

# Numerical Modeling to Investigate the Effect of Slippage on the Settlement Response of Reinforced Soft Soil

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**Abstract-**In this paper, a numerical study using F.E. method is undertaken to predict the settlement response of a flexible footing, considering the plane strain conditions, resting on a reinforced granular bed on a soft soil. The granular fill, soft soil and geosynthetic reinforcements are considered as non-linear 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 was a slip. It appears that allowing slip has a negligible effect on the settlement predicted. The results obtained from the present investigation showed very close agreement when compared with the results of finite element analysis and lumped parameter modeling carried out by previous researchers, assuming no slip conditions. The number of reinforcement layers was taken as one and three. A parametric study has been carried out to illustrate the effect of slippage of the reinforcement layer on the settlement response as dry and phreatic surface (saturation) conditions. The increase in the settlement is not significant when the slippage of the reinforcement is considered.

**Keywords-** *Geosynthetic Reinforcements; Granular Bed; PLAXIS; Slippage; Soft Soil; Parametric Modeling*

## I. INTRODUCTION

Reinforced granular beds with single or multiple layers of geosynthetics are very common in use over a soft soil bed to increase the overall loading capacity of soft soils and improve settlement performance. The lumped parameter modeling is very often adopted to analyze such problems due to its simplicity. Most of the studies reported in literatures are only with single layer of geosynthetics [1-4], but, recently some work in the area with multi-layer of reinforcements has also been reported [5, 6] 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 [3, 7, 8]. 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.

Deb et al. (2007) [9] 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. In the present study, the slippage between the reinforcement and the granular layer is considered and its effect on the settlement response is investigated

## II. STATEMENT OF THE PROBLEM

Fig. 1 shows a one-meter 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 reinforcement layers is varied from one to three enmeshed within the sand bed such that it is equally divided. 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 reinforcements is chosen to be twice the width of the footing.

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

The main objectives of the present study are to predict the settlement of the foundation and the bending moments within the medium using the PLAXIS, when slip of the reinforcement is considered and compare the results so obtained with other solutions reported in literature when the slip is not considered for an assessment of the difference in the response due to slippage, as not many researchers studied the effect of slipping on settlement, as well as, the effect of phreatic surface as a saturated strata on the settlement response of reinforced soil.

