Slippage effect on the settlement response of a granular soft soil system
Effet du glissement sur la réponse du règlement de système du sol doux granuleux

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ABSTRACT
In this paper a numerical study using the finite element method is undertaken to predict the settlement response of a footing, considering plane strain conditions, resting on a reinforced granular bed on soft soil. The granular fill, soft soil and geosynthetic reinforcement are considered as non linear materials. The geosynthetic reinforcement is modelled with interface elements for allowing slip between the soil and reinforcement. The results obtained from the present investigation showed close agreement when compared with the results of finite element analysis and lumped parameter modelling carried out by previous researchers, assuming no slip conditions. The number of reinforcement layers was taken as one or three (multilayer). A parametric study has been carried out to illustrate the effect of slippage of the reinforcement layer on the settlement response. The increase in the settlement is not significant when the slippage of the reinforcement is considered.

RÉSUMÉ
Dans ce papier, une étude numérique qui utilise l'élément fini est entreprise obtenir la réponse du règlement d'une charge spécifique , étant donné les conditions de la tension ordinaires, poser sur un lit granuleux renforcé sur sol doux. Le granuleux remplissez, le sol doux et renforcements du geosynthetic sont considérés comme non matières linéaires. Le renforcement du geosynthetic est modelé avec les éléments de l'interface pour autoriser la fiche entre le sol et renforcement. Les résultats obtenus de l'enquête présente ont montré l'accord proche quand a comparé avec les résultats d'analyse de l'élément finie et paramètre modeler mis en bloc portés dehors par chercheurs antérieurs, sans conditions de la fiche. Le nombre de couches du renforcement a été pris comme un et three (multilayer). L'étude paramétrique a été emportée pour faire sortir l'effet de glissement de la couche du renforcement sur la réponse du règlement. L'augmentation dans le règlement n'est pas considérable quand le glissement du renforcement est considéré.

Keywords : soil reinforcement, granular bed, slippage, soft soil

1 INTRODUCTION

Reinforced granular beds with single or multiple layers of geosynthetics are very commonly used over soft soil to increase the load bearing capacity of the soft soils and to improve the settlement performance. Lumped parameter modelling is very often adopted to analyze such problems due to its simplicity. Most of the studies reported in the literatures are only with a single layer of geosynthetic (Madhav and Poorooshasb, 1988; Ghosh and Madhav, 1994; Yin, 1997a, 1997b, 2000), but recently some work with multiple layers of reinforcement has also been reported (Nogami and Yong, 2003; Deb et al., 2005). Finite element studies of single layer reinforced systems are also reported in the literature (Love et al., 1987; Poran et al., 1989; Yin, 1997a, 2000).

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 modelling. It was assumed that there is no slip between the reinforcement and the granular soil. In the present study the slippage between the reinforcement and the granular layer is considered and its effect on the settlement response is investigated.

2 STATEMENT OF THE PROBLEM

Figure 1 shows a 1 m thick granular fill layer reinforced with geosynthetic layers placed over a 6 m thick soft soil underlain by a very stiff layer, such as hard bedrock. The number of A footing load of uniform intensity q is applied over a width of $2B$ (4 m) on the reinforced granular fill and the length of the reinforcement is chosen to be two times the width of the footing. In this study two problems are considered: problem-1 with a single layer of reinforcement and the fill taken to be dry; and problem-2 in which 3 layers of reinforcement are considered together with presence of a phreatic surface.

The main objectives of the present study are to predict the settlement of the foundation within the medium using the PLAXIS finite element software, when slip of the reinforcement is considered. The results so obtained are compared with other solutions reported in literature for case where slip is not considered.

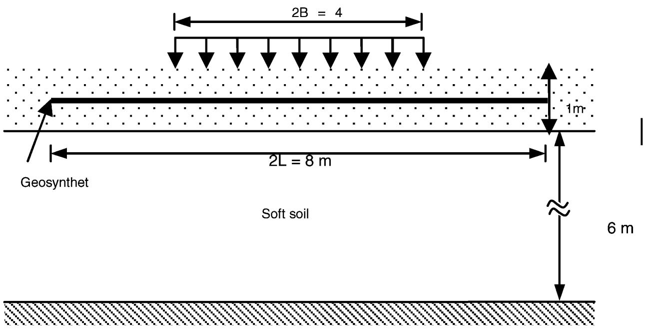

Figure 1. Multi layer geosynthetic-reinforced granular fill over soil

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2.1 *Numerical Modelling*

The numerical approach used in this research is the 2-D finite element special purpose computer package PLAXIS-8 (Brinkgreve & Vermeer, 2002). To minimize the boundary effect, the vertical boundary at the far end, on the right-hand side (Figure 2), is set 12 m away from the centre of loading. These surfaces 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.

