Numerical Analyses of Geogrid Reinforced Embankment Over Soft Clay

C. Keerthana, M. P. Vibhoosha, and Anjana Bhasi

Abstract Construction of embankments on weak foundation soils is a challenging task for civil engineers due to excessive settlement, bearing capacity failure and slope stability issues. To solve this problem, a variety of ground improvement techniques, including vertical drains, grouting, complete soil replacement, geosynthetic reinforcement and piling, are adopted. Geosynthetics provides an alternative and economical solution and has been increasingly applied as reinforcement in embankments on soft soil. In the present study, 3D numerical analyses using the finite element program ABAQUS was carried out to study the time-dependent behaviour of geogrid reinforced embankment. Parametric studies were carried out by varying the height of the embankment.

Keywords Soft soil · Embankment · Numerical analyses · Geogrid · Settlement

1 Introduction

Design and construction of the infrastructure is the most important need in the present time. Many times construction takes place on poor soil due to space constraints. Construction over poor quality soil with heavy loads is a challenging task for civil engineers. Shallow foundation construction on week soil leads to excessive settlement and low bearing capacity, which could ultimately lead to structural damage [4]. Replacement of weak soil by some strong soil or improvement of engineering properties of weak soil by different ground improvement techniques is used in such a situation.

Geogrid reinforcement is an effective method to improve the stability and service life of different earth structures such as embankments, pavements, foundations and retaining walls. Reinforced embankments have been successfully used to reduce costs

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and speed of construction compared to the conventional methods. The function of the geogrids is to improve the internal and external embankment stability, restraining the lateral deformation, reduce the settlement and pore pressure and significant improvement in the bearing capacity. It can increase the embankment stiffness and reduce the shear stress, strain magnitudes and plastic deformation in foundation soil [3]. In the case of geogrid reinforced embankment, reinforcement is placed at the base of an embankment and at a particular distance from the base. Hence, results of multiple layers of geogrid reinforced embankment were also studied. Mainly, reinforcement can increase the stiffness of embankment fill, but only some part of the mobilized tensile force helped to stiffen the fill and remaining went into the less stiff foundation soil.

2 Numerical Analyses of Model

Embankment geometry and properties were adopted from the paper 'Numerical modelling of geosynthetic-encased stone column-reinforced ground' [1]. Figure 1 represents the right half of the embankment having 45 m wide and 6 m height with a side slope of 1V: 2H. The soft clay layer, which is 10 m deep, overlying a firm layer. A 1-m-thick sand mat was placed over the clay. Embankment construction was completed in three equal stages with 2 m fill placement. Each layer construction was done within 15 days followed by 10 days of waiting period for consolidation.

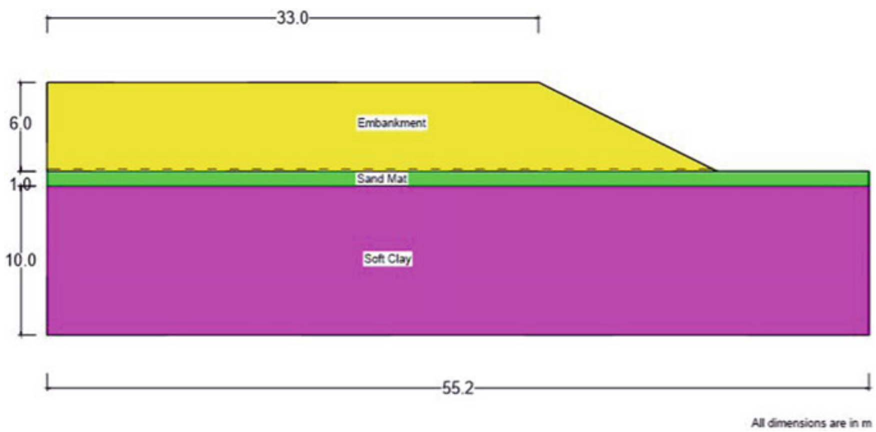


Fig. 1 Cross section of embankment

Table 1 Summary of model parameters for clay, sand mat and fill material

Property	Clay	Sand/fill
	Model	
	Modified cam clay	Mohr–Coulomb
Unit weight (kN/m^3)	18	19
Young's modulus (kPa)	–	15,000
Poisson's ratio	0.3	0.3
Cohesion, c' (kPa)	–	3
Friction angle, ϕ'	–	28
Dilation angle, Ψ'	–	10
Critical state stress ratio, M	1	–
Logarithmic hardening constant for plasticity, λ	0.2	–
Logarithmic bulk modulus for elastic material behaviour, κ	0.02	–
Initial yield surface size, a_o, (kPa)	50	–
Initial void ratio, e_o	1	–
Permeability, k (m/s)	1.2×10^{-6}	1.2×10^{-2}