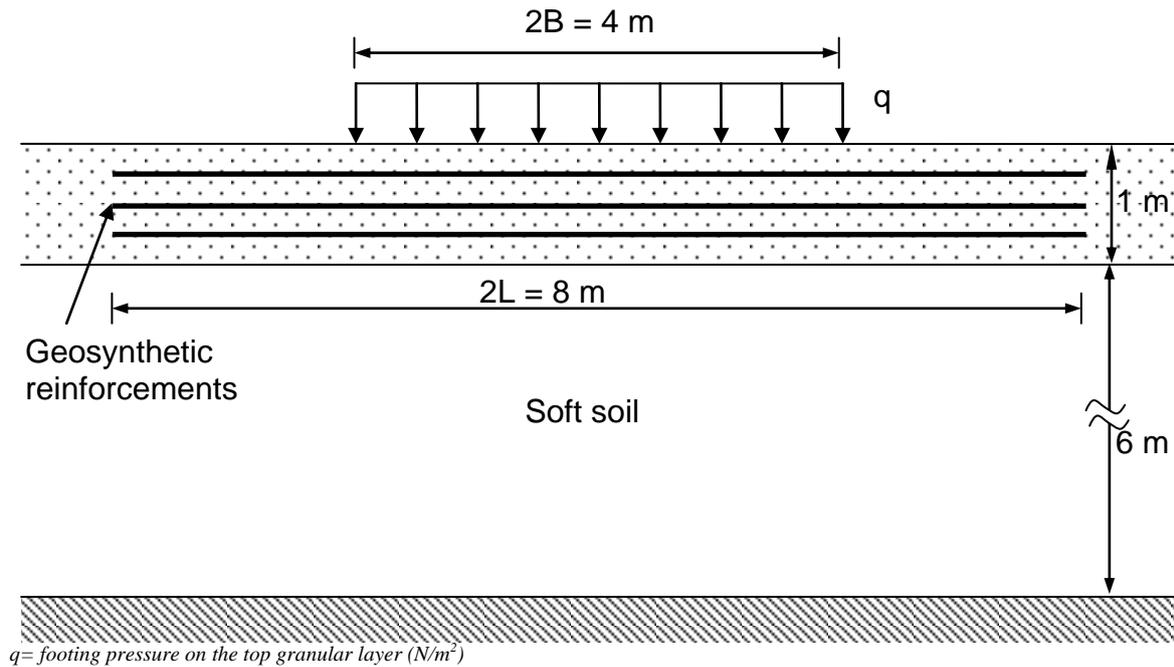


Fig. 1 Multi-layer geosynthetic-reinforced granular fill over soft soil

#### A. Numerical Modelling

The numerical approach used in this research is the 2-D finite element special purpose computer package PLAXIS-8 [10], to determine the settlements of surface soils with and without slippage (at the interface) and the bending moment distribution. To minimize the boundary effect, the vertical boundary at the far end, on the right-hand side, is set 12 m away from the center of 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 (Fig. 1).

The analysis is based on plane strain with Mohr – Coulomb material model to simulate the behavior of soil and continuum, with drained conditions for problems 2 and 3, to simulate the soil conditions and to assess the settlements on, as well as, the elastic – plastic deformation. 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).

Three different materials are involved in the analysis: soft soil, granular fill, and geosynthetic reinforcements. However, all the materials are assumed to be non-linear. For simplification, creep of geosynthetic reinforcements is not considered while allowing for slippage between geotextile and soil, to compare it with the previous results of [3, 9], which assumed that the reinforcement layers are rough enough to prevent slippage at the geosynthetic-soil interface under no slip conditions.

Realistic values of different parameters representing the physical properties of the materials used in the analysis are chosen based on previous studies [3, 9, 11] and are presented in Table 1. In the present study, higher Poisson's ratio values of the soft soil and granular fill have been chosen to simulate the undrained condition.

TABLE 1 PHYSICAL PROPERTIES OF THE SOIL AND GEOSYNTHETICS

Material	Parameters
Soft soil	$E_s = 800 \text{ kPa}$ , $\mu_s = 0.45$
Granular bed	$E_{gb} = 10 \text{ MPa}$ , $\mu_{gb} = 0.45$
Geosynthetic layers	$E_g = \text{varies}$ , $\mu_g = 0.49$ , $L = 4 \text{ m}$

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

The discretization of the medium for modeling is shown in Figs. 2, 3 and 4 for Problems 1, 2 and 3, respectively. From considerations of symmetry, only half portion of the problem is analyzed.

