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Settlement analysis of Shahid Kalantari highway embankment and assessment of the effect of geotextile reinforcement layer

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ABSTRACT: Large compressibility and low shear strength of soft soil deposits has led to challenging problems involving long-term deformation and instability associated with design and construction of embankment on these soils. In this paper, the settlement of the Shahid Kalantari Highway which is located in West Azarbayjan province of the northwest of Iran is studied. This highway is underlain by thick layers of organic soil and soft silty clay layers that have undergone a significant settlement of about one meter since its construction was completed. A good agreement is obtained between the settlement calculated by finite element analysis using a soft soil creep model and field measurements of embankment settlement. The effect of geotextile layer at the base of the embankment is then evaluated as a remedial measure to control the settlement. The results show that the application of geotextile, as a reinforcement layer, would improve the performance of the embankment in this section of the highway.

1 INTRODUCTION

The study of embankments on soft soil is one of the everlasting problems in the soil mechanics and has been analyzed by a large number of investigators. Low strength of these soils significantly limits their load (embankment height) bearing capacity for short term stability conditions. In addition, large compressibility and low permeability lead to large settlements that continue over a significant period of time as the excess pore water pressure dissipates slowly (primary consolidation). Geotechnical engineers have developed several techniques to cope with the low shear strength and settlement of soft soils. In recent years, geosynthetic reinforcement has been added to the list of possible solutions for embankment construction on very soft soil. In many cases, the use of a geotextile or geogrid can significantly increase the safety factor, reduce ground settlement, and reduce costs in comparison to more conventional solutions (Borges and Cardoso, 2001). Over the last two decades, with the availability of faster computers with larger data storage capacities, it has been possible to perform finite element analyses with increasingly complex formulations and advanced soil constitutive models. The earliest analyses used elastic soil models but quickly moved to non-linear elastic and elasto-plastic models. A critical state model was used by Wroth and Simpson (1972) on a trial embankment, and coupled analyses have been used to predict the pore pressure response in the field and in centrifuge tests (Schafer, 1987; Almeida, 1984; Smith and Hobbs and Biot, 1976; Wroth, 1977). Hird and Kwok (1990) used interface elements and showed that useful information regarding transfer of shear stresses from the soil to the reinforcement could be extracted from numerical analysis. They further carried out a parametric study and concluded that sufficiently stiff and strong reinforcement may significantly reduce subsoil deformations and for a subsoil of constant strength, the influence of reinforcement reduces with increasing depth.

The construction of Shahid Kalantari highway was completed in 1992. Since then, the embankment has settled significantly in the middle part of the 100 meters long highway until 1996. The maximum amount of settlement was 0.7 meters and as a remedial measure, about 500 tons of asphalt has so far been paved to elevate the highway surface to its original level. However, settling of this section of the highway has continued and as of 2002, 0.4 meters of settlement had occurred. Geotechnical investigations show that a thick layer of organic soil followed by soft silty clay layers underlying the highway is the main reason of road settlement in this part. In this study, a numerical modeling of the embankment is performed using the finite element software Plaxis to predict the amount of highway settlement with and without a geotextile reinforcing layer. The settlements estimated from these analyses are compared, and the advantages of using geotextiles are discussed.

2 SOIL PROFILE AND PARAMETERS

Fig. 1 illustrates the cross-section of the embankment and soil profile. The embankment height in the middle section is 2.7 meters. The soil profile consists of thick layers of organic soil, silt and clay. The water level is 1 meter below the natural ground surface. The elastic perfectly plastic Mohr-Coulomb failure criterion is used to model the embankment material, and the Soft Soil Creep (SSC) model, which is similar to the modified Cam Clay model, is used to model the behavior of soft subsoil (Van Baars, 2003; Haval 2004; Ravask, 2006). The input data for FEM simulations are tabulated in Table 1.

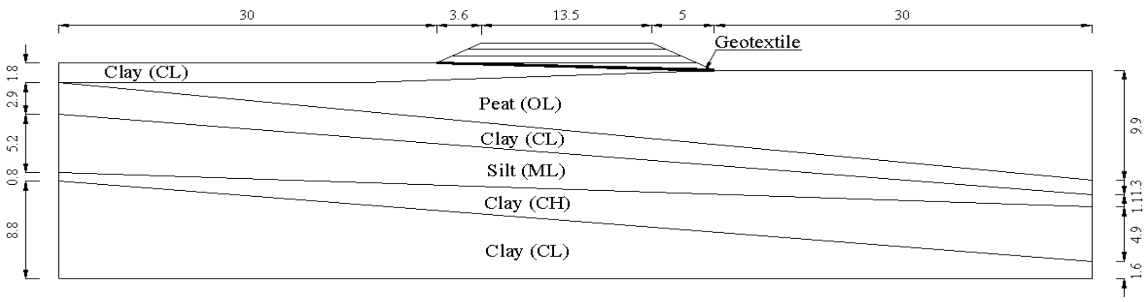

Figure 1. Cross-section of the embankment and soil profile.

