# Performance of Geocell Reinforced Embankment over Soft Soil Deposit

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**Abstract.** This paper studies the performance improvement due to the presence of geocell layer at the base of the embankment over soft clay deposit. The experimental study was carried out by conducting tests on model embankments overlying soft clay with reinforcement by geocell mattress at the interface between the earthen embankment and soft clay foundation bed, by varying its parameters like aspect ratio (pocket size), and type of infill material. Experiments were also carried out for unreinforced foundation soil beneath the earthen embankment, to show comparative performance and ground improvement due to soil reinforcement using geocell mattress. Test results indicated a considerable percentage reduction in settlements, lateral deformations and percentage increase in ultimate capacity of geocell reinforced embankments, over unreinforced embankment. The test results were also validated using finite element analyses of geocell reinforced foundation over unreinforced foundation.

## 1 Introduction

Construction of embankment or other geotechnical structures over soft soil has always been a challenge for engineers or contractors. The difficulty arises mainly due to large settlements and lateral deformations that take place due to the extremely low shear strength of the soft foundation soil. Methods like soil excavation and replacement or piling are not practical or economical in many cases. In this aspect, the use of geocells has been a major contribution as a ground improvement technique. Geocell reinforcement is generally provided at the foundation level, however it can also be effectively provided as a slope reinforcement technique owing to its three-dimensional structure. Geocells are three-dimensional, honey-combed like, polymeric structures which are interconnected at their joints. Due to its 3-D structure, it can contain the soil at the base of the embankment, which helps to distribute the load over a wider area by providing a stiff and rigid base to the embankment and thus, improving the


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performance of embankments over soft soil in terms of increased bearing capacity and reduced settlements and lateral deformations. From literature, it has been also seen that it is economical as well as much less time consuming than piling or other conventional methods.

Use of Geocells has been established to be an effective reinforcement technique by experimental studies in the laboratory (e.g. Rea and Mitchell 1978; Mhaiskar and Mandal 1994; Emersleben and Meyer 2008), by numerical modeling (Mehdipour et al. 2013; Leshchinsky and Ling 2013) and also by conducting field studies of geocell applications (Paul 1988; Sitharam and Hegde 2013). Mandal and Gupta (1994), Dash et al. (2001a, b, 2004), Tafreshi and Dawson (2012) reported the beneficial effects of using geocells on strip footing by conducting laboratory model tests. Krishnaswamy et al. (2000) observed that geocell used at the embankment base overlying soft clay could greatly reduce the deformations for various applied surcharge pressures. Dash et al. (2003a, b) conducted laboratory model tests on circular footings using geocells to investigate the improvement in performance of circular footings. Latha et al. (2006), Zhang et al. (2010) studied the advantages of geocell application at the base of embankment over soft foundation soil by conducting laboratory model embankment tests. The confinement effect provided by the geocells on sand samples were studied by triaxial compression tests and found that a large amount of apparent cohesion is developed in the reinforced samples (e.g. Rajagopal et al. 1999; Chen et al. 2013) which showed that the shear strength of soils increased using geocells. Chen and Chiu (2008) conducted laboratory model tests on geocell retaining walls and found considerable reduction in settlement and lateral displacement. Pokharel et al. (2009), Pokharel et al. (2010) carried out laboratory tests to study the improvements in bearing capacity of base course using geocell. Hegde and Sitharam (2017) conducted laboratory studies as well as numerical simulations using three types of cellular reinforcement, namely geogrid cells, commercial geocells and bamboo cells and obtained the best performance using bamboo cells owing to its higher stiffness.