The plane strain analysis adopts the Mohr–Coulomb material model to simulate the behaviour of the soil continua. The interface between the reinforcement and the soils is represented by special interface elements, which in PLAXIS are treated as continuum elements having a small virtual thickness (imaginary thickness = 0.1 m). The interface can be regarded as either perfectly rough (no slip) or perfectly smooth (slip).

All the materials are assumed to be non linear. For simplification, creep of the geosynthetic reinforcement is not considered while allowing for slippage between geotextile and soil, to compare it with the previous results of Yin(1997) and Deb et al.(2007) which assumed no slippage at the geosynthetic-soil interface.

The physical properties of the materials used in the analysis are chosen based on previous studies (Yin, 1997a; Zhan and Yin, 2001, Deb et al., 2007) and are presented in Table 1. The geosynthetic in this model was modeled as geogird. The discretization of the medium for modelling is shown in Figure 2. From considerations of symmetry only one-half portion of the problem is analyzed.

A convergence study was done for one particular value of the load intensity (q = 52.6 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 mesh for all the cases in this study.

Table 1. Physical properties of the soil and geosynthetics

Material	Parameters
Soft soil	E_s = 800 kPa, μ_s = 0.45
	c = 5 kPa, ϕ = 25°, ψ = 0
Granular bed	E_{gb} = 10 MPa, μ_{gb} = 0.45
	c = 1 kPa, ϕ = 30°, ψ = 0
Geosynthetic layers	E_g = 0.526 MPa, μ_g = 0.49, L = 4 m

Note: L = half length of the geosynthetic layers E_s = Elastic modulus of soft soil; μ_s = Poisson's ratio of the soft soil; E_{gb} = Elastic modulus of granular fill; μ_{gb} = Poisson's ratio of the granular fill; E_g = Elastic modulus of geosynthetic layer; μ_g = Poisson's ratio of the geosynthetic layers; c = cohesion; ϕ = friction angle; ψ = dilation angle.

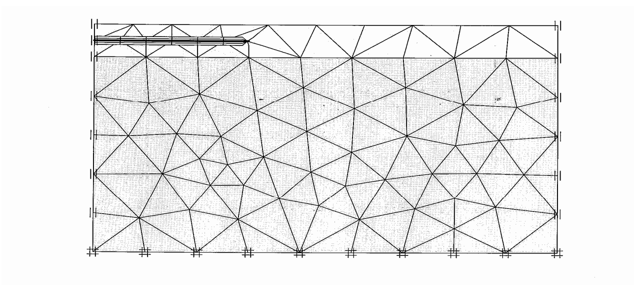

Figure 2. Discretization of the problem

Table 2. Convergence study

Mesh type	No. of elements	Maximum Displacement(mm)
Coarse	134	199.8
Refined-1	257	201.3
Refined-2	560	203.4

2.2 *Comparison of Results*

The results obtained from the present numerical analysis using PLAXIS for a single layer of geosynthetic reinforcement are compared with the results obtained from finite element analysis (Yin, 1997a) and the results obtained by Deb et al. (2007), using FLAC and are presented in Figure 3. Here, X and W are dimensionless parameters defined as

$$W = w/B \text{ and } X = x/B \tag{1}$$

where x is the distance from the centerline, and the settlement (w) is normalized with respect to half width of the loading (B). Yin (1997a) idealized the soft soil by a series of springs whereas Deb et al., (2007) modeled it as a 2-D continuum. It can be seen from the Figure 3 that the results match very well with the previous studies and the errors are with in permissible limits.

