Deformation Analysis of Reinforced Embankments

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ABSTRACT: The improvement of soil behaviour of an embankment constructed over a soft soil foundation stratum on a layer of a strong geosynthetic material as reinforcement, is examined in this paper. Emphasis is given in the analysis of deformations under undrained conditions.. A Finite Element elastoplastic code is used for the analysis of foundation soil displacements. Reduction of the lateral and vertical soil movements, compared with an unreinforced case are presented and discussed for a range of values of reinforcement tensile stiffness. Reinforcement in general, reduces the horizontal and vertical movements of soil. This improvement depends on the reinforcement tensile stiffness and on the displacement field of the soil layer, which is a function of the thickness of the foundation soil and of the soil strength.

1 INTRODUCTION

The use of high strength geotextiles and other geosynthetics in the base of embankments constructed over soft soil layers, is a common practice, recently. Geosynthetic reinforcement can improve stability, decreases lateral and vertical soil deformations under working conditions and allows embankments to be constructed to greater heights or without the need of staged construction. The methods of analysis for reinforced embankments are classified into three (3) main categories:

- Limit equilibrium methods
- Plasticity solutions
- Finite Element (FE) analysis.

Limit equilibrium and plasticity solutions have been used by several investigators, to predict with accuracy in general, the critical height of failure of reinforced embankments, over cohesive soft soil layers, but the prediction of deformations requires the use of FE analysis (Rowe and Soderman, 1987). Analysis of deformations is important, since an embankment is possible to fail due to excessive deformations, even though collapse has not occured (Rowe et.al, 1984).

In addition, the FE analysis allows also the study of other parameters, as the extension of plastic zones in the foundation soil and the stress distributions in the embankment, the foundation and the reinforcement.

In this paper emphasis is given on the influence of limited thickness of foundation soil layer and of the soil strength profile on deformation behaviour of reinforced embankments, using the FE analysis.

Based on an extensive study of case histories of embankments over soft soil, Humphrey and Holtz (1986) found, that prediction of embankment height based on a classical plasticity solution underestimates the real critical value for soil collapse and they concluded that the limited thickness, as well as the increase of strength with depth are responsible for critical heights larger than expected. Plasticity solutions (Matar and Salençon, 1977) can also take into account the limited thickness and the increase of strength for the prediction of the critical height of embankments.

2 METHOD OF ANALYSIS

The Finite Element elastoplastic code PLAXIS (Vermeer, 1991) is used for the analysis of reinforced embankments, with the Mohr-Coulomb criterion for soil stress - strain behaviour. Undrained conditions are assumed for the analysis.

The reinforcement, in the base of an embankment, is modelled as elastic line elements with zero bending stiffness and axial tensile stiffness J (kN/m) given by product of the elastic modulus E of the geotextile material and the thickness of the geotextile. Geotextile elements are not allowed to sustain compressive forces. We also assume that no relative movement occurs at the interface between the reinforcement and the soil bellow it.

Embankment load is applied on foundation soil using vertical and horizontal boundary tractions. A triangular distribution of the shear stresses along the base of an embankment is indicated in Figure 1.
To examine the influence of variation of undrained shear strength of the foundation soil with depth, two soil profiles (I: uniform strength, II: increasing strength with depth) are examined.

Soil I: $Cu(z) = 25\ (kN/m^2)$

Soil II: $Cu(z) = 18 + 2.5z\ (kN/m^2)$

The ratio of undrained Young's modulus to undrained shear strength Eu/Cu for many soft clays lies in the range $125 \leq Eu/Cu \leq 500$. A value of Eu/Cu equal to 150 is used in the present analysis.
Two values of thickness of soil layer (D=5m and D=25m) are used in this analysis, to examine the two cases of deformation modes (translational and rotational). The width at the base of the embankment is taken equal to 40m. Figure 1 presents the assumptions of the analysis.
Critical embankment's heights, leading soil deposit to failure, are computed, using PLAXIS, for the unreinforced embankments. Two soil profiles (Fig.1) and two values of soil deposit thickness are examined. A value of $\gamma = 20kN/m^3$ is assumed for the unit weight of the embankment material.