Robertson and Gilchrist (1987) reported the selection of geocell mattress as the most cost effective method for constructing a 4 m high embankment over soft foundation soil. The selection of geocell option was made after economic analysis of excavation and replacement. Other options were not considered because they were either impractical or would take too long to construct. Paul (1988) examined four alternatives for embankment construction over areas in Scotland and found geocell option to be the most economical and rapid. Mehdipour et al. (2013) studied the behavior of geocell reinforced slopes and found that the lateral deformation and shear strain of slope considerably decreased. Leshchinsky and Ling (2013) studied the confinement provided by geocells to railway ballast through numerical modeling and showed that geocell was effective in reducing the stresses on the subgrade by distributing it more uniformly.

The purpose of the present research is to show the improvement in performance of geocell reinforced soft foundation soil of embankment with respect to increase in bearing capacity and decrease in settlements and lateral deformations of embankment and heaving of soft clay foundation under applied loads and validate the results using finite element analyses.

# 2 Model Tests

## 2.1 Materials Used

Soft foundation bed was prepared using locally available clayey and organic soil in the ratio 1:3 by weight. The specific gravity of the soft soil was found to be 1.56 by water pycnometer method. The undrained shear strength of soft foundation bed was found by unconfined compression tests. Locally available clayey soil was used as embankment soil and also as infill material in geocells. The effective shear strength parameters of embankment soil were found by consolidated drained triaxial tests. The properties of the soft foundation soil and embankment soil used in the present investigation are given in Table 1. In few tests, dry river sand was also used as infill soil. The properties of the sand used as infill material are given in Table 2. The geocell was constructed using biaxial geogrid. The ultimate tensile strength of the biaxial geogrid was 20 kN/m at failure strain 25%. The properties of geogrid used for geocell construction are given in Table 3. The geocells were constructed having diamond pattern for all the tests.

**Table 1.** Properties of soft foundation soil and embankment soil used in the present investigation

| Property | Soft foundation soil | Embankment soil |
|---|---|---|
| L.L. (%) | 52 | 53.9 |
| P.L. (%) | 25 | 22.64 |
| Optimum moisture content (%) | 24.91 | 17.2 |
| Max dry density (kg/m$^3$) | 1320 | 1540 |
| Mean specific gravity (G) | 1.56 | 2.39 |
| Placement moisture content (%) | 40 | 17.2 |
| Placement density (kg/m$^3$) | 1670 | 1540 |
| Cohesive strength (kPa) | 20 | 90 |
| Angle of internal friction (°) | – | 7 |

**Table 2.** Properties of sand used as infill material

| Property | Infill sand |
|---|---|
| Minimum density, $\rho_{min}$ (kg/m$^3$) | 1370 |
| Maximum density, $\rho_{max}$ (kg/m$^3$) | 1700 |
| Uniformity coefficient (Cu) | 1.55 |
| Coefficient of curvature (Cc) | 0.903 |
| Mean specific gravity (G) | 2.69 |
| Porosity ($\eta$) (%) | 0.2 |
| Maximum void ratio ($e_{max}$) | 0.992 |
| Minimum void ratio ($e_{min}$) | 0.605 |

**Table 3.** Properties of geogrid used for geocell construction

| Property | Geogrid |
|---|---|
| Ultimate tensile strength (kN/m) | 20 |
| Failure strain (%) | 25 |
| Thickness (mm) | 2 |
| Aperture opening shape | diamond |

## 2.2 Test Set-up

A steel tank having dimensions 1150 mm × 550 mm × 975 mm was fabricated for conducting model tests on embankment overlying soft clay. The test set-up was prepared in a two-side Perspex fitted steel tank so that the deformation behavior of the embankment could be clearly observed. Geocell mattress was placed above soft clay bed within the tank and the embankment was constructed above the geocell layer. The test bed was instrumented using proving ring and dial gauges. The load was applied to the embankment using a hydraulic jack supported against a reaction frame. The load was measured using a pre-calibrated proving ring of capacity 10-tonne. The vertical displacements and lateral deformations were measured using dial gauges of sensitivity 0.01 mm and maximum deflection 50 mm. Figure 1 represents the test set-up of the model embankment tests used in the present investigation.