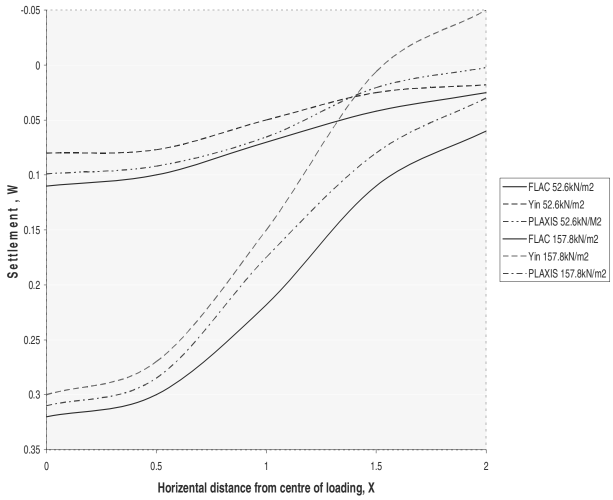

Figure 3. Settlement profile and comparison of results of previous studies

However, the soil reinforced with geotextile exhibits reduced settlement in the present study, by 10% and 6% of the original settlement predicted for a soil without reinforcement for the 1-layer case and with loads of 52.6 kN/m^2 and 157.8 kN/m^2, respectively. When reinforcement is present, major parts of the shear stresses are taken up by the geosynthetic layers. Thus, the presence of the reinforcement causes a reduction in the outward acting shear stresses leading to better performance of the foundation under the superimposed load.

3 RESULTS AND DISCUSSION

The results obtained from the present numerical analysis using PLAXIS ver-8 are presented in this section. In Figure 4, the plot of settlement versus distance is presented. The plot for the unreinforced case is also 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 settlements are slightly greater than when it is assumed there is no slip. It can be observed that the maximum settlement is reduced by about 11% when a single layer of reinforcement is placed without considering the slip. When the slip of the reinforcement is considered the settlement is reduced by only 8.6%. This clearly indicates that if the slippage of the reinforcement is considered there is a variation of about 4 to 5% in the settlement response.

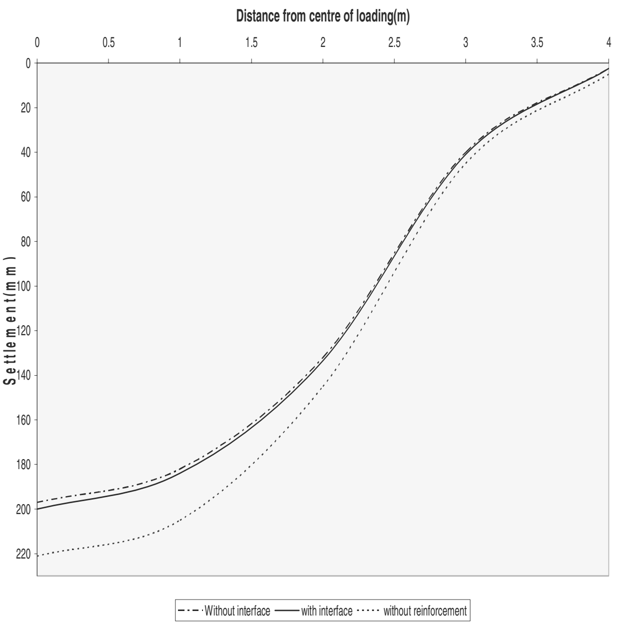

Figure 4. Settlement profile for 1-layer of Geogrid

In each case the load is applied in increments and the corresponding maximum settlements are calculated. The load–settlement plot is shown in Figure 5. The settlement for the soil without reinforcement and for 1-layer of geotextile with and without slip when the final load is applied has been 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.

Furthermore, in order to predict the effect of a phreatic surface (i.e., the presence of pore water pressure) in the soil strata, the case was considered where the surface load was increased to 52.6kN/m^2 for the problem of single layer reinforcement, and the settlement reduction was calculated. The results showed that the reduction in settlement for this case of 1-layer of reinforcement is 18% and 17% with and without slip, respectively (Figure 6).

To improve the settlement reduction by using geogrid, 3-layers of geotextile have been used in problem-2 with a water table being present at 2 m depth. The effect of the tensile stiffness of the geosynthetic on the settlement response and the mobilized tension in the geosynthetic layers have also been studied for multi layer reinforced soil. The soil parameters used for the model are summarized in Table 3. The reduction of settlement for the case of 3-layers of reinforcement is 19% and 17% where no slip and slip were allowed. Figure 7 shows the settlement profile at the ground level.

Table 3. Soil properties assumed in the model for multilayer geogrid.

Parameters	Granular soil	Soft soil
Dry unit weight (kN/m^3)	18	16
Permeability-horizontal (m/day)	0.5	0.0001
Unit weight saturated (kN/m^3)	20	18
Permeability-vertical (m/day)	0.5	0.0001
Young modulus (kN/m^2)	10000	800
Poisson's ratio	0.33	0.3
Cohesion (kN/m^2)	1	5
Friction angle (degrees)	30	25
Dilatancy angle (degrees)	0	0

It can be concluded here that 3-layers of geotextile have a larger effect on settlement reduction than 1-layer, especially when the reinforcement within the granular materials has equal depth distribution. It is seen that irrespective of the number of reinforcement layers the maximum settlement decreases.

