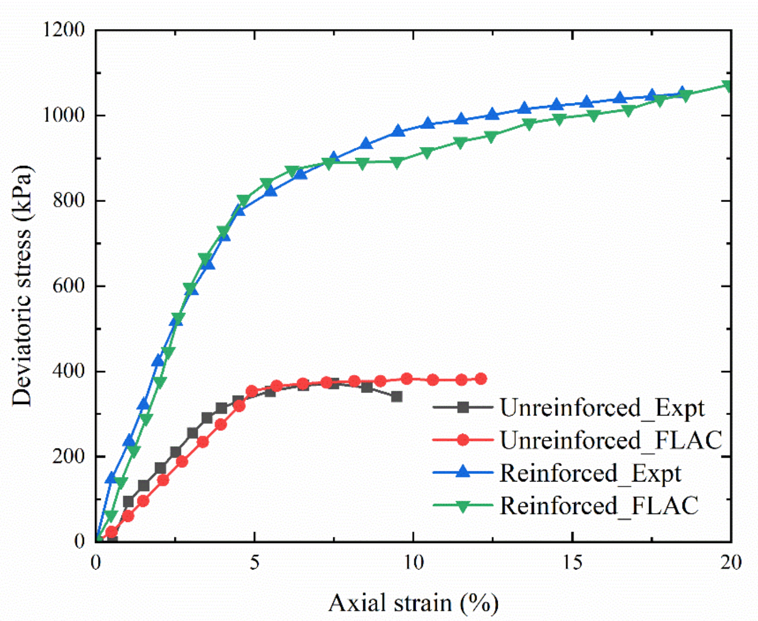

Fig.2 Validation of the numerical model

3 Parametric analyses

The validated model was used to conduct further analyses to understand the effects of parameters effects of confining pressure, geocell diameter, and geocell material modulus on the stress-strain response of the geocell reinforced sand. The improvement in the shear strength of the sand due to the geocell reinforcement was quantified by the parameter ‘Improvement Factor’(IF), given as the ratio of the peak deviatoric stress in the geocell reinforced sample to the peak deviatoric stress in the unreinforced sample.

3.1 Effect of confining pressure

Additional confinement pressure will get applied to the soil sample due to the three-dimensional nature of the geocell. Hence, the external applied confining pressure in which the reinforcement was placed also plays a significant role in the performance of the geocell reinforced sand. To understand the effects of the applied confining pressure, the confining pressure was varied from 50 kPa to 300 kPa. The variation of the IF with confining pressure is given in Fig.3. It was observed that with the increase in confining pressure, the IF decreases. The IF value becomes constant beyond the confining pressure of 200 kPa. This can be attributed to the easy expansion of the geocell at lower confining pressure. Hence, the circumferential strain developed in the geocell is more and hence higher is the improvement. This implies that the efficiency of the geocell in improving the shear strength properties of the soil is higher at lower confining pressure.

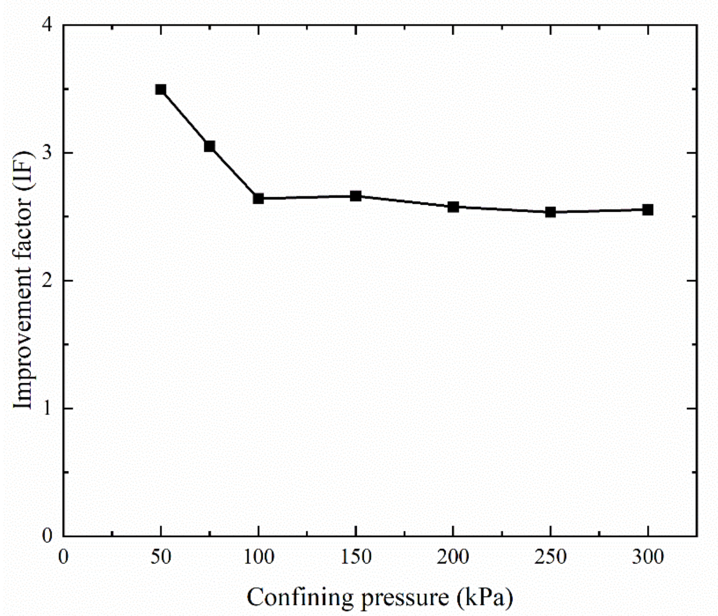

Fig.3 Variation of the Improvement Factor with Confining pressure

3.2 Effect of geocell size

The effect of cell size of the geocell was studied by conducting two sets of simulations. In the first set, a single geocell of an effective diameter 0.074 m was considered. In the second set, four interconnected geocells with each of an equivalent diameter 0.033 m was considered. The diameters were chosen in such a way that the overall area of sand enclosed by the geocell system remains the same. The simulations were conducted at the confining pressure of 100 kPa. The variation of the Improvement factor with confining pressure for both the sets of the simulations is plotted in Fig.4. The IF is higher for four cell condition as compared to that of single-cell condition though the overall area of sand enclosed by the geocell is the same. This is due to, with the increase in the number of geocells per unit area, confinement per unit area increases and hence higher is the improvement.