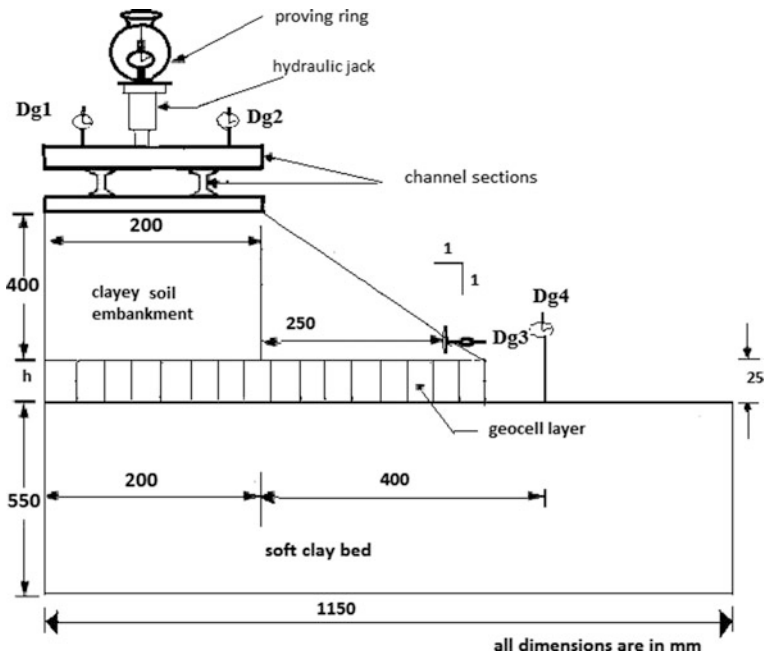


**Fig. 1.** Test set-up of model embankment tests

## 2.3 Test Bed Preparation

### 2.3.1 Preparation of Soft Clay Bed at Foundation

The soft foundation bed was prepared by using clayey and organic soil in the ratio 1:3 by weight. The soil was mixed with predetermined amount of water to maintain same placement moisture content throughout and uniform moisture distribution was obtained. The foundation was prepared by layer-wise proper compaction of the soil to the desired height. The amount of soil needed, water content of soil, height of fall and number of blows of the compacting equipment required to achieve the desired density was determined prior to the model tests through a series of trials. The water content and compaction were carefully controlled to achieve a fairly uniform test condition throughout the entire test program. Each layer was uniformly compacted in order to achieve uniform density in all the tests. Undisturbed samples were taken from each layer to determine the in situ unit weight and moisture content of the foundation soil so that uniformity could be maintained for each test.

### 2.3.2 Fabrication and Laying of Geocell Mattress

After leveling the soft foundation bed, a layer of geocell mattress was placed at the interface of the soft foundation and embankment which was truncated at the embankment toe. The geocell mattress was prepared by cutting the geogrid to required length and height from full rolls. The geogrids were bound with wires to achieve the desired diamond shape. After the fabrication of geocell layer, the geocell pockets were filled with sand/clay by dropping it from a certain height. The height of fall to achieve the desired relative density was determined beforehand through trials with different heights of fall. Samples were collected in small aluminium cans of known volume to monitor the relative density achieved. The cans were placed at different locations in the test tank and the difference in densities was measured and found to be less than 1%.

### 2.3.3 Preparation of Clay Embankment

The embankment having a slope 1:1 was prepared by compacting the soil in four equal layers till the desired height was attained. The embankment was compacted at optimum moisture content to achieve the maximum dry density. The amount of soil, number of blows and height of fall were determined prior to the model tests by a series of trial tests. Each layer was compacted using calculated number of blows to achieve uniform density in all the tests. Undisturbed samples were taken during each loading and unloading stage to carefully monitor the water content and compaction to maintain uniformity during each test.

