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Settlement of embankment on reinforced granular fill – Soft soil system

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ABSTRACT: A mechanical modeling approach has been adopted for settlement analysis of geosynthetic-reinforced granular fill - soft soil system subjected to embankment loading. The parametric studies bring out the effects of various factors such as load intensity, prestress in geosynthetic reinforcement, compressibility of granular fill, and consolidation of soft foundation soil. This approach can also be used to study the effect of several other factors like shear modulus of the granular fill, lateral stress ratio in the granular fill, and fill-geosynthetic interface characteristics. The results have been presented in nondimensional form which may be directly used in practical applications for the range of parameters studied. Prestressing the geosynthetic reinforcement has been found to reduce the differential settlements significantly.

1 INTRODUCTION

Use of geosynthetic-reinforced granular layer between the embankment and the soft foundation soil provides several beneficial characteristics viz., stiff and rough foundation to the embankment to resist lateral stresses, improved load-carrying and settlement characteristics, and a drainage blanket to assist the consolidation of the underlying soft foundation soil. The present work uses a mechanical modeling approach to carrry out the settlement analysis of geosynthetic-reinforced granular fill-soft soil system subjected to embankment loading. In this approach, each sub-system of the geosynthetic-reinforced granular fill-soft soil system is idealized by mechanical elements such as Winkler springs, Pasternak shear layer and spring-dashpot system which are commonly adopted for solving soil-foundation -structure interaction problems in civil engineering (Kerr 1964; Selvadurai 1979; Shukla and Chandra 1994a,b; Shukla 1995).

2 STATEMENT OF THE PROBLEM

Figure 1 shows the reinforced soil system supporting an embankment. The bottom layer of thickness, H_s , is a soft soil (soft clay/peat) layer with modulus of subgrade reaction, k_s and coefficient of consolidation C_v. The granular fill of modulus of subgrade reaction, k_f, is resting on the soft soil layer. The geosynthetic reinforcement (geotextile or geogrid) has been placed inside the granular fill. The thickness and the shear modulus of the granular layer above the geosynthetic layer are respectively H_t and G_t whereas H_b and G_b are respective parameters for the granular layer below the geosynthetic layer. The widths of the embankment at the top and bottom are respectively 2b and 2B. The side slope of the embankment is 1 vertical to n horizontal. The reinforced zone has a width of 2L. The problem is to make a settlement analysis of the system shown in Figure 1.

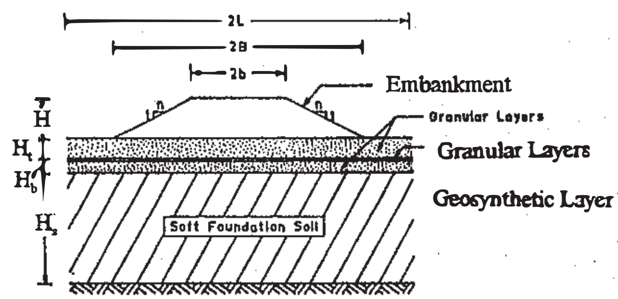

Figure 1. The reinforced soil system to be analyzed.

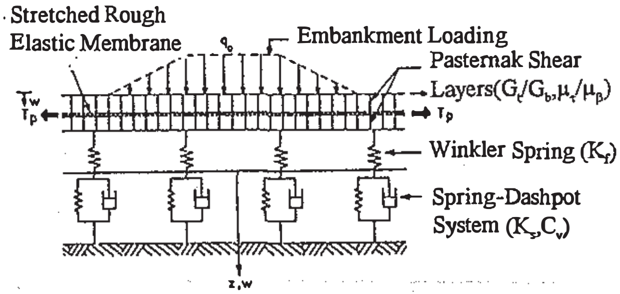

Figure 2. Mechanical foundation model subjected to embankment loading.

3 MODEL DESCRIPTION

The reinforced soil system shown in Figure 1 is idealized by the mechanical model in Figure 2. In this model, the spring-dashpot system represents the saturated soft foundation soil. The spring represents the soil skeleton and the dashpot simulates the dissipation of excess pore water pressure of the soil (Taylor 1943). The spring constant is assumed to have a constant average value with depth of the soft soil and also with time. The consolidation characteristics of the soft foundation soil both within the loaded region and beyond it are considered to be the same and their variation in the z-direction is not considered. It is also assumed that due to one-dimensional consolidation of the soft soil, the displacement of the geosynthetic layer is zero at the end of construction of the embankment and deformation takes place only after a finite time has elapsed.