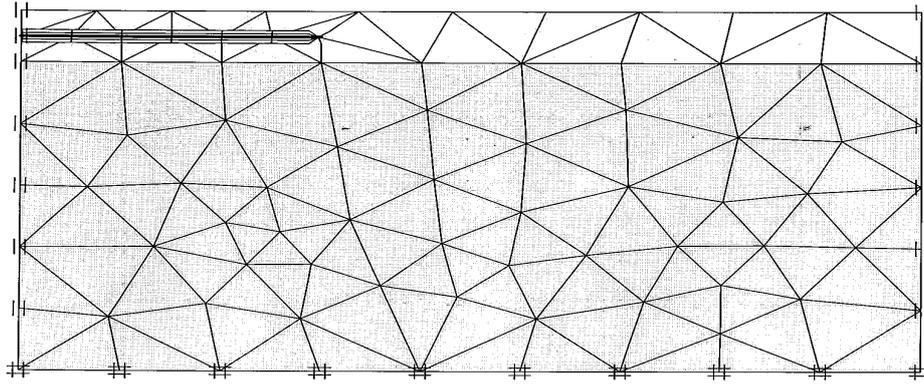


Fig. 2 Discretization of Problem-1

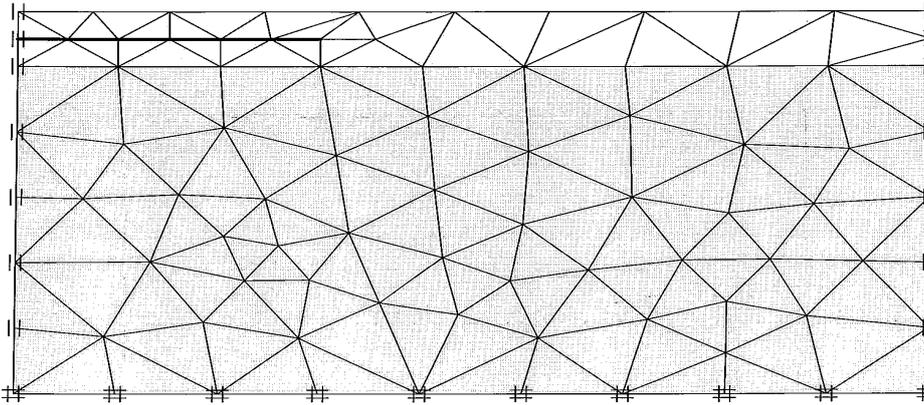


Fig. 3 Discretization of Problem-2

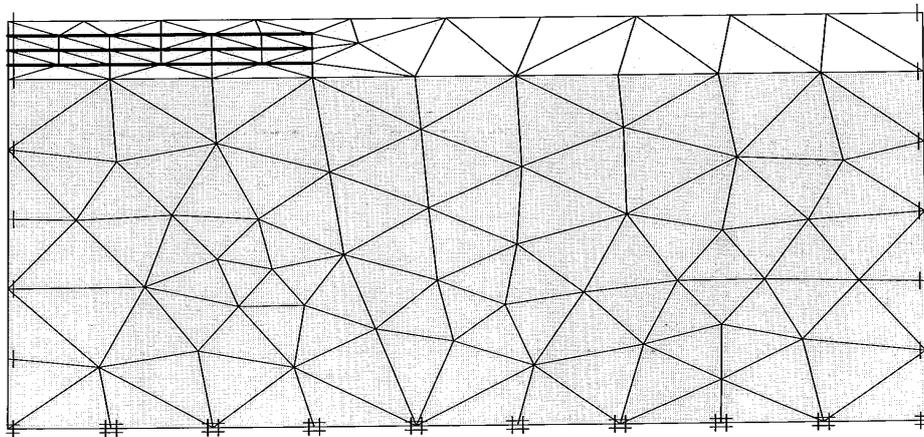


Fig. 4 Discretization of Problem-3

The elastic parameters used for granular fill as:  $E_{gb} = 1.0$  MPa,  $g_b = 0.45$ ; and for geosynthetic layer as:  $E_g = 0.526$  MPa,  $g = 0.49$ ,  $L = 4$  m (these values are identical to the values chosen by [3, 9]).

A convergence study was done on Problem- 1 for one particular value of the load intensity ( $q=52.6$  kN/m<sup>2</sup>) 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 2 CONVERGENCE STUDY

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

### B. 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 from [3] and the results obtained by [9], using FLAC and are presented in Fig. 5. Here,  $X$  and  $W$  are dimensionless parameters defined as:

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

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) [3] idealized the soft soil by a series of springs whereas Deb et al. (2007) [9] modeled it as a 2-D continuum. In both the approaches the reinforced granular soil bed is treated to be elastic half-space.

It can be seen from Fig. 5 that the results are matching very well with the previous studies, and the errors are within permissible limits.

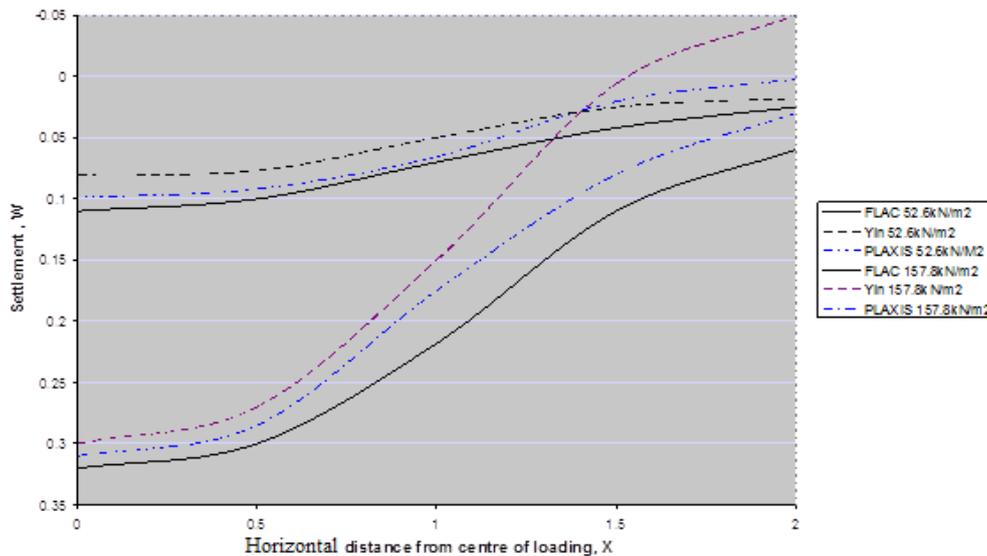


Fig. 5 Problem-1 settlement profile and comparisons of results with previous studies

However, the soil reinforcement with geotextile exhibits reduced the settlement in the present study with 10% and 6% of original settlement (without reinforcement) for 1-layer case and with load  $52.6 \text{ kN/m}^2$  and for load  $157.8 \text{ kN/m}^2$ , respectively. 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 load.