2.1 Finite Element Modelling

ABAQUS [2], a commercial finite element code was selected for the analysis, for considering soil non-linearity and stress–pore pressure-coupled problems. Modified cam clay material was used to model the soft clay. The sand mat and fill were modelled using the linear elastic, perfectly plastic model with the Mohr–Coulomb failure criterion. Linear elastic model was used for geosynthetics. Geogrids are modelled as membrane here. Parameters and properties of each component are given in Table 1.

In this analysis, geogrid membrane thickness is taken as 15 mm and E is the Young's modulus of elasticity (1.7×10^5 kPa). J is the secant stiffness of the geogrid, it can be defined as J = E t. Hence, J = 2500 kN/m.

2.2 Boundary Condition and Mesh Generation

Vertical side boundaries of the model were horizontally fixed and full fixity at the clay bottom (Fig. 2a). The element type used to represent the clay layer was 20-node stress pore pressure elements with reduced integration (C3D20RP) and 20-node stress only element (C3D20R) were used to represent the sand mat and embankment fill. Eight-node membrane element (M3D8R) was used to model the geosynthetic reinforcement (Fig. 2b). The top boundary of the clay layer makes as drained, which means zero pore pressure boundary condition. The loading of embankment was simulated by adding individual layers of the embankment.

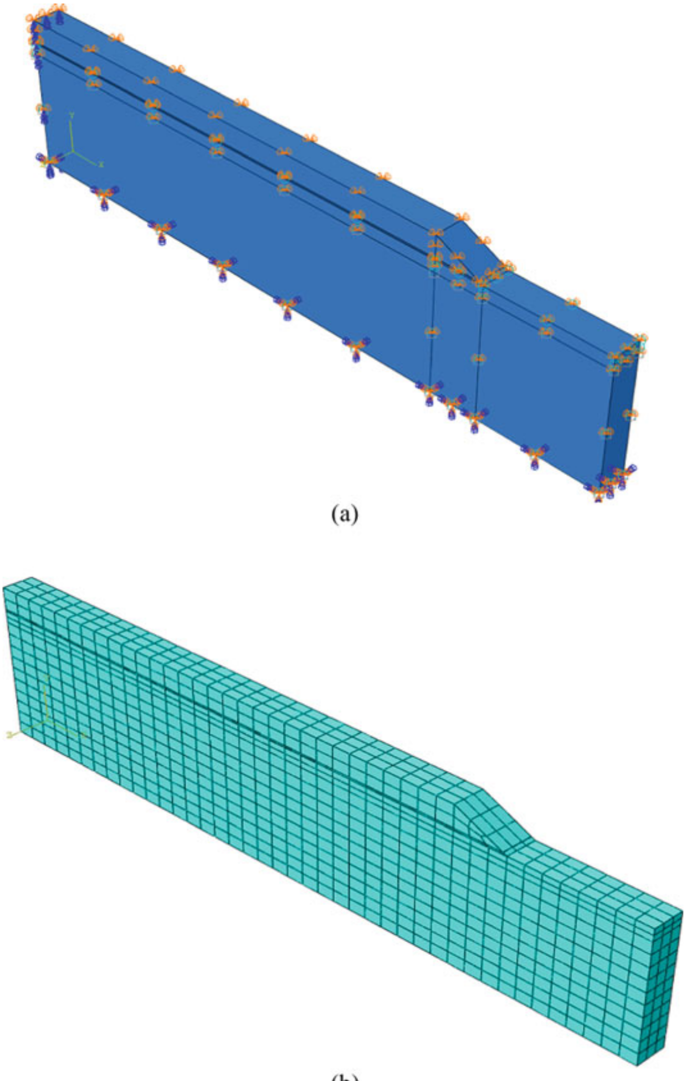


Fig. 2 Three dimensional embankments: **a** model after boundary conditions; **b** structured mesh of the reinforced model

3 Results and Discussions

The results obtained from the unreinforced and reinforced cases were compared in terms of settlement and pore pressure. A reinforced embankment was modelled using geogrid membrane elements. Two layers of geogrids were spaced 15 cm apart just above the sand mat.