## 2.4 Test Procedure

The experimental program for the model tests conducted is given in Table 4. Surcharge pressure was applied on the embankment using a hydraulic jack. A 10-tonne proving ring was used to measure the surcharge load. Until the deformation under a particular load increment had stabilized, it was maintained constant. Uniform surcharge pressure distribution was achieved using an arrangement of three steel I-sections between two rigid steel plates running for full width of the tank on the embankment crest. Four dial gauges were placed at different locations to measure vertical and horizontal deformations (Fig. 2 a, b). Two dial gauges (Dg1 and Dg2) measured vertical settlements (Fig. 2a); Dg3 measured lateral deformations near the embankment toe and Dg4 measured the heaving of the soft foundation under applied load (Fig. 2b). For each test, the pressure versus deformation readings were taken till the ultimate capacity was reached. The laboratory model tests continued for approximately 30 min. After each test, the foundation and embankment soil were completely unloaded and again freshly prepared for the next test. The moisture content and density were maintained uniformly by taking undisturbed samples for each loading and unloading stage. The geocell mattress was also carefully removed after completion of each test. The trial test results on reinforced and unreinforced ensured uniformity of test conditions.

**Table 4.** Experimental program for the model tests conducted

| Type of material | Pattern | Thickness (mm) | Type of infill material | Aperture size (mm) | Aspect ratio | No. of tests |
|---|---|---|---|---|---|---|
| Unreinforced | – | – | – | – | – | 1 |
| Geocell | Diamond | 25 | Clay | 75 × 75 | 0.33 | 1 |
| | | | | 100 × 100 | 0.25 | 1 |
| | | | Sand | 75 × 75 | 0.33 | 1 |
| | | | | 100 × 100 | 0.25 | 1 |

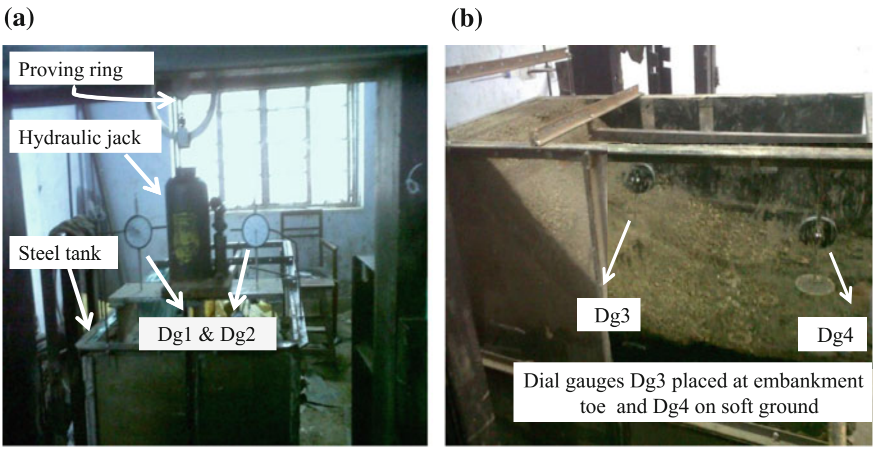


**Fig. 2.** Dial gauges placed at different location in the model tests: **a** Dg1 and Dg2 for vertical settlements; **b** Dg3 at embankment toe and Dg4 on soft foundation for heaving measurement

### 2.5 Model Test Results

Since the model tests were completed in approximately 30 min, the short term behavior of the embankment under applied load was considered in this study. Figure 3 shows the pressure-settlement behavior of unreinforced and geocell reinforced embankments for different aspect ratios and infill materials. From the model test results, it was observed that for unreinforced case, the pressure-settlement curve slope became almost vertical beyond a settlement of 7.5% of embankment top width, indicating failure. It can be seen that the clay-filled geocells (h/D = 0.25) gives an ultimate capacity of 218.72 kPa as compared to the unreinforced embankment (82 kPa) which means that 166.67% increase in ultimate capacity was achieved using clay-filled geocells. Also at the ultimate capacity of unreinforced embankment, clay-filled geocells (h/D = 0.25) gave 87.9% reduction in vertical settlement. For sand-filled geocells having same aspect ratio (h/D = 0.25), increase in ultimate capacity was 6.25% over clay-filled geocells and further reduction in vertical settlement was 11.27%.