### III. RESULTS AND DISCUSSION

The results obtained from the present numerical analysis using PLAXIS Ver-8 are presented in this section. In Fig. 6, the plot of settlement versus distance is presented for problem-1 for single layer of reinforcement, and settlement was calculated for load without soil reinforcement, soil with interface, and soil without interface. The plot for 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. When the slip is allowed, the settlements are slightly greater than when it is assumed that 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 8.6 percent. This clearly indicates that if the slippage of the reinforcement is considered, there is a variation of about 4 to 5 percent in the settlement response.

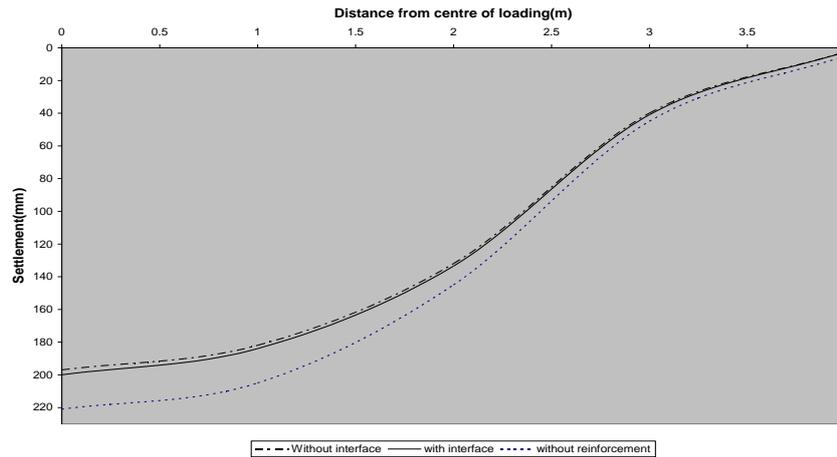


Fig. 6 Settlement profile for problem-1

In each case, the load is applied in increments and the corresponding maximum settlements are calculated. The load–settlement plot for problem-1 is shown in Fig. 7. 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.

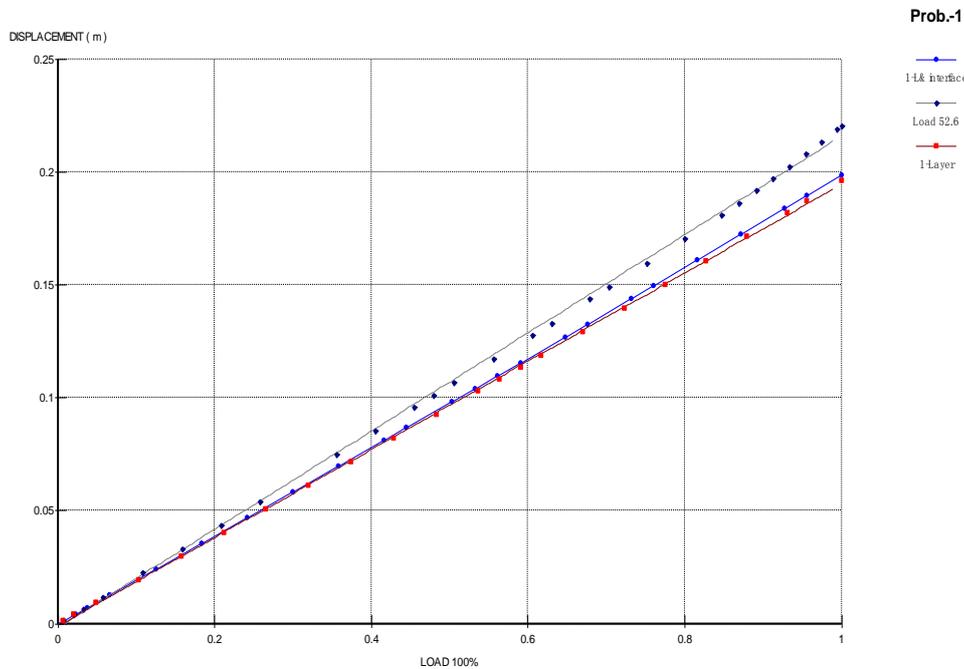


Fig. 7 Load–displacement curve for the footing problem-1

Fig. 7 presents the displacement (settlement) for soil without reinforcement and 1-layer geotextile as well as, 1-layer geotextile with interface (slippage), at the points when the concentrated load 100% (final situation of loading).