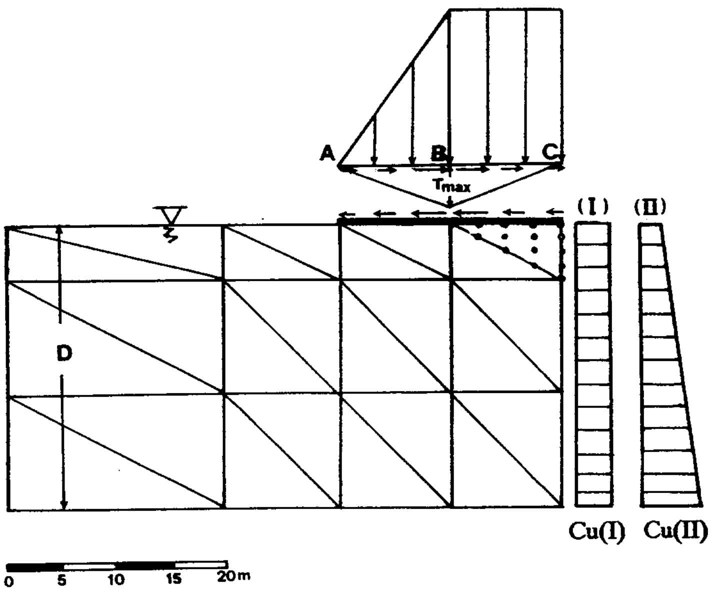

Fig.1: Considerations of analysis for two soil profiles: (I) $Cu(I)=25kN/m^2$ const.with depth, (II) $Cu(II)=18+2.5z\ kN/m^2$ variable.

Table 1 presents the results of the analysis. Values of critical heights agree, in general, well, with results obtained from plasticity solutions (Davis & Booker, 1973; Matar & Salençon, 1977).

TABLE 1: Critical heights for unreinforced embankments leading to foundation soil failure

Soil thickness (m)	Soil Profile	Embankment height (m)
5	I	6.95
5	II	6.75
25	I	6.45
25	II	6.75

Embankments with heights given in Table 1 are reinforced at the foundation soil surface and the reduction of soil deformations, due to reinforcement, is examined for the four (4) cases of soil strength profile and thickness of soil deposit.
Three (3) values of axial tensile stiffness modulus J of reinforcement, equal to 1000, 2000, 5000 kN/m are examined. Figure 2 presents results for the analysis of limited soil deposit thickness D=5m (D/B = 0.125).
Figure 2a gives the displacement field for the unreinforced case, for soil profile I (constant value of undrained shear strength $Cu = 25kN/m^2$). The displacement field for soil profile II presents small differences, compared with results presented in Figure 2a. It is clear that a translational mode of deformations occurs and reinforcement is expected to resist these -mainly lateral- movements of the foundation soil.
Figure 2b presents the horizontal displacement at points A and B of the soil surface, as function of the reinforcement tensile stiffness modulus J. Figure 2c also presents vertical displacements at points B and C. The reduction of displacements, as a function of J, is greater for horizontal deformations, as expected from the deformation mode for limited deposit thickness situation.
The maximum horizontal displacement, at point B, for the unreinforced case, is computed equal to 17.5cm, for soil profile I. The horizontal displacement at the same point for the most heavily reinforced embankment (J= 5000 kN/m) is obtained equal to 10.3cm, leading to a significant reduction of horizontal displacement of the unreinforced case.
In general, results of Figure 2b demonstrate a reinforcement which substantially reduces the horizontal deformations, in the case of limited soil deposit thickness, for soil profiles I and II. It is also clear that reinforcement influences -a little- the vertical displacement of the soil surface for limited thickness conditions.