The Pasternak shear layers represent the shear characteristics of the granular layers at the top and bottom of the geosynthetic layer. The Winkler springs attached to the bottom of the bottom shear layer represent the compressibility of the granular layers. The stretched rough elastic membrane represents the geosynthetic layer. The membrane will be in stretched condition for non-zero values of prestress, T_p. It is assumed that the geosynthetic layer is rough enough to prevent slippage at the interface with fill and has no shear resistance. The interface behavior is represented by a rigid-perfectly plastic friction model.

The equations governing the response of the model at any particular instant of time (t > 0) are derived by considering the equilibrium of forces on different elements of the reinforced soil system as (Shukla and Chandra 1994b, Shukla 1995):

$$q^* = \bar{X}_1 \frac{\alpha W}{1+\alpha U} - \{G_t^* + \bar{X}_2(T_p^* + T^*)\cos\theta + \bar{X}_1 G_b^*\} \frac{\partial^2 W}{\partial X^2} \tag{1}$$

and

$$\frac{\partial T^*}{\partial X} = -\bar{X}_3\left(q^* + G_t^* \frac{\partial^2 W}{\partial X^2}\right) - \bar{X}_4\left(\frac{\alpha W}{1+\alpha W} - G_b^* \frac{\partial^2 W}{\partial X^2}\right) \tag{2}$$

where

$X = x/B$, $W = w/B$, $G_t^* = G_t H_t / k_s B^2$, $G_b^* = G_b H_b / k_s B^2$, $q^* = q/k_s B$, $T_p^* = T_p / k_s B^2$,

$\alpha (= k_f/k_s)$ is the modular ratio, q is embankment load intensity, T is the tensile force per unit length mobilized in the membrane, w is vertical surface displacement, x is the distance measured from the center of the loaded region along the x-axis. The parameters, $\bar{X}_1$, $\bar{X}_2$, $\bar{X}_3$, *and* $\bar{X}_4$, and the average degree of consolidation, U, are given as:

$$\bar{X}_1 = \frac{1 + K_{0R}\tan^2\theta - (1-K_{0R})\mu_b \tan\theta}{1 + K_{0R}\tan^2\theta + (1-K_{0R})\mu_t \tan\theta} \tag{3.1}$$

$$\bar{X}_2 = \frac{1}{1 + K_{0R}\tan^2\theta + (1-K_{0R})\mu_t \tan\theta} \tag{3.2}$$

$$\bar{X}_3 = \mu_t \cos\theta(1 + K_{0R}\tan^2\theta) - (1-K_{0R})\sin\theta \tag{3.3}$$

$$\bar{X}_4 = \mu_b \cos\theta(1 + K_{0R}\tan^2\theta) + (1-K_{0R})\sin\theta \tag{3.4}$$

$$U = 1 - \sum_{m=0}^{m=\infty} \frac{2u_0}{M^2} e^{-M^2 T_v} \tag{3.5}$$

in which, θ is the slope of the geosynthetic layer, K_{0R} is the coefficient of lateral stress, μ_t and μ_b are interface friction coefficients at the top and bottom faces of the membrane respectively, u_0 is the initial excess pore water pressure, $M=(2m+1)\pi/2$, m = 0, 1, 2, 3, .., $T_v (= C_v t/H_s^2)$ is the time factor for primary consolidation, C_v is the coefficient of consolidation and H_s is the thickness of the soft foundation soil layer.

4 SOLUTION TECHNIQUE

To carry out parametric study, Eqs. (1) and (2) are solved iteratively by finite difference method. The loading conditions considered are given as:

$$q^*(X) = q_0 \quad \text{for } |X| \le \frac{b}{B} \tag{4.1}$$

$$= q_0 \left(1 - \frac{X - b/B}{nH/B}\right) \quad \text{for } b/B < |X| \le 1.0 \tag{4.2}$$

$$= 0 \quad \text{for } |X| > 1.0 \tag{4.3}$$

The boundary conditions considered at the center and at the edge of the reinforced zone are as follows:

$$\frac{dW}{dX} = 0 \quad \text{at } X = 0.0 \tag{5.1}$$

$$\frac{dW}{dX} = 0 \quad \text{at } X = L/B \tag{5.2}$$

$$T^* = 0.0 \quad \text{at } X = L/B \tag{5.3}$$

5 RESULTS AND DISCUSSIONS

The results have been obtained using the HP-9000/850 computer system. Due to symmetry of the problem analyzed, only half region of the problem ($X \ge 0$) has been considered. The solutions have been obtained with a convergence criterion of 0.0001. The following parameters have been considered constant throughout the study: n = 2, b/B = 0.273, $\mu_t = \mu_b = 0.5$, and $K_{0R} = 0.36$.