The variation of bending moment within the footing along the horizontal distance from the center line is shown in Fig. 8. As expected, at the center line ( $x = 0$ ) and at the edge of the footing ( $x = 2$ ), the bending moment is zero, and it is the maximum at  $x = 1m$ . The bending moments are slightly smaller when geosynthetic is allowed to slip. The maximum bending moment which is close to the center of the footing is observed to be more in the case where slip of the reinforcement is allowable than the one where slip is not allowable.

The soil parameters used for the model in problem-2 and 3, where the water table was present in order to predict the effect of phreatic surface, are summarized in Table 3. The load–settlement plot for  $q = 25$  kPa and  $q = 100$  kPa are shown in Fig. 9. For  $q = 100$  kPa it is quite clear from this figure that the load–settlement plot is not linear.

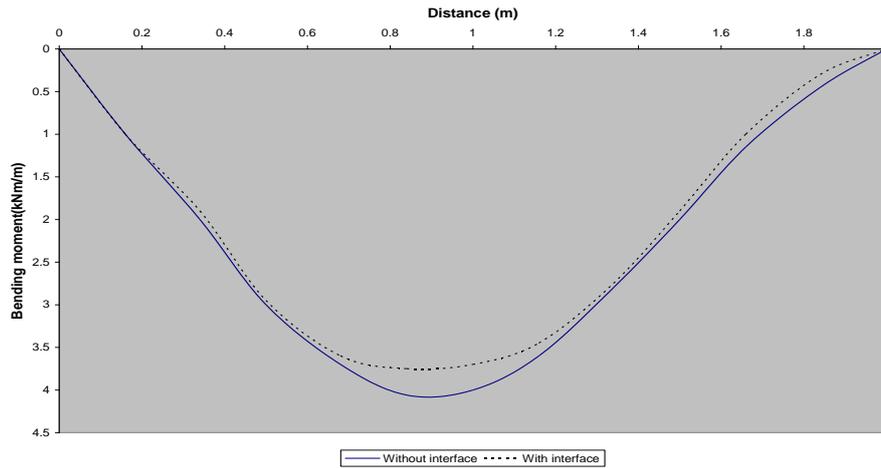


Fig. 8 Bending moment variations along distance from origin for problem-1

TABLE 3 SOIL PROPERTIES ASSUMED IN THE MODEL FOR MULTILAYER GEOGRID

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

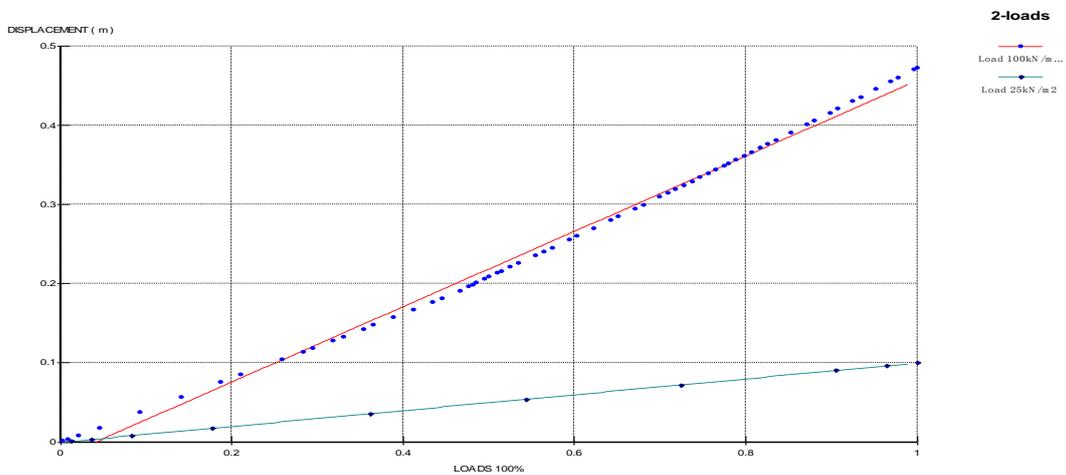


Fig. 9 Load–displacement variation for problem -2 with two different load intensities of 25 and 100 kN/m<sup>2</sup>

Fig. 10 presents the load displacement curve for problem 2 where phreatic line is also presented at 2 m depth (i.e., the presence of pore water pressure). Again it can be seen that allowing the geosynthetic to slip has a negligible effect on the settlement profile. The maximum settlement, which occurs beneath the center of the footing, is reduced by about 8%.