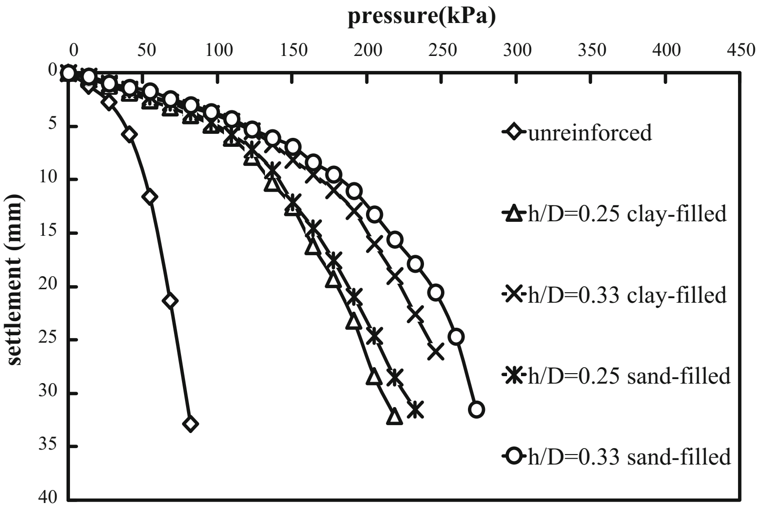


**Fig. 3.** Pressure-settlement behavior of model embankments for different aspect ratios and infill materials

For clay-filled geocells having higher aspect ratio 0.33, increase in ultimate capacity over 0.25 sand-filled geocells was 5.88%. The reduction in settlement for clay-filled geocells (h/D = 0.33) was 28.25% over sand-filled geocells (h/D = 0.25) at the ultimate capacity of 0.25 sand-filled geocells. For same aspect ratio (h/D = 0.33), sand-filled geocells gave further increase in ultimate capacity of 11.11% over clay-filled geocells. It was observed that the pressure-settlement curves were much stiffer than unreinforced case, indicating that performance substantially improved using geocells.

Figure 4 shows the lateral deformation at the toe of the embankment for different values of applied pressure. It is observed that lateral deformation is considerably reduced using geocell as reinforcement irrespective of the infill material. This happens due to the frictional resistance offered by the composite geocell-infill system. However for the same aspect ratio, sand-filled geocells gave better results as compared to clay-filled geocells. A higher aspect ratio increased the performance of geocell irrespective of the infill material.

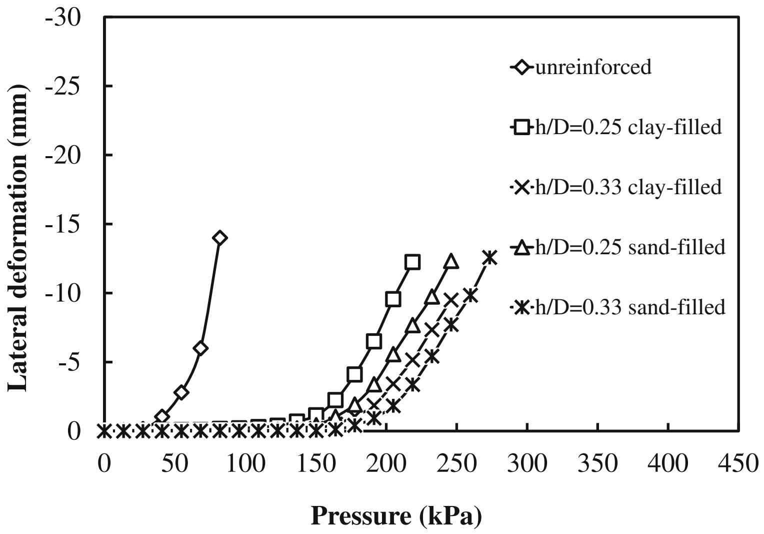


**Fig. 4.** Pressure-lateral deformation behavior of model embankments for different aspect ratios and infill materials at embankment toe