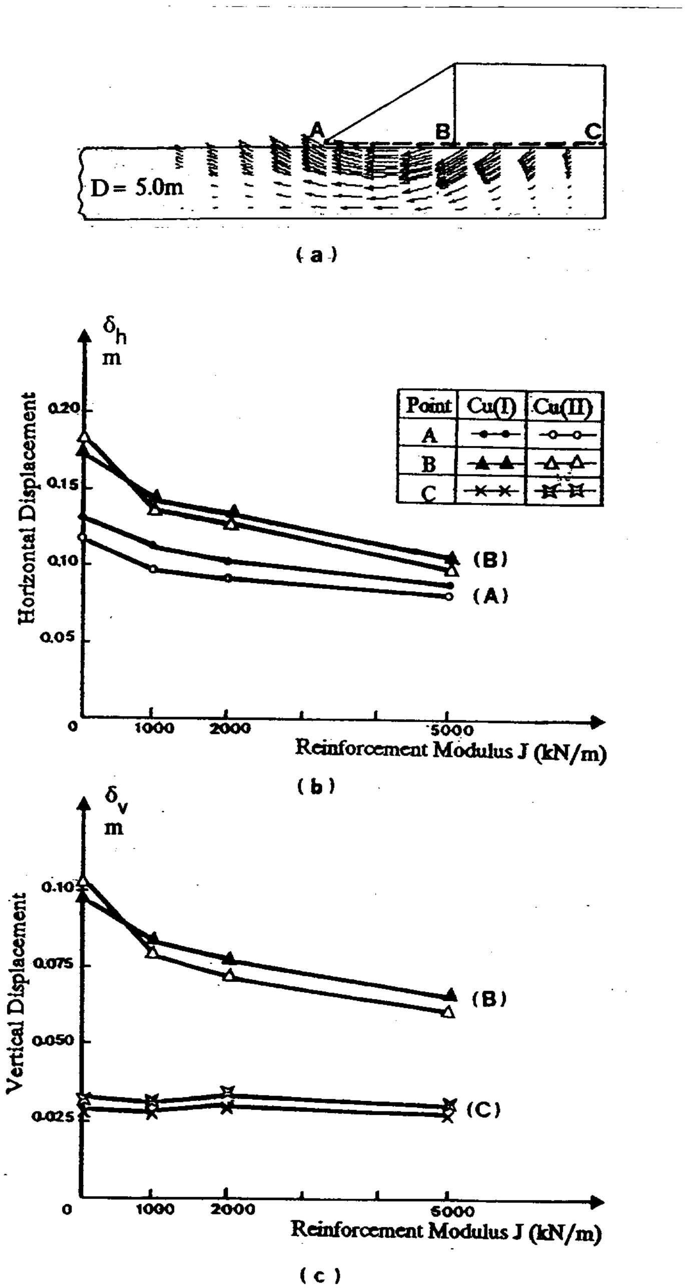

Fig. 2: Results for foundation soil depth D=5.0m (a) Displacement field without reinforcement, (b) Horizontal displacement with reinforcement modulus J, (c) Vertical displacement with J.

Figure 3a presents the displacement field for unreinforced case for soil profile I and for a deep soil deposit (D=25m, D/B= 0.625). A rotational mode of deformations is obtained. Significant vertical displacements are computed at the embankment's axis of symmetry (point C). Increasing soil strength with depth (soil profile II) has a significant influence on the magnitude of horizontal and vertical displacements, at the foundation soil and also, in its deformation mode. A soil profile with increasing strength with depth, presents a deformation behaviour analogous to limited thickness soil deposit.
Figures 3b and 3c present the horizontal and vertical displacements at points A, B and C, on soil surface, as function of reinforcement modulus J.