3.1 Settlement and Excess Pore Pressure

Figures 3 and 4 represent the settlement of embankment at the top and excess pore pressure distribution at the mid-depth of the clay layer, respectively. Comparison of settlement and pore water pressure was done for both unreinforced and reinforced cases. Reinforced embankments over a weak soil can stiffen the base of the embankment and reduce the shear stress and plastic shear deformation. Reinforcement placed near or at the base of the embankment can increase the tensile stiffness of the embankment and this stiffness increases as the stiffness of geogrid increases up to an optimum value. A part of mobilized tensile force increases the embankment stiffness and the rest of the tensile force propagated from stiffer embankment fill to softer foundation soil.

Time history of the settlements under the centre of the embankment was shown (top point of the third layer of embankment). Note that consolidation settlement started immediately when the first embankment layer was constructed. Here, the settlement starts only after 50 days. It can be seen that only a 4% reduction in settlement by comparing the plain case.

Figure 4 represents the development of excess pore pressure for a 6 m embankment. Initially, water takes the external load and pore pressure increases. Then the soil skeleton absorbs the extra stress, the pore pressure decreases and the soil consolidates. It is essential to consider that both water flow (due to excess pore pressure dissipation) and deformation take place in the vertical direction only in many of the consolidation problems. Figure 4 shows how the excess pore pressure increases in steps as the embankment constructed and pore pressure dissipates gradually, after

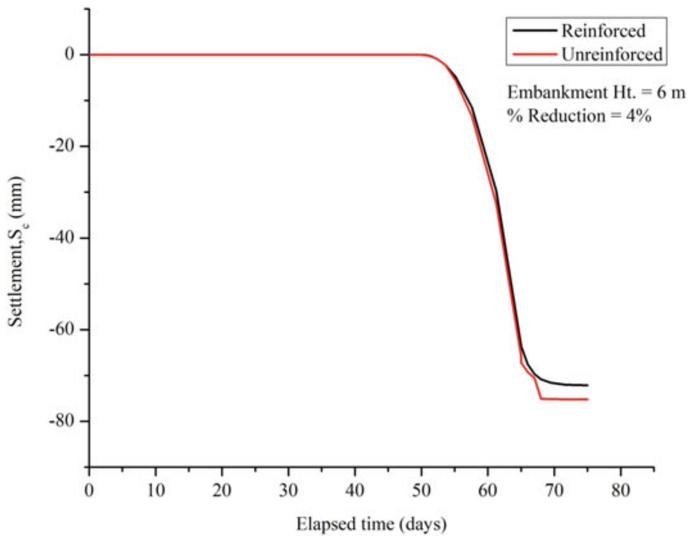


Fig. 3 Development of settlement

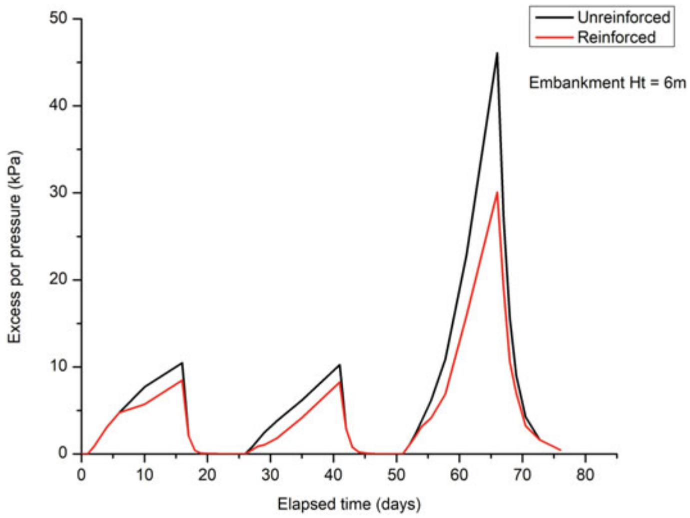


Fig. 4 Development of excess pore pressure

the end of construction. The maximum pore pressure is developed for unreinforced case compared to reinforced one; this difference is due to the less embankment load transfer to the clay layer when it is reinforced.

3.2 Embankment Height Versus Settlement and Pore Pressure

Embankment height is a parameter considered for the parametric study. The settlement and pore pressure on changing the height of the embankment were evaluated. The embankments with height 2 and 4 m were Numerically simulated and the variation of settlement and pore pressure were studied according to the height change (Fig. 5).

