Numerical model to predict the settlement response of two nearby foundations due to geotextile slippage

ARTICLE in INTERNATIONAL JOURNAL OF GEOTECHNICAL ENGINEERING · OCTOBER 2008
DOI: 10.3328/IJGE.2008.02.04.441-453
Aqeel Sh. Al-Adili1* and N. Sivakugan2

Numerical model to predict the settlement response of two nearby foundations due to geotextile slippage

ABSTRACT: In this paper, a numerical study is undertaken on the settlement response of two nearby flexible loads resting on a reinforced granular bed underlain by a soft soil, considering plain strain loading conditions. The finite element code PLAXIS-8 has been used. The granular fill, soft soil and geosynthetic reinforcements are considered as linear elastic materials. The geosynthetic reinforcement is modeled with interface elements for allowing slip between the soil and reinforcement. When no interface elements were used, the geosynthetic reinforcement was modeled as if there were no slip. It appears that allowing slip has a negligible effect on the settlement predicted.

The results obtained from the present investigation showed that as the number of reinforcement layers increase up to three layers, the vertical stresses in the loaded region decreases causing maximum settlement reduction at a decreasing rate of 16% and 20% for 3-layers without and with slippage respectively. A parametric study has been carried out to bring out the effect of slippage of the reinforcement layer on the settlement response in dry and saturated soils. The increase in the settlement is not significant when the slippage of the reinforcement is considered. An interesting observation in this note is that the settlement was about 10% less when there were two nearby footings compared to when there was only one. The interaction between the footings resulted in reduction in the settlements, possibly due to reduced confining pressures.

KEYWORDS: Geosynthetic reinforcements, dependence of foundations, PLAXIS, multi layer, interface slippage.

1. INTRODUCTION

Reinforced granular beds with single or multiple layers of geosynthetics are commonly used over soft soil beds to increase the overall load bearing capacity of soft soils and improve their settlement performances. The lumped parameter modeling is very often adopted to analyze such problems due to its simplicity. Most of the studies reported in the literatures are only with single layer of geosynthetics (Ghosh and Madhav 1994; Madhav and Porooshesh 1988; Yin 1997a&b), but, recently some work in the area with multi layer of reinforcements has also been reported (Nogami and Yong 2003; Deb et al. 2005), using lumped parameter modeling. Some studies on single layer reinforced system with finite element modeling to solve such problems are also reported in the literature (Poran et al. 1989; Love et al. 1987; Yin 1997). Though some qualitative comparison with respect to the settlement profile obtained with these two methods could be made, there is always a need for quantitative comparison.

Improvement of soft soils with geosynthetics (Geogrid) is increasingly common practice in the construction industry. The soil reinforcement method is well established and suited for a wide range of soils. The design methods for geosynthetics are mainly semi-empirical.

Deb et al., (2007) reported the results of a numerical study conducted for multi layer geosynthetic-reinforced granular fill on soft soil and compared their results with results of the finite element study and lumped parameter modeling. It was assumed there is no slip between the reinforcement and the granular soil. However, most of the studies reported in the literature are limited to single loads with no interferences from any adjacent ones. Nevertheless, in reality, there are situations where there is interference of the influence zones of two adjacent loaded areas.
In the present study the slippage between the reinforcement and the granular layer is considered and its effect on the settlement response is investigated. Moreover, the second aim of this paper is to investigate the interactions of nearby loads on settlements upon soil reinforcement in saturated and dry conditions.

2. STATEMENT OF THE PROBLEM

Figure 1 shows a two meter thick granular fill reinforced with geosynthetic layers placed over a 12 m thick soft soil underlain by a very stiff layer, such as hard bedrock. The number of reinforcement layers is varied from one to three enmeshed within the sand bed such that it is equally divided vertically. Two different footing loads of nonuniform intensities \( q_1 \) and \( q_2 \) are applied over a width of foundation \( B = 4 \text{m} \) and \( 6 \text{m} \) on the reinforced granular fill and the reinforcements are chosen to be extending beyond the edge of the footing on both sides, by a distance equal to twice of footing width.