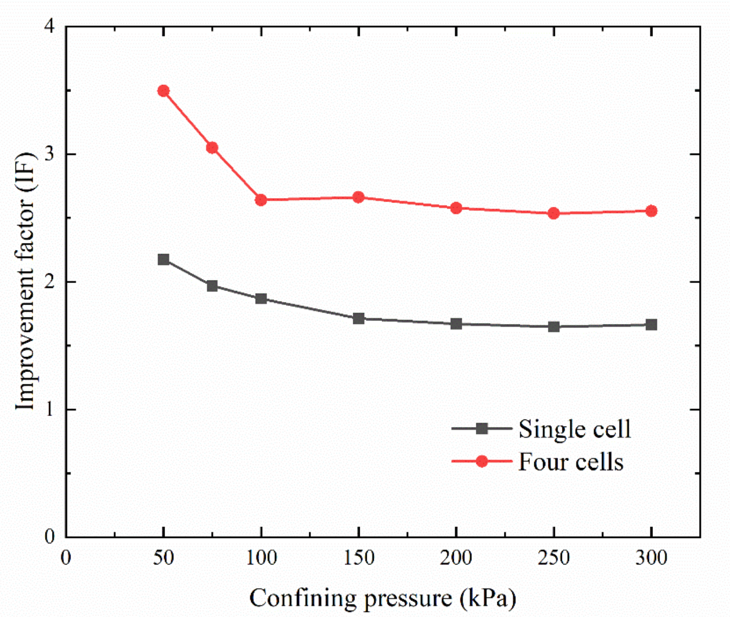

Fig.4 Variation of Improvement factor with confining pressure for different geocell sizes

3.3 Effect of modulus of the geocell material

The geocell modulus considered in the analyses until now was 173 MPa. Hence, to understand the effects of the geocell modulus, modulus of 87 MPa (i.e. 0.5 times 173 MPa), 173 MPa and 346 MPa (i.e. 2 times 173 MPa) were considered for the analyses. The analyses were conducted at a confining pressure of 100 kPa. The variation of IF with confining pressure for various values of geocell modulus is given in Fig.5. It is observed that with the increase in confining pressure, IF decreases. Further, it is also evident that at lower confining pressure, the value of IF is almost the same for all values of geocell modulus. With the increase in confining pressure, the rate of decrease of IF is more for the geocell of lower modulus as compared to that of higher modulus. This indicates that at lower in situ confining pressure, the geocells of lower modulus are highly effective whereas at higher in situ confining pressures, the geocells of higher modulus are more effective.

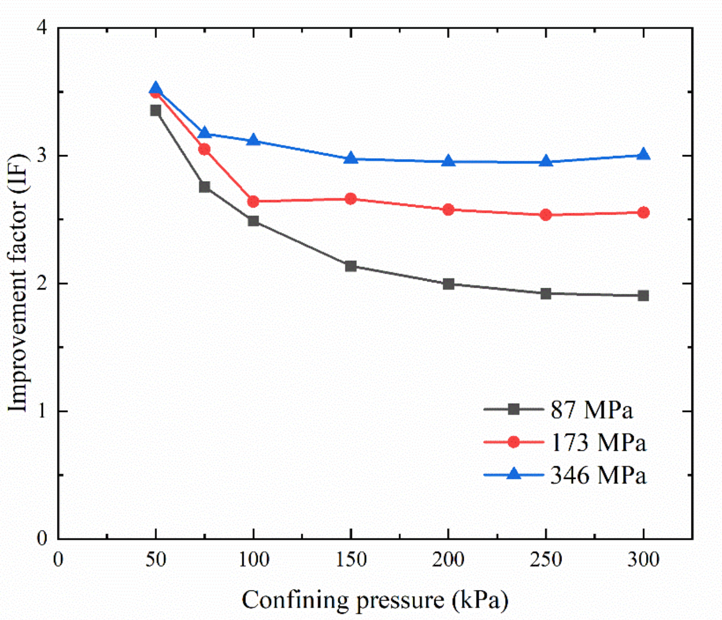

Fig.5 Variation of the Improvement factor with confining pressure for different geocell modulus

4 Conclusions

The validated numerical model was used to conduct the parametric analyses. The analyses showed that the improvement in the shear strength of sand caused due to the geocell reinforcement is highly dependent on the applied confining pressure, geocell size, sand's friction angle and geocell modulus.

- As the confining pressure increases, the Improvement factor decreases. The value of IF becomes almost constant beyond the confining pressure of 200 kPa.
- As the number of geocells per unit area increases, the confinement per unit area increases and hence higher is the improvement. For the same area of confinement, a large number of small geocells gives more improvement than a small number of large cells.
- As the geocell modulus increases, the improvement increases. However, at lower confining pressure, geocells of different moduli were found to impart the same improvement and hence the geocell of lower modulus is more effective whereas at higher confining pressure, the geocell of higher modulus is more effective.

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