Figure 5 shows the heaving of soft foundation bed under applied pressure during the model tests. The heaving of the soil also follows the same pattern i.e. it reduces using geocells of higher aspect ratio and sand as infill material.

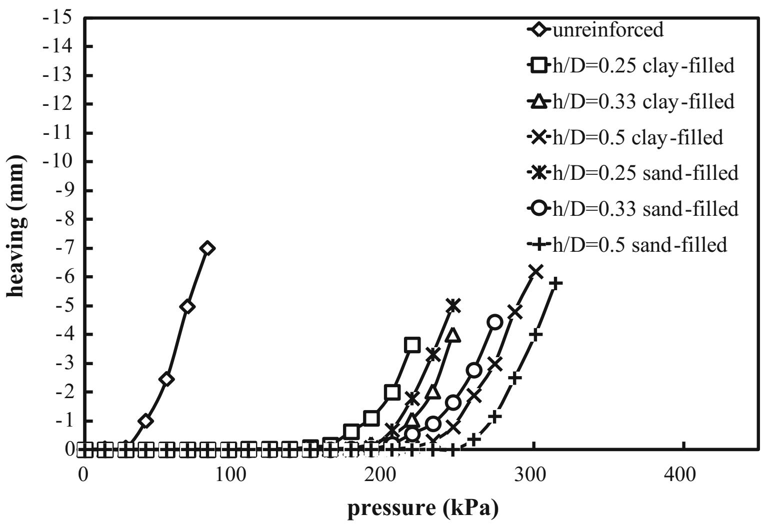


**Fig. 5.** Pressure-heaving behavior of soft soil bed for different aspect ratios and infill materials

Thus, the highest load carrying capacity was achieved by using geocell having 75 mm pocket size (h/D = 0.33) i.e., smaller pocket size. The different aspect ratios were achieved by varying only the pocket size as height of geocell layer was kept constant in all tests (25 mm). The decrease in pocket size results in increase in confinement of cells per unit volume and increase in rigidity of geocell mattress which results in the performance improvement. Sand as infill material can be compacted with better stiffness and rigidity than clay. However, in absence of good quality sand near construction site, locally available clay can also be used as infill material.

## 3 Fem Modelling

Midas GTS Software (Midas 2013) was used to perform three-dimensional finite element analyses of model embankments. Midas GTS is a commercially available, fully integrated 2D and 3D finite element software. In this investigation, straight analyses have been used to validate the test results which implies that while the soft foundation was modeled using elasto-plastic, Mohr-Coulomb, undrained relationship, the embankment soil and infill material were modeled using elasto-plastic, Mohr-Coulomb, drained relationship.