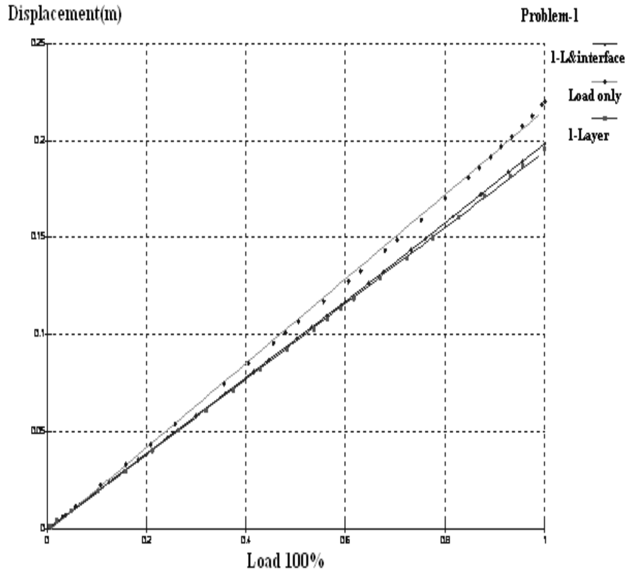

Figure 5. Load – displacement curve of the footing

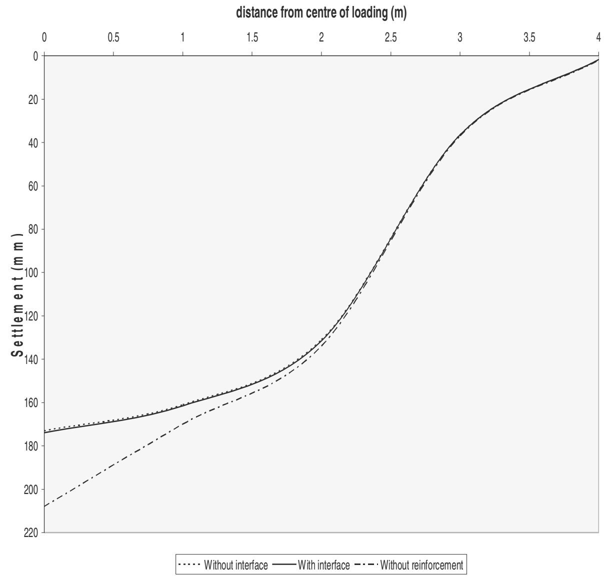

Figure 6. Settlement profile for a load of 52.6 kN/m^2 for cases including a phreatic surface

4 CONCLUSION

Some interesting conclusions drawn from this study are stated below.

1. The present study demonstrates a successful application of PLAXIS in analyzing the response of geosynthetic-reinforced granular fill placed over a soft soil deposit. The results obtained are found to be in close agreement with the results of finite element and lumped parameter studies reported in the literature.
2. The slippage of the reinforcement at the interface of reinforcement and granular soil shows about 5 percent increase in settlement.
3. As the number of reinforcement layers increases, the vertical stresses in the loaded region decreases causing

maximum settlement reduction at a decreasing rate. Beyond the loaded region a reversal in the trend occurs.

4. The presence of a phreatic surface reduces the settlement rate compared to the dry soil strata.

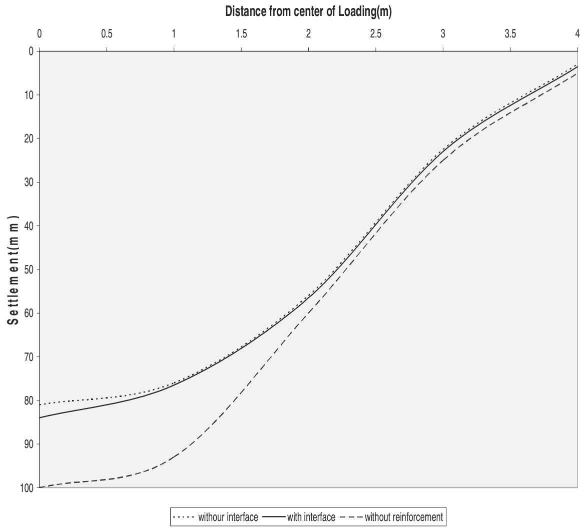

Figure 7. Settlement profile for 3-layers of Geogrid.

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