Numerical Simulation of Geocell Reinforced Foundation Beds: A Comparative Study Using PLAXIS\textsuperscript{3D} and FLAC\textsuperscript{3D}

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\textbf{ABSTRACT:} PLAXIS\textsuperscript{3D} and FLAC\textsuperscript{3D} are the two most popular commercial packages used to solve the complex geotechnical problems. Though the origin and background of these packages are different, both are used for the same purpose of solving the geotechnical problems. This paper discusses the advantages and disadvantages of using these packages in the analysis of geocells. The geocell reinforced foundation bed was simulated using these packages and the results were compared with the experimental results reported by Hegde and Sithara (2015a). The results reveal that the bearing capacity of the sand bed increase by 4 times and the settlement reduces by more than 70\% in the presence of geocells. As compared to PLAXIS\textsuperscript{3D}, FLAC\textsuperscript{3D} was found more suitable for the simulations of geocells due to the availability of robust structural elements.

\textbf{KEYWORDS:} geocell; foundation, PLAXIS\textsuperscript{3D}, FLAC\textsuperscript{3D}

\section{Introduction}

The numerical simulation of the geocell is not easy due to its complex honeycomb shape. Generally, the equivalent composite approach is used to model the geocells (Bathurst and Knight, 1998; Madhavi Latha and Somwanshi, 2009; Hegde and Sitharam, 2013). 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 (Hegde and Sitharam 2015a&b). This paper presents a more realistic modelling approach to model geocells in 3-dimensional (3D) framework using finite element (FE) and finite difference (FD) methods.

Finite element method (FEM) and Finite difference method (FDM) are the two popular numerical methods used in geotechnical engineering to solve the initial and boundary value problems. FEM solves the physical problem by dividing the geometry into smaller elements. At each element, the stresses and strains are separately calculated. These element stresses and strains are assembled back to the global geometry using the theory of superposition. On the contrary, FDM divides the problem into small time steps. Based on the present time step values, the stress and strain values of the next time step are predicted using the finite difference formulations. In the present study, two commercial programs, namely PLAXIS\textsuperscript{3D} and FLAC\textsuperscript{3D} representing to each of the above methods have been chosen for the analysis.

PLAXIS\textsuperscript{3D} is 3-dimensional the finite element program, used for deformation and stability analysis of the geotechnical problems. The program is inbuilt with a convenient and easy-to-use graphical user interface, which facilitates the quick generation of the model geometry. PLAXIS\textsuperscript{3D} uses the implicit integration based solution scheme to solve the initial and boundary value problem. In implicit method, the solutions are determined by solving the differential equation involving both the current and the future state of the system. On the contrary, FLAC\textsuperscript{3D} is the finite difference software, which uses the explicit Lagrangian solution scheme. Explicit method calculates the state of a system at a later time from the current time state of the system. FLAC\textsuperscript{3D} has several built-in material models and structural elements to model the variety of geo-materials and the reinforcements. FLAC\textsuperscript{3D} also contains a powerful built-in programming language called FISH that enables the user to define new variables and functions.

\section{Methodology}

Experimental results reported by Hegde and Sitharam (2015b) have been used in the present study to validate the numerical model. Hegde and Sitharam (2015a) have conducted the laboratory plate load tests on geocell
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Reinforced sand bed. In their study, a cast iron test tank of size 900 mm length, 900 mm width and 600 mm height was used. The performance of the geocell reinforced sand bed was compared with the unreinforced bed. Further details of the experimental study are explained elsewhere by Hegde and Sitharam (2015b).

Even though the PLAXIS\textsuperscript{3D} and FLAC\textsuperscript{3D} are originated from the different concepts, the fundamental modeling principals are same in both the packages. In the present investigation, the dimension of the model was kept same as that of the dimension of test bed used by Hegde and Sitharam (2015a). However, only quarter portion of the test bed was modeled using the symmetry to reduce the computational effort. Accordingly, the mesh of size 0.45 m x 0.45 m x 0.6 m was developed in both the cases to represent the model. The elastic-perfectly plastic Mohr Coulomb model was used to simulate the behavior of the foundation and the infill soil. The displacement along the bottom boundary (which represents tank bottom) was restrained in both horizontal as well as vertical directions. The side boundaries (which represent tank side) were restrained only in the horizontal direction, such that the displacements were allowed to occur in the vertical direction.

The geogrid structural element available in the FLAC\textsuperscript{3D} and Plaxis\textsuperscript{3D} was used to model the geocells. Linear elastic model was used to simulate the behavior of the geocell. A photograph of the expanded geocell was taken and it was digitized to obtain the actual curvature of the cell. The co-ordinates were deduced from the actual curvature and the same were used in the FLAC\textsuperscript{3D} to model the actual shape of the geocell. However, the actual curvature of the geocell pocket could not be formed in the Plaxis\textsuperscript{3D} due to the modeling difficulties. Hence, geocell pocket was modeled as a square shaped box instead of actual honeycomb shape. Figure 1a-b shows the FLAC\textsuperscript{3D} and Plaxis\textsuperscript{3D} models used in the study.

The material properties of the sand and the geocell were determined using various laboratory tests. Table 1 lists the different material properties used in the simulations. The analyses were carried out under the controlled displacement loading.