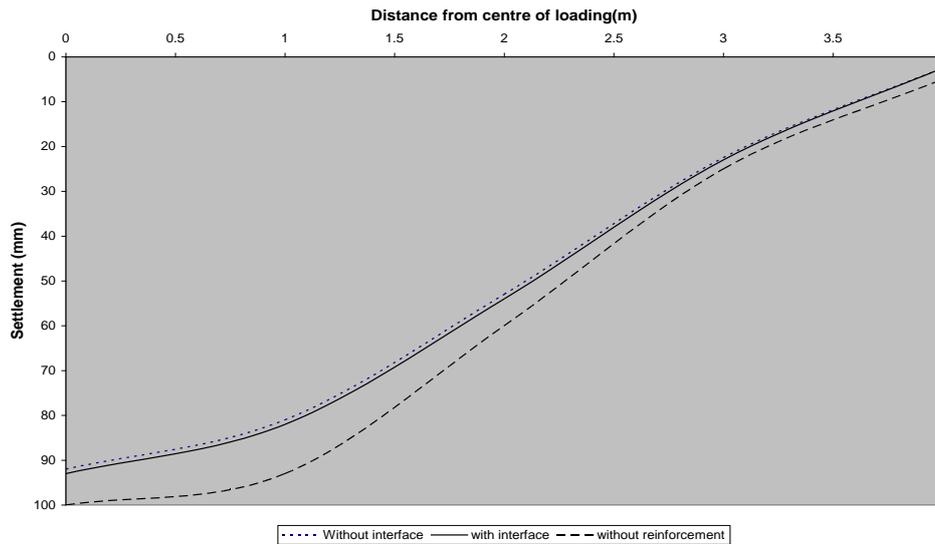


Fig. 10 Settlement distance curve for 1-layer (problem-2)

While Fig. 11 revealed that the settlement decreasing more without using interface, and the reduction of settlement is 8.5% and 7.5% for the case (with /without slip respectively) from the non-reinforcement soil settlement.

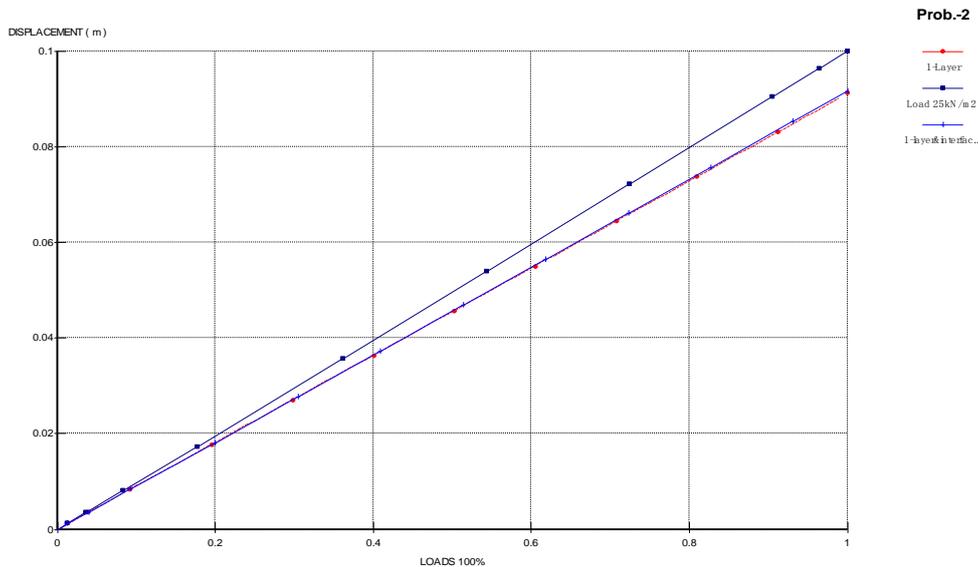


Fig. 11 Load-displacement curve for problem -2

To improve the settlement reduction by using geogrid, 3layers of geotextile have been used in problem-3. 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 multi-layer reinforced soil. The reduction of settlement in 3layers is 19 percent and 17 percent when 3layers where slip was allowed. Fig. 12 shows the settlement profile at the ground level and Fig. 13 shows the load displacement curves for problem-3.