Settlement analyses of the embankment with different heights were carried out. These embankments were reinforced with two layers of geogrid placed 15 cm apart. It was found that the settlement reduced by 85.64, 25.58 and 4% for 2, 4 and 6 m, respectively. As the embankment height increases, the percentage reduction in the settlement was reduced. Figure 6 shows the deformation behaviour of both plain and reinforced embankment. Figure 7 illustrates the excess pore pressure variation with respect to time. The maximum pore pressure was developed in an unreinforced case,

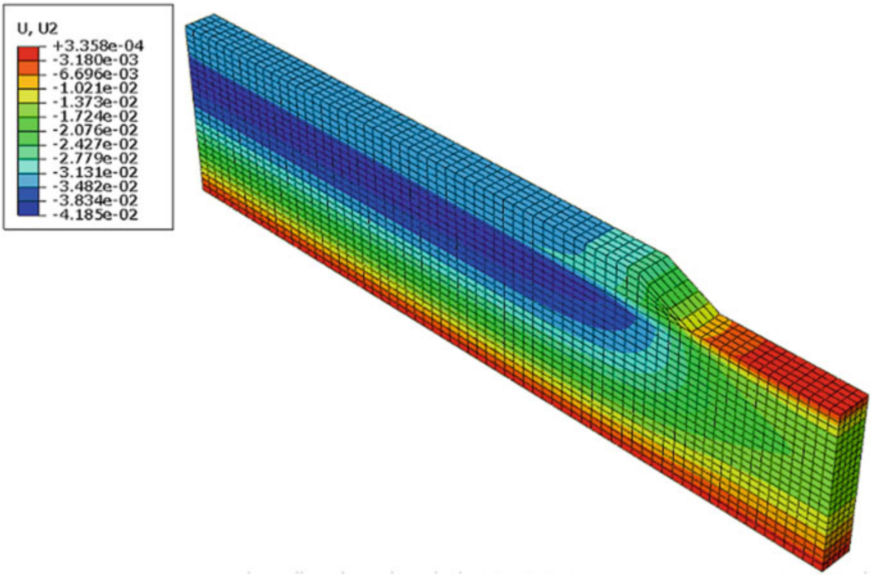


Fig. 5 Contour plots of vertical deformation of the unreinforced embankment with height 2 m

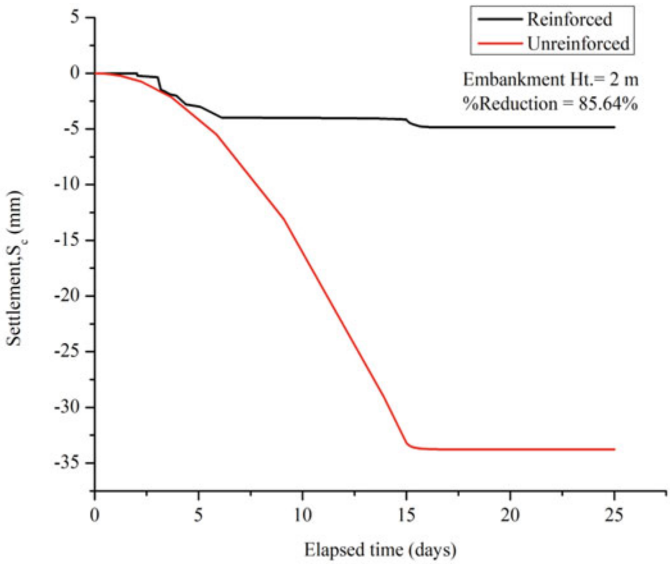
the difference in which was a direct consequence of the difference in load transfer to the clay layer. This trend was well supported in the development of settlement.