### 3 Results and Discussions

Figure 2a compares the pressure-settlement responses of experiment and FLAC\textsuperscript{3D} for unreinforced as well as the geocell reinforced cases. A good agreement was observed between the experimental and the FLAC\textsuperscript{3D} results. The ultimate bearing capacity of 200 kPa was observed in case of the unreinforced bed. Steep reduction in the slope of the pressure-settlement curve

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sand</td>
<td></td>
</tr>
<tr>
<td>Shear modulus, $G$ (MPa)</td>
<td>5.77</td>
</tr>
<tr>
<td>Bulk modulus, $K$ (MPa)</td>
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<tr>
<td>Poisson's ratio, $\mu$</td>
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<tr>
<td>Cohesion, $C$ (kPa)</td>
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<tr>
<td>Friction angle, $\varphi$ ($^\circ$)</td>
<td>36</td>
</tr>
<tr>
<td>Unit weight, $\gamma$ (kN/m$^3$)</td>
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</tr>
<tr>
<td>Geocells</td>
<td></td>
</tr>
<tr>
<td>Young's modulus, $E$ (MPa)</td>
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<tr>
<td>Poisson's ratio, $\mu$</td>
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<tr>
<td>Interface shear modulus, $k_i$ (MPa/m)</td>
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<tr>
<td>Interface cohesion, $c_i$ (kPa)</td>
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<tr>
<td>Interface friction angle, $\varphi_i$ ($^\circ$)</td>
<td>30</td>
</tr>
<tr>
<td>Thickness, $t_i$ (mm)</td>
<td>1.5</td>
</tr>
</tbody>
</table>

Fig. 1a-b. Numerical model: (b) FLAC\textsuperscript{3D}; (b) PLAXIS\textsuperscript{3D}

Table 1 Properties of different materials
was observed at the settlement \( S \) of 10% to 12% of the footing width \( B \), indicating the failure of the foundation bed. The bearing capacity of the foundation bed was found to increase by 4 times in the presence of geocells. In case of the geocell reinforced sand beds, there was no clear cut failure, even at very large settlements.

Similarly, Figure 2b compares the pressure-settlement response of the PLAXIS\(^{3\text{D}}\) with the experiment. A relatively good match was observed in case of the unreinforced bed. However, in case of the geocell reinforced case, the PLAXIS\(^{3\text{D}}\) results were found to deviate from the experimental results beyond \( S/B = 5\% \). Hence, the analysis was terminated beyond the \( S/B = 5\% \). Since the same material properties were used in both PLAXIS\(^{3\text{D}}\) and FLAC\(^{3\text{D}}\), the deviation was attributed to the shape of the geocell. Due to the modeling difficulties, the geocell shape was modeled as the square shaped box in the PLAXIS\(^{3\text{D}}\) instead of honeycomb shape. The change in the shape of the geocell pocket has resulted in the deviation in the pressure settlement response.

The reduction in the settlement due to the provision of geocell was calculated using the non-dimensional term called percentage reduction in settlement (PRS). PRS is defined as,

\[
PRS = \left( \frac{S_o - S_r}{S_o} \right) \times 100 \tag{1}
\]

where \( S_o \) is settlement of the unreinforced foundation bed corresponding to its ultimate bearing capacity. \( S_r \) is settlement of reinforced foundation bed corresponding to the footing pressure equal to the ultimate bearing pressure of unreinforced foundation bed. In the present case, ultimate bearing capacity of 200 kPa was observed in the case of the unreinforced bed. Beyond 200 kPa, a steep reduction in the pressure-settlement was observed indicating failure of the bed.

Figure 3a-b shows the displacement contours obtained from PLAXIS\(^{3\text{D}}\) for unreinforced and geocell reinforced cases corresponding to 200 kPa. These displacement contours belong to a point on the load-settlement response, where the change in the curvature was observed. At 200 kPa pressure, the settlement of 19 mm was observed in case of the unreinforced bed. At

Fig.3a-b. Displacement contours, PLAXIS\(^{3\text{D}}\) : (a) unreinforced; (b) geocell reinforced
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the same pressure, the settlement of 5 mm was observed in case of the reinforced foundation bed. The PRS value calculated corresponding to these settlement values found to be 73%.

Figure 4a-b shows the vertical stress contours obtained from FLAC$^{3D}$ for unreinforced and geocell reinforced cases. The reported stress contours are corresponding to the applied vertical stress equal to the ultimate bearing capacity of the unreinforced bed i.e. 200 kPa. Uniform distribution of the stress up to the large depth was observed in case of the unreinforced bed. In case of geocells, the stresses are transferred to a relatively shallow depth as compared to unreinforced bed. However, stresses are transferred laterally to the wider areas in the top portion of the bed.

4 Conclusions

This paper presented the results of the numerical simulations of geocell reinforced foundation beds performed using PLAXIS$^{3D}$ AND FLAC$^{3D}$. The results revealed that the bearing capacity of the sand bed increases by 4 times in the presence of geocells. In addition, the settlement of the foundation bed was found to decrease by more than 70% in the presence of geocells. The geocell was found to distribute the load in lateral direction instead of vertical the direction. At the lower settlements, both PLAXIS$^{3D}$ and FLAC$^{3D}$ results were found to be in good agreement with the experiment results. However, beyond $S/B=5\%$, the PLAXIS$^{3D}$ results were found to deviate from the experimental results. This deviation was attributed to the shape of the geocell pocket size used in the PLAXIS$^{3D}$ analysis.

In overall, FLAC$^{3D}$ was found more robust than the PLAXIS$^{3D}$. However, due to its command driven approach, the modeling process in FLAC$^{3D}$ was found to be laborious and demanding. In contrast, PLAXIS$^{3D}$ is more user friendly due to the presence of easy-to-use graphical user interface. It is advised to use FLAC$^{3D}$ for the geotechnical problems involving complex shapes and geometry. On the other hand, PLAXIS$^{3D}$ is better suited for the geotechnical problems with the simple geometry. It should be noted that the author’s observations are purely based on the personal judgment and are restricted to present problem only.

References


Fig. 4a-b. Vertical stress contours, FLAC$^{3D}$: (a) unreinforced; (b) Geocell reinforced (data sourced from Hegde and Sitharam, 2015a)