It can be concluded here that 3-layer geotextile will affect largely in settlement reduction than 1-layer especially when the reinforcement within the granular materials and in equal distribution in depth. It is seen that irrespective of the number of reinforcement layers the maximum settlement decreases.

Furthermore, to predict the effect of phreatic surface in the soil strata, the loads on problem -3 were increased to 52.6kN/m<sup>2</sup> as the same load on problem-1 and settlement reduction was calculated. The results showed that the reduction is 18 percent and 17 percent for 3layers and 3layers with interface respectively (Fig. 14).

The settlement verses geotextile stiffness was also examined in this study to find out the effect of increasing geotextile stiffness effect and the suitable stiffness for designing of soil reinforcement (Fig. 15).

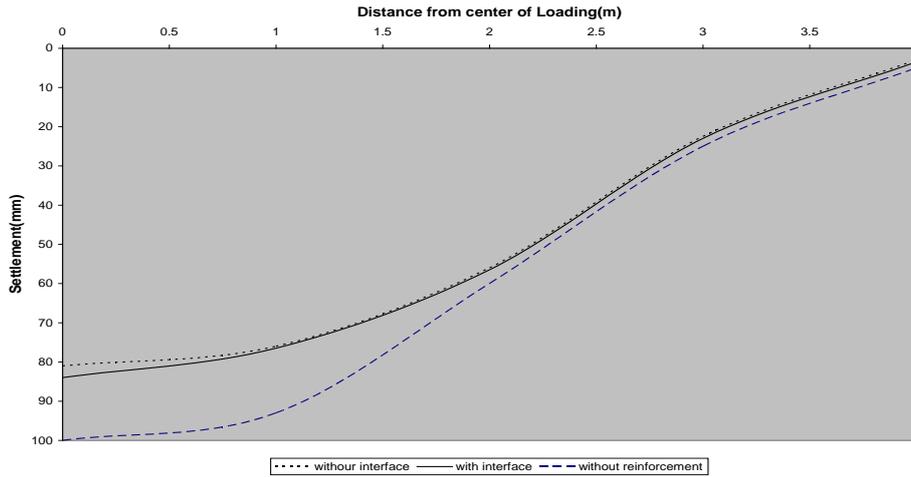


Fig. 12 Settlement profile for 3-layer Geogrid (problem-3)

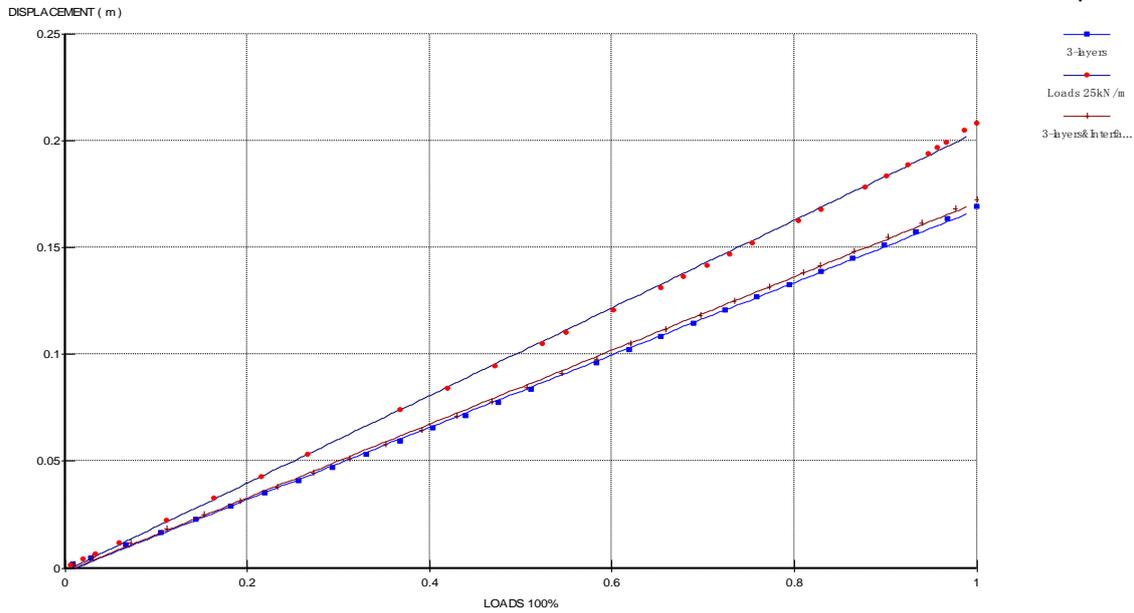


Fig. 13 Load-Displacement curve for 3-Layers (problem-3)