Figure 3 shows the typical settlement profiles for different widths of reinforced zone. It is observed that the settlement is maximum for x/B = 1.0 and it reduces throughout the reinforced zone with the increase in L/B. The settlement is almost same for L/B ≥ 1.4 near the center (x/B<0.4) of the embankment, however, beyond this region, it is slightly less for higher values of L/B. This suggests that it will not be beneficial to use higher width of reinforced zone (L/B>1.4).

Figure 4 shows the typical settlement profiles for three field situations: (i) embankment on soft foundation soil, (ii) embankment on granular fill - soft soil system, and (iii) embankment on geosynthetic-reinforced granular fill-soft soil system (T_p^* = 0.0, 0.05, 0.1). In the first case, there is uniform settlement up to x/B = 0.273 and beyond this, settlement decreases linearly and become zero at x/B = 1.0. In the second case, with the presence of granular fill, the settlement reduces in the region x/B<0.7 whereas beyond this, there is an increase in settlement. In the third case with the presence of geosynthetic layer (with or without prestress) alongwith the granular fill, the settlement further reduces in the region x/B<0.7 and beyond this increase occurs. Compared with the settlement with the case of no prestress in geosynthetic reinforcement, the settlement at the center is less by 7.92% for T_p^* = 0.05 and 14.27% for T_p^* = 0.05 whereas the corresponding increases in settlements at the edge of the embankment are respectively 71.43% and 108.57%. This suggests that prestressing the geosynthetic is a very effective technique to reduce the differential settlement of the embankment. Such observations have also been made by Shukla and Chandra (1994a,b; Shukla, 1995) in case strip loading on geosynthetic-reinforced soil system. However, there is significant difference in the behavior. In case of uniform strip loading as a result of prestressing, the settlement reduces both at the center (% reduction more) and at the edge (% reduction less) of the loaded footing whereas, in the present case, the settlement reduces at the center of the

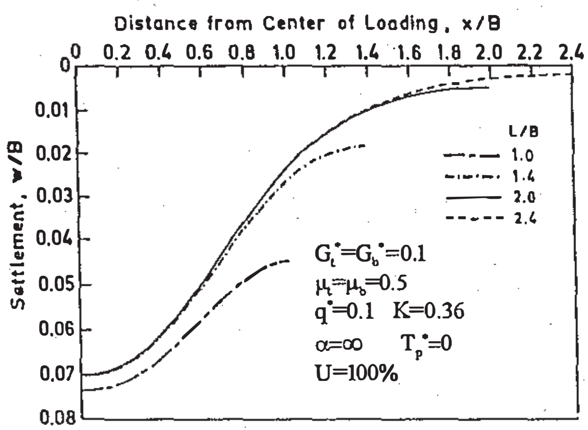

Figure 3. Effect of width of reinforced zone on settlement profiles.

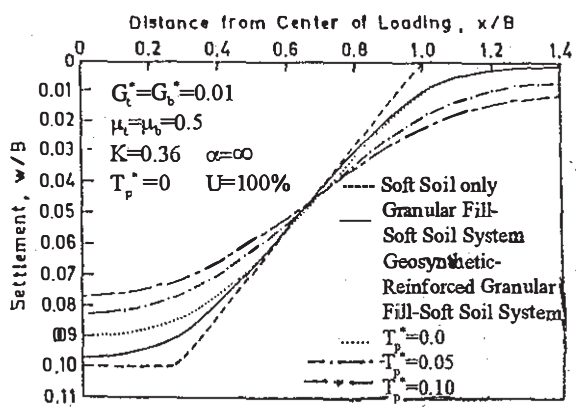

Figure 4. Settlement profiles.