4 Conclusion

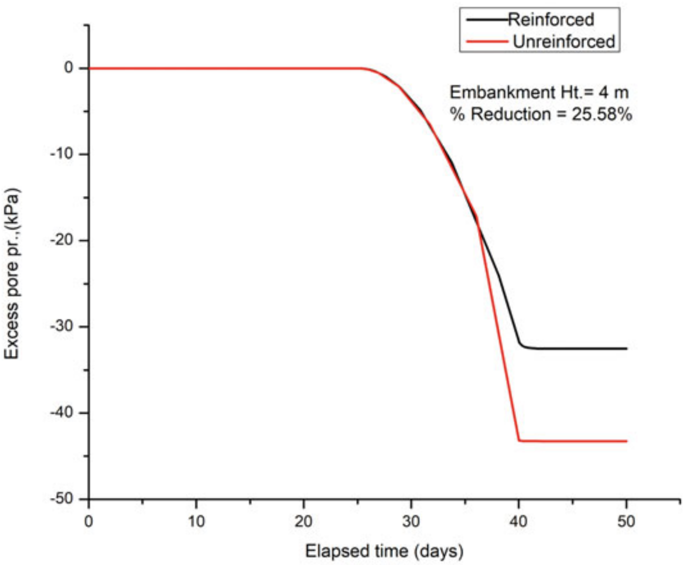
For an embankment constructed over soft ground, settlement of the embankment and the pore pressure distribution on the soft ground were studied with time. The use of geogrid decreased the embankment load-induced excess pore water pressure on the foundation soil as well as the vertical settlement of embankment.

The time-dependent settlement behaviour of geogrid reinforced embankment was compared with an unreinforced embankment. It was observed that the use of basal geogrid reduced the embankment settlement (end of consolidation) by 85.64, 25.58 and 4 for 2, 4, and 6 m height embankments, respectively.

As the embankment height increased, the percentage reduction in settlement decreased significantly. From the study, it was observed that two layers of geogrid had a significant effect on the behaviour for embankments of small height ($H_{emb} \leq$ 2 m). This can be compensated by incorporating multiple layers of geogrid.



(a)



(b)

Fig. 6 Settlement behaviour for different embankment fill heights: **a** $H_{\mathbf{emb}} = 2$ m; **b** $H_{\mathbf{emb}} = 4$ m

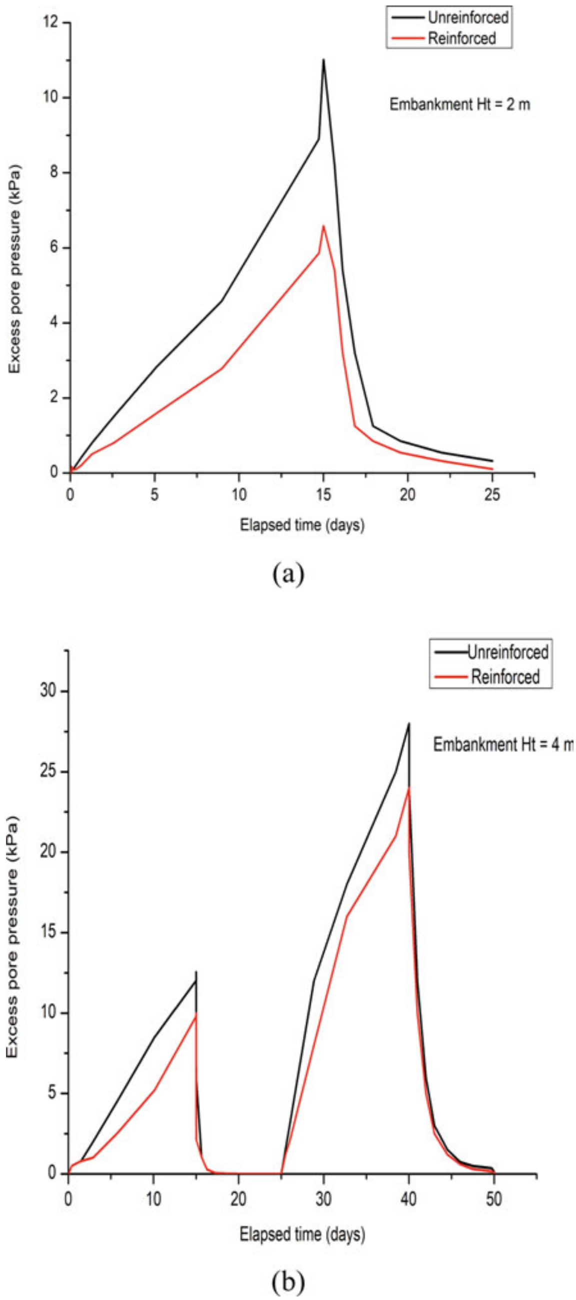


Fig. 7 Excess pore pressure distribution for different embankment fill height **a** $H_{\mathbf{emb}} = 2$ m; **b** $H_{\mathbf{emb}} = 4$ m

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