In this study there are three problems analyzed – in Problem 1 only single layer of reinforcement is considered with the water table (level) being present at 3 m below the ground surface. In Problem 2, three layers of reinforcement are considered with the water table being present at 3 m depth as in Problem 1. In Problem 3, one and three layers of reinforcement are considered and the fill is taken to be dry.

The main objectives of the present study are to predict the settlement of two adjacent interfering foundations and the bending moments within the medium using PLAXIS, when slip of the reinforcement is considered and compare the results when the slip is not considered for 1-layer (Problem 1) and 3-layers (Problem 3) for an assessment of the difference in the response due to slippage, as well as the effect of phreatic surface on the settlement behavior of the reinforced soil.

2.1 Numerical Modeling

The numerical approach used in this research is the 2-D finite element special purpose computer package PLAXIS-8 (Brinkgreve, et al.1998), to determine the settlements of surface soils and the bending moment distribution, with and without slippage of the geosynthetic reinforcement. To minimize the boundary effect, the vertical boundary at the far ends, on both sides is set as 2B away from the end of each loading that are assumed to be free in the vertical direction and restricted in horizontal direction. The bottom horizontal boundary is restricted in both the vertical and horizontal directions against displacements.

Plane strain analysis with Mohr–Coulomb material model was used to simulate the behavior of soil, with drained conditions for Problems 1 and 2, not taking the decay of excess pore pressures with time into account.

Furthermore, ground water flow in this porous medium could be described by Darcy’s law, assuming steady flow. The interface elements are treated specially in ground water calculations in PLAXIS ver-8. When the element is activated there is full coupling of the pore pressure degrees of freedom.

Three different materials are involved in the analysis: soft soil, granular fill, and geosynthetic reinforcements.
Numerical model to predict the settlement response of two nearby foundations due to geotextile slippage

However, all the materials are assumed to be non-linear. For simplicity, creep of geosynthetic reinforcements is not considered while allowing for slippage at the interface between geotextile and soil.

Realistic values of different parameters representing the physical properties of the materials used in the analysis are chosen based on previous studies (Deb et al. 2007; Yin 1997a; Zhan and Yin 2001;) and are presented in Table 1. In the present study higher Poisson ratio value of the soft soil and granular fill have been chosen ($\mu = 0.45$) to simulate the undrained condition in Problem 3. The discretization of the medium, for modeling, is shown in Figures 2, 3 and 4 for the problems.

A convergence study was done on Problem 1 for the particular value of the loads intensity ($q_1 = 10 \text{kN/m}^2$ and $q_2 = 20 \text{kN/m}^2$) and the results are presented in Table 2. As the results for coarse mesh are not significantly different from the results obtained for fine meshes, it was decided to adopt coarse meshes for all three cases considered in this study.

### Table 1. Physical properties of the soil and geosynthetics

<table>
<thead>
<tr>
<th>Material</th>
<th>Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soft soil</td>
<td>$E_s = 800 \text{kPa, } \mu_s = 0.3$</td>
</tr>
<tr>
<td>Granular bed</td>
<td>$E_{gb} = 10 \text{MPa, } \mu_{gb} = 0.33$</td>
</tr>
<tr>
<td>Geosynthetic layers</td>
<td>$E_g = \text{varies, } \mu_g = 0.49, L = 4 \text{m}$</td>
</tr>
</tbody>
</table>

Note: $L = \text{half length of the geosynthetic layers}$; $E_s = \text{Elastic modulus of soft soil}$; $\mu_s = \text{Poisson’s ratio of the soft soil}$; $E_{gb} = \text{Elastic modulus of granular fill}$; $\mu_{gb} = \text{Poisson’s ratio of the granular fill}$; $E_g = \text{Elastic modulus of geosynthetic layer}$; $\mu_g = \text{Poisson’s ratio of the geosynthetic layers}$.