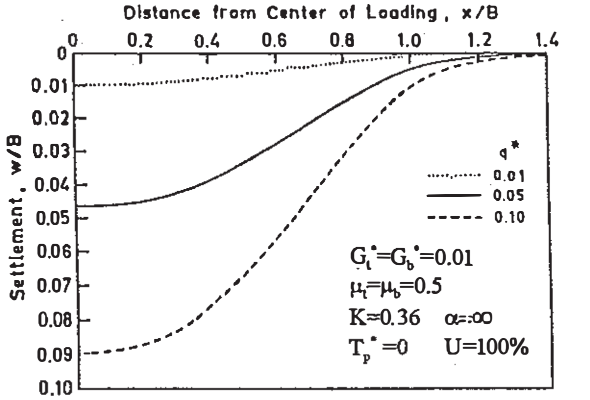

Figure 5. Effect of load intensity on settlement profiles.

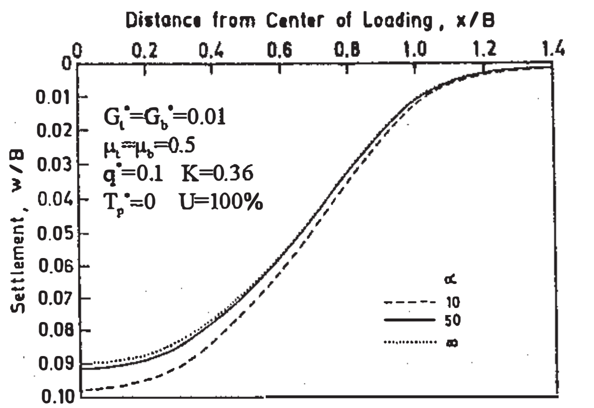

Figure 6. Effect of modular ratio on the settlement profiles.

embankment whereas increase occurs at the edge.

Figure 5 shows the settlement profiles for three different load intensities. It is noted that the settlement at any location increases with the increase in load intensity. For example, the nondimensional settlements at the center of the embankment for $q_0^* = 0.01$, 0.05 and 0.1 are respectively 0.010, 0.047, and 0.090.

Figure 6 shows the settlement profiles for different modular ratios. It is observed at any location for $\alpha = 50$ and and $\alpha = \infty$ differ negligibly. This indicates that one can neglect the compressibility of the granular layers in settlement estimation if the modular ratio is greater than 50.

Figure 7 shows the typical settlement profiles for several values of average degree of consolidation of soft foundation soil. It is observed as a result of consolidation of the soft foundation soil, the settlement is very high near the center compared with the settlement near

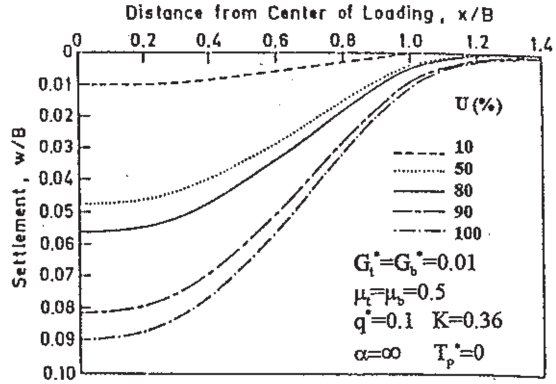

Figure 7 Settlement profiles at different stages of consolidation.

the edge. Hence a large differential settlement will occur with time.

6 CONCLUSIONS

From the parametric studies, it has been found that the settlement below the embankment does not reduces for the width of reinforced zone greater than about 1.5 times the base width of embankment. Prestressing the geosynthetic reinforcement has been found to reduce the differential settlements significantly. The compressibility of the granular fill can be neglected in settlement calculations if the modular ratio is grater than 50.

REFERENCES

Kerr, A.D. 1964. Elastic and viscoelastic foundation models. *J. App. Mech.* 31:491-498.

Selvadurai, A.P.S. 1979. *Elastic analysis of soil-foundation interaction*. Elsevier Science Ltd, Amsterdam.

Shukla, S.K. 1995. *Foundation model for reinforced granular fill - soft soil system and its settlement response*. Ph.D. Thesis, Department of Civil Engineering, I.I.T. Kanpur, India.

Shukla, S.K. & S, Chandra 1994a. The effect of prestressing on the settlement characteristics of geosynthetic-reinforced soil. *Geotextiles and Geomembranes* 13:531-543.

Shukla, S.K. & S. Chandra 1994b. A generalized mechanical model for geosynthetic-reinforced foundation soil. *Geotextiles and Geomembranes* 13:813-825.

Taylor, D.W. 1948. *Fundamentals of soil mechanics*. Asia Publishing House, Bombay, India.