### 3.1 Geometry and Mesh Generation

For validating the model test results, a three dimensional finite element model of exactly the same geometry as laboratory model embankment was prepared using Midas GTS. The linear elastic model was used to simulate the loading plate. The modulus of elasticity for the loading plate and Poisson's ratio were taken from Sowmiya (2013). The geometry of the geocell layer of individual pocket size 100 mm × 100 mm was prepared with the required diamond shape over the surface of the foundation soil. It was then extruded as a solid element of required height. The geocell was modelled as a linearly elastic material. The Young's modulus of geocell used was 120 MPa from a range of values of geocell stiffness used by Leschinsky and Ling (2013). The Poisson's ratio for the geocell was assumed to be 0.2. The undrained Mohr-Coulomb model was used to model the soft foundation while the drained Mohr-Coulomb model was used for the infill soil and embankment. The undrained shear strength parameters for the foundation soil and the effective shear strength parameters for the embankment soil used were the same as found experimentally as already given in Table 1. The moduli of elasticity and Poisson's ratio for the embankment soil, infill sand and soft foundation soil were taken from Bowles (1996). The effective angle of internal friction for infill sand was found by direct shear tests. The cohesion value was assumed to be 0.1 kPa for ease of computation. After geometry modeling, the mesh was generated using auto-mesh generation option having triangular elements. A desired element size with adaptive seeding was used for this purpose. The model components were separated using 'Boolean Cut' option before auto-mesh generation. Figure 6a–f shows all the model embankment components used for the three-dimensional finite element model. The parameters assigned to each mesh set of individual embankment components for straight analyses are given in Table 5.

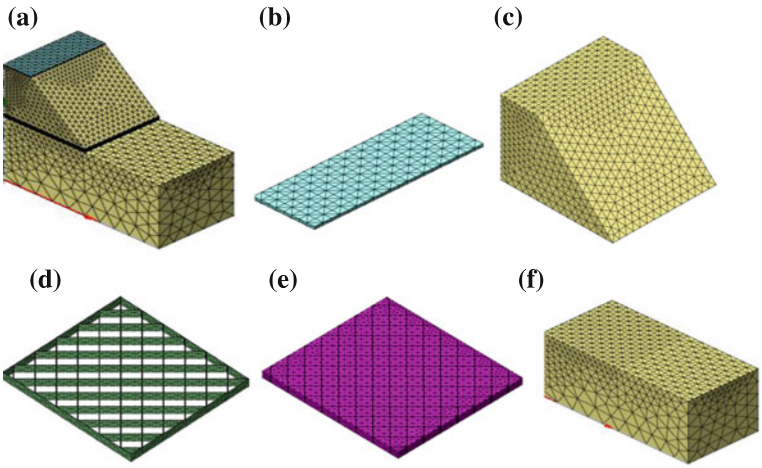


**Fig. 6.** Components of model embankment: **a** model embankment with all layers; **b** loading plate; **c** embankment soil layer; **d** geocell; **e** infill soil; **f** soft foundation

**Table 5.** Parameters for straight analyses of FEM model

| Model components | Straight analysis model parameters used in FEM | E (MPa) | μ | ($c_u$) (kPa) | ϕ′ (°) |
|---|---|---|---|---|---|
| Loading plate | Elastic | 200,000 | 0.27 | – | – |
| Embankment soil | Mohr coulomb (drained) | 6 | 0.3 | 90 | 7 |
| Sand | Mohr coulomb (drained) | 30 | 0.3 | 0.1 | 30 |
| Soft foundation clay | Mohr coulomb (undrained) | 2 | 0.4 | 20 | – |
| Geocell | Elastic | 120 | 0.2 | – | – |

## 3.2 Boundary Conditions

Roller supports were assigned to the vertical faces of embankment model meaning that the side boundaries of the model in the tank were restrained only in the horizontal direction while vertical displacements were allowed to occur, but no boundary conditions were applied to the sloping surfaces of the embankment layers. The bottom face of the subgrade was considered fixed. The default values of most of the computational control parameters were kept same as given in Midas GTS except displacement norm, which was changed to 0.01.

## 3.3 Validation of Test Results Using FEM

The results of the model embankment tests were compared with that of FEM results. A total of two tests using straight analyses were simulated for geocells having aspect ratio 0.25 with sand and clay as infill material. The tests were completed in 30 min. Figure 7 shows the comparison of FEM results with the measured results of laboratory model tests for aspect ratio of 0.25, having sand and clay as infill material. The FEM analysis gives fairly similar behavior as compared to the model test results. Figures 8a, b show the distribution of total displacements and vertical stresses for different model embankment components for sand-filled geocell (h/D = 0.25). The displacement contours portray the efficiency of geocell in reducing vertical displacements while the vertical stress contours show that the incorporation of geocell leads to minimizing the stresses gradually in the subsequent layers leading to a shift from punching to local shear failure. The presence of a geocell layer shifts the potential failure planes further downwards leading to increase in ultimate capacity. From the FEM results, it is clear that the geocells having sand as infill material gives better results than clay as infill material. Also higher aspect ratios give better performance in terms of ultimate capacity and reduction in settlements, lateral deformations and heaving of soft foundation bed.