### Table 2. Convergence study

<table>
<thead>
<tr>
<th>Mesh type</th>
<th>No. of elements</th>
<th>Maximum Displacement(mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coarse</td>
<td>134</td>
<td>199.8</td>
</tr>
<tr>
<td>Refine -1</td>
<td>257</td>
<td>201.3</td>
</tr>
<tr>
<td>Refine-2</td>
<td>560</td>
<td>203.4</td>
</tr>
</tbody>
</table>

3. COMPARISON OF SLIPPAGE RESULTS

The results obtained from the present numerical analysis using PLAXIS-8 for a single layer of geosynthetic reinforcement is presented in Figure 5. Here, $X$ and $W$ are dimensionless parameters defined as:

$$W = \frac{w}{B} \quad \text{and} \quad X = \frac{x}{B}$$

where $x = \text{distance from the centerline}$, $w = \text{settlement}$ and $B = \text{half width of the footing}$. Here, the soft soil is idealized by a series of springs (Yin 1997a). In this approach the reinforced granular soil bed is treated as an elastic material. The elastic parameters used for granular fill are $E_{gb} = 10 \text{MPa}$ and $\mu_{gb} = 0.45$. For geosynthetic layer, $E_g = 0.5 \text{MPa}$, $\mu_g = 0.49$, $L = 2B$, which are the same values used by Yin (1997a). It can be seen from the Figure 5 that the settlements computed allowing slippage were about the same as the ones computed without allowing slip. Understandably, the settlements were less when the granular soil bed was reinforced with the geosynthetic. The reduction in settlement was significant near the centerline where the settlements are generally large. The
Figure 3. Discretization of soil with 1-layer geotextile (Problem 1)

Figure 4. Discretization of soil with 3-layers of geotextile (Problem 2).
reduction in settlements with the geotextile is slightly greater when the slippage at the interface is neglected.

To improve the settlement reduction by using geogrid, three layers of geotextile have been used in Problem 2. The effect of tensile stiffness of the geosynthetic on the settlement response and the mobilized tension in the geosynthetic layers have also been studied for the multi layer reinforced soil. Significant reduction in settlement can be noticed in the 3-layer geotextile system, especially beneath the centre of loading (Figure 6). As in Problem 1, the reduction in settlement was greater when slippage is neglected.

4. RESULTS AND DISCUSSION

The results obtained from the numerical analysis using PLAXIS-8 are presented in this section. As shown in Figure 7, the single layer of geotextile reinforcement within the granular soil bed has reduced the settlement by 7.5% and 6% of the original settlement for slippage and without slippage. In the presence of reinforcements, major parts of the shear stresses are taken up by the geosynthetic layers. Thus, the presence of the reinforcements causes a reduction in the outward acting shear stresses leading to better performance of the foundation under the superimposed loads. This is more pronounced when three layers of geotextile have been used (Problem 2). Figure 8 presents the load-displacement curve, which shows the reductions of settlement are 15% and 20% respectively for slippage and no slippage of geotextile allowed. The load is applied in increments to reach 100% of the loading at the final situation. The corresponding maximum settlements are calculated and the load–settlement was plotted. It is very clear that at all stages of loading, the geosynthetic reinforcement reduced the settlement and these settlements were slightly larger when slip is allowed.

The plot of settlement versus distance is presented for Problem 1 is presented in Figure 9. Here, the plot for unreinforced case is presented and the results are compared with the response with reinforcement when the slip is permitted and when it is not permitted. When slip is allowed, the settlement are slightly greater then when it is assumed there is no slip, especially in the vicinity of the centre line. Figure 10 clearly indicates that for the three-layer geotextile system, allowing slip gives 4-5% larger settlement than the case when no slippage is allowed.

The variation of bending moment within the footing along the horizontal distance from the centre line is shown in Figure 11. As expected at the centre line (x = 0) and at the edge of the footing (x = 6 m) the bending moment is zero and it is the maximum at x = 3 m (centre of foundation). The bending moments are smaller when geosynthetic is applied. The maximum bending moment which is close to the centre of the footing is observed to be less in the case where slip of
Figure 6. Dimensionless settlement profile for Problem 2

Figure 7. Load – settlement curve for 1-layer geotextile, Problem 1.
Numerical model to predict the settlement response of two nearby foundations due to geotextile slippage

Figure 8. Load – settlement curve for 3-Layers geotextile, Problem 2

Figure 9. Settlement (mm) profile along foundation width ($B = 6$ m) for problem-1.
Figure 10. Settlement (mm) profile along foundation width ($B = 6$ m) for Problem 2.