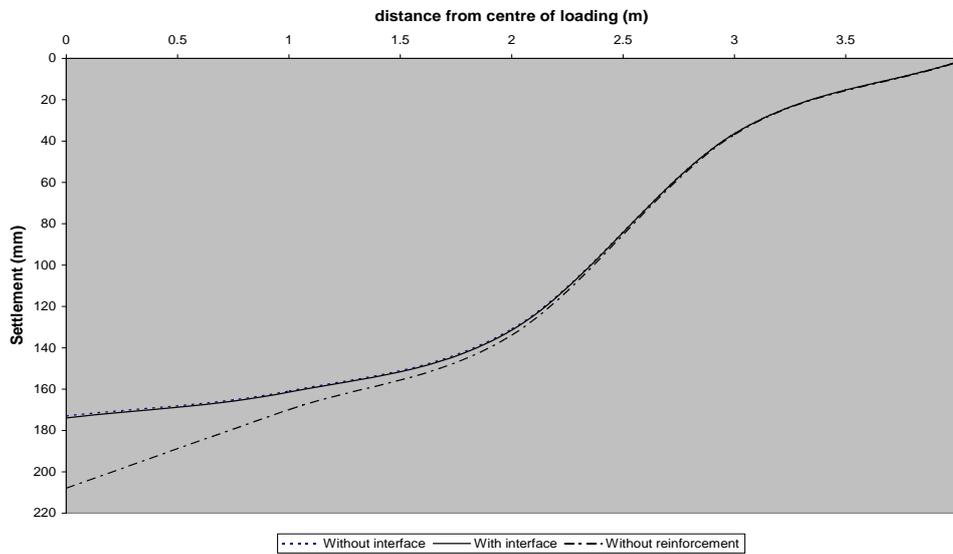


Fig. 14 Settlement profile for a load 52.6 kN/m<sup>2</sup> with phreatic level

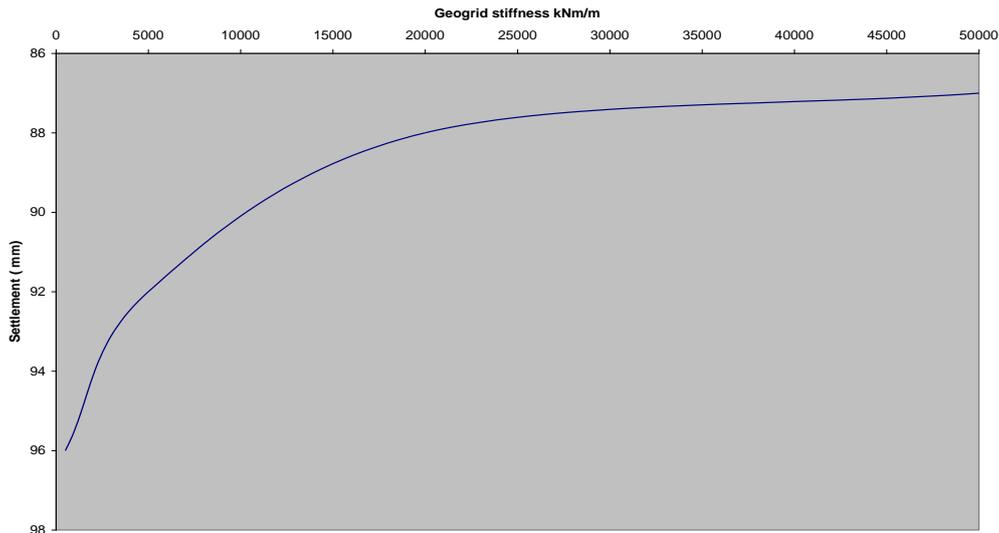


Fig. 15 Settlement–Geogrid stiffness curve

#### IV. CONCLUSIONS

Some interesting conclusions drawn from this study are stated below:

1. The present study demonstrates a successful application of PLAXIS software in analyzing the response of one as well as, multi-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 and lumped parameter studies reported in literature.
2. 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.
3. The slippage of the reinforcement at the interface of reinforcement and granular soil shows less reduction of settlement from reinforcement soil in both 1-Layer and 3-Layer cases (about 5 percent).
4. The presence of phreatic surface (saturation condition) reduces the settlement rate compared to the dry soil strata.
5. This study can lead authors to further researches to study the effect of slippage and soil reinforcement with different soil types and substructures like tunnels and deep foundations, as well as dynamic loads.

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