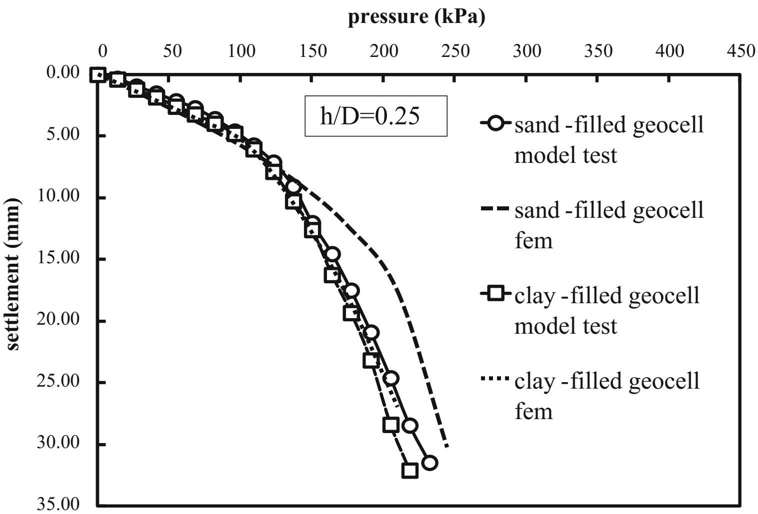


**Fig. 7.** Comparison of pressure-settlement behavior of laboratory model embankment tests with FEM for geocells with 0.25 aspect ratios and sand and clay as infill materials

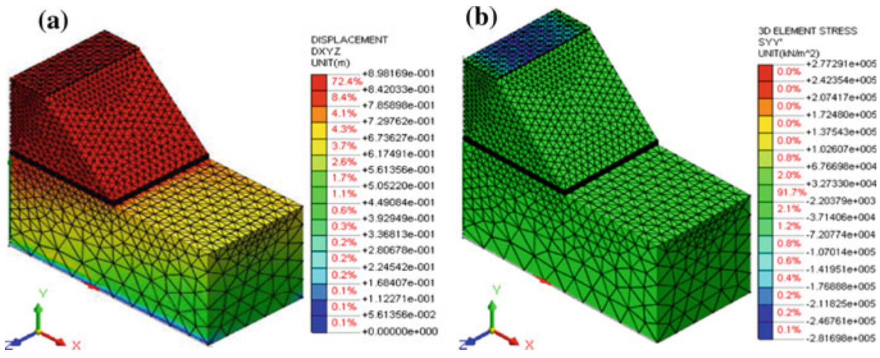


**Fig. 8.** Distribution of **a** total displacement and **b** vertical stress for sand-filled geocell having aspect ratio 0.25

## 4 Conclusions

Laboratory model tests were conducted on model embankments and FEM modeling using straight analyses were performed. From the present study, the following conclusions can be drawn:

1. The inclusion of geocell mattress at the base of embankment can increase its ultimate capacity by about 3 times to that of unreinforced embankment.
2. The improvement in performance increased when geocells with higher aspect ratio (smaller pocket size) was used.
3. For the same aspect ratio, geocells having sand as infill material gave better results than clay, both in terms of increase in ultimate capacity and decrease in settlements, lateral deformations and heaving of soft foundation.
4. The settlements, lateral deformations and heaving of soft foundation were greatly reduced using geocell mattress.

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