Figure 11. Bending moment of large foundation with 3-layers geotextile (Problem 2).
the reinforcement is allowed than the one where slip is not allowed.

4.1. Adjacent Foundations Interaction
To find out the interaction between the two dependant loads and the effect of such adjacent foundation this calculation has been carried out by considering one footing \((q = 20 \text{ kN/m}^2)\) under the same conditions of 1 and 3 geotextile layers. Figure 12 shows the results of settlement profile along foundation width with 1 and 3 layers of geotextiles (same as Problems 1 & 2). The reductions in settlement at the centerline are 7\% and 18.6\% for 1 and 3 layers respectively. But the interesting phenomenon is that the settlement with one footing is higher than the settlement with two footings. The settlement of the single isolated footing was 145.5 mm (Figure 12) while it is 131.3 mm (Figure 10) when the second nearby footing is present. This result could be attributed to the interaction within the soil grains in the region between the two footings. It appears that the additional footing increases the confining stresses in the region, and reduces the settlement.

4.2. Effect of Phreatic Level
Problem 3 deals with dry soil when there is no phreatic surface within the soil strata. Figure 13 shows settlement profile along foundation width for dry soil. This figure presents the settlement trend which is similar to the settlement profiles in the saturated soil strata with 1 and 3 layers of geotextiles (Problem 1 & 2) shown in Figures 9 and 10. These results indicate that the effective stress is the dominant stress in such conditions and the dissipation of pore water pressure is a minimal (Figure 14 & 15). This can also be seen from Figures 16 and 17 for total stresses, which indicate the difference between the effective stresses for dry and saturated soils is insignificant. However, the settlements can vary with fluctuations of phreatic level.

4.3. Geotextile Stiffness
The settlement versus geotextile stiffness was also examined in this study to determine the effect of increasing geotextile stiffness on settlement and the suitable stiffness for designing of soil reinforcement (Figure 18).

5. CONCLUSIONS
Three separate problems were analyzed using Plaxis V.8. The conclusions are summarised as follows:

1. The present study demonstrates a successful application of PLAXIS in analyzing the response of one and three layer geosynthetic-reinforced granular fill placed over a soft soil deposit. The results obtained are found to be compatible and in close agreement with the results of finite element for soil reinforcement studies reported in literature.

2. As the number of reinforcement layers increase, the vertical stresses in the loaded region decrease, caus-
Figure 13. Settlement (mm) profile along foundation width ($B = 6$ m) for Problem 2.

Figure 14. Bending moment of large foundation with 3-layers geotextile (Problem 2).
Numerical model to predict the settlement response of two nearby foundations due to geotextile slippage

Figure 15. Effective stress for saturated soils (Problem 1)

Figure 16. Total stresses within dry soils (Problem 3)
Figure 17. Total stress for dry soils (Problem 1).

Figure 18. Settlement – Geogrid stiffness curve.
ing maximum settlement reduction at a decreasing rate. Beyond the loaded region a reversal in the trend occurs.

3. The reduction in settlement due to the geosynthetics is slightly higher when no slippage occurs between the geosynthetics and the soils. The effect of allowing slippage is to increase the settlements slightly, compared to the case with no slip. This difference is in the order of 4% to 5% for 3-layer geosynthetic system.

4. The presence of phreatic surface does not reduce the settlement rate compared to the dry soil strata.

5. Allowing slippage reduces the bending compared to the situation when no slip is allowed.

6. For both 1 and 3 layer geotextile systems, the settlements were about 10% more when there was only one footing compared to having two nearby footings. The effect of the nearby footing was to increase the soil confinement and reduce the settlement of the nearby footing.

7. Geotextile stiffness increasing up to 5000 kN/m leads to reduction in settlement, whereas increasing the stiffness beyond 5000 kN/m will not be very effective in such soil conditions.

REPRESENTS