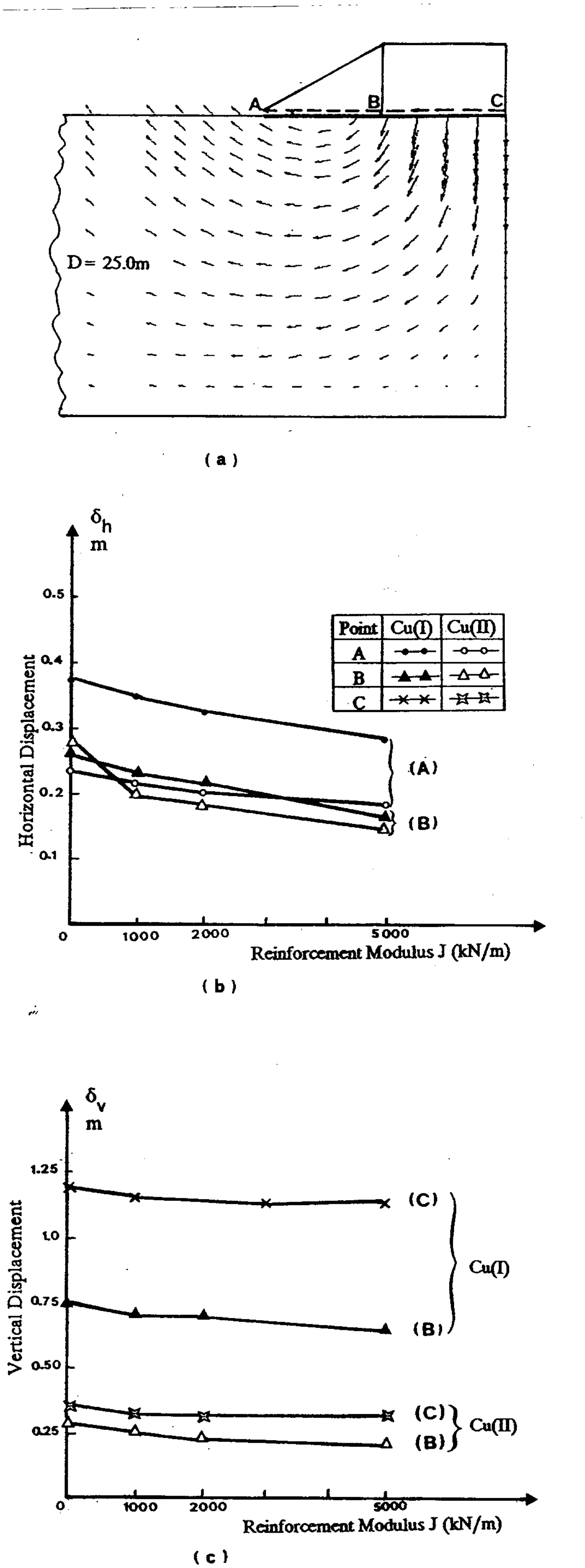

Fig. 3: Results for foundation soil depth D=25m (a) Displacement field without reinforcement, (b) Horizontal displacement with reinforcement modulus J, (c) Vertical displacement with J.

Figure 4 presents the maximum forces in the reinforcement for the examined cases, as a function of reinforcement stifness modulus J. The computed reinforcement forces are less than the typical breaking strength of strong geotextiles. This indicates that the strength of the foundation soil is fully mobilized before there are sufficient deformations, which develop the full capacity of the reinforcement. As expected the force mobilized in the reinforcement increases with increasing stifness modulus J.

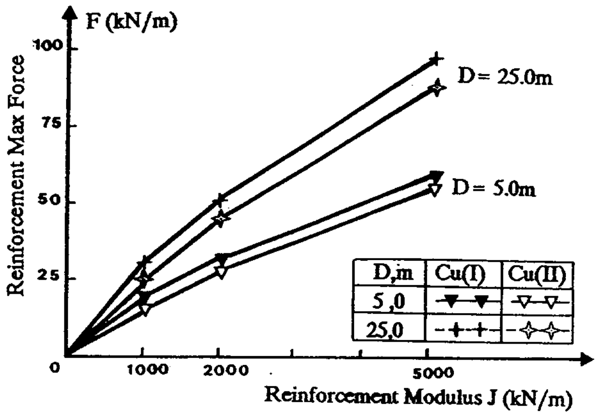

Fig. 4: Maximum force in the reinforcement for various reinforcement modulus J.

Figure 5 presents the distribution of force F (kN/m) in the reinforcement for soil deposit thickness D=5m and soil profile I. Values for J= 1000 kN/m and J= 5000 kN/m are presented.

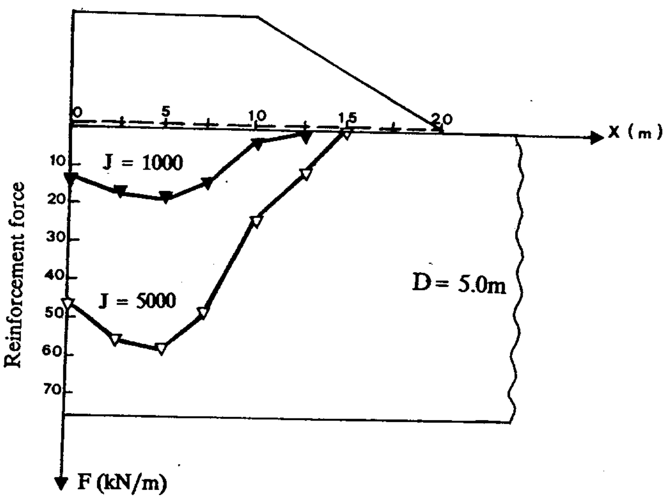

Fig. 5: Reinforcement force distribution for depth D=5m and soil strength Cu(I) = 25 kN/m^2.

Results for distribution of force in reinforcement are consistent with field observations (Rowe et.al, 1984) and Finite Element Analysis (Humphrey, 1986).

3 CONCLUSIONS

Deformations of embankments, constructed on a layer of reinforcement over a soft soil deposit, are examined in this paper. Emphasis is given in the analysis of soil surface displacements under undrained conditions.

Two cases of undrained shear strength profile are examined with two values of soil deposit thickness, in order to examine the two cases of deformation mode (translational and rotational).

Results of horizontal and vertical displacements of soil surface are presented, as function of reinforcement axial tensile stiffness modulus J and compared with the unreinforced case.

Reinforcement, in general, reduces the horizontal and vertical movements of the soil. The improvement depends on the undrained soil strength profile and relative depth of the deposit. Also forces mobilized in the reinforcement increase with stiffness modulus.

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