Table 1.Geotechnical properties of the foundation soil and the embankment

Material	Unit	Embankment	Clay1	Peat	Clay2	Silt	Clay3	Clay4
Unit weight above phreatic level	kN/m^3	20.5	15.5	14.8	15.5	13.4	12.6	11.1
Unit weight below phreatic level	kN/m^3	21.5	17	18	16	18.6	17.7	15
Permeability	m/day	1	3E-5	3.5E-4	1E-4	3.8E-4	6.7E-4	3.1E-4
Young's modulus	kN/m^2	50000	-	-	-	-	-	-
Poisson's ratio	-	0.35	-	-	-	-	-	-
Cohesion	kN/m^2	0	10	5	10	3	12	14
Friction angle	degree	34	22	30	20	22	14	24
Dilatancy angle	degree	-	0	0	0	0	0	0
Modified compression index	-	-	0.06	0.12	0.07	0.075	0.064	0.098
Modified swelling index	-	-	0.015	0.037	0.02	0.02	0.015	0.019
Secondary compression index	-	-	0.0025	0.003	0.0028	0.0031	0.0029	0.0033
Over consolidation ratio	-	-	1	1.27	1	1	1	1.54

3 NUMERICAL MODELING

The finite element analyses were conducted using the finite element software, Plaxis 2D (version 8.2). Plaxis allows a realistic simulation of construction sequences, and the ability to include reinforcement and interface elements at any stage of the analysis without any significant changes of the input data and finite element mesh. The section shown in Figure 1 is analyzed with a plain strain model. A finite element mesh is generated using 15-node elements which are shown in Figure 2. The in situ at-rest (K_o) stress conditions are introduced in the foundation soil. In the subsequent stage of modeling, embankment construction is modeled. Embankment construction consists of five phases each lasting two days. After the fifth construction phase a consolidation period of four years is allowed. In the sixth phase of the analysis, the addition of the 500 tons asphalt is simulated by the application of a uniformly distributed load. Subsequently, consolidation periods of 4, 9, and 10.5 years, and end-of-primary consolidation (until all excess pore pressure is dissipated) are modeled. Analyses results are plotted for several locations (control points in Figure 3) of the model. The finite element model of the reinforced embankment consists of geotextile reinforcement and soil-reinforcement interface elements. Six-node triangular elements are used to generate the finite element mesh. An elasto-plastic model is used to describe the interaction behavior at the soil-reinforcement interface. The strength properties of the interface are linked to strength properties of the adjacent soil layer. Each data set is associated with strength reduction factors for the interface (R_{inter}). The interface properties are calculated from the soil properties in the associated data set and the strength reduction factor by using the following rules:

$C_i = R_{inter}\, C_i$ & $\tan\Phi_i = R_{inter} \tan\Phi_i$

Where, Φ_i and C_i are friction angle and cohesion of the interface, respectively. And similarly, Φ_{soil} and C_{soil} are friction angle and cohesion of the adjacent soil, respectively. Based on pullout test results, Bergado et al. (2003), suggested an interface coefficient (R_{inter}) of 0.9 for soil-reinforcement interface that is also used in this study.

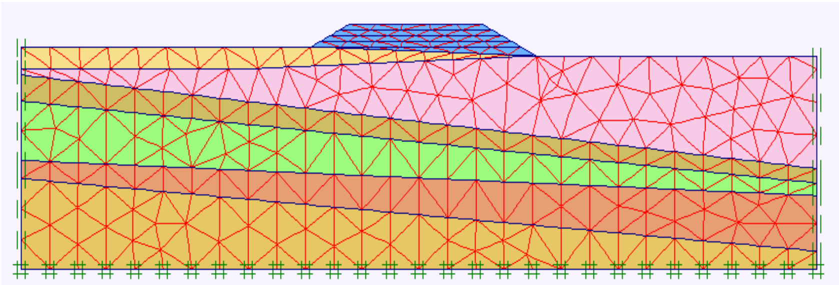

Figure 2. Finite element model of the embankment

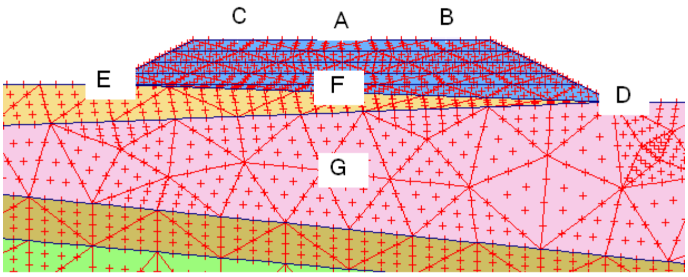

Figure 3. Control points selected for obtaining data

4 RESULTS AND DISCUSSION

The surface settlements of the embankment at each phase of analyses are plotted in Figure 4. Maximum settlement at end of construction is about 8 cm that is essentially as a result of the embankment deformation. Settlements of the original soil surface and embankment increase considerably with time, as the excess pore pressure dissipates. Figure 5 and 6 show the settlement of control points with time. Maximum settlement of the embankment is 73.6 cm which occurs at point

B (right side of the embankment). At the left side (point C) the settlement is 40 cm. This differential settlement of the embankment reflects the sloping ground surface, varying embankment height, and the variable thickness of the underlying compressible peat stratum. Maximum settlement of compressible subsoil is 65 cm which occurs under the middle of the embankment. Heaving has also occurred at toes of the embankment (points E and D). It can be seen that settlement of the embankment increases over time so at ninth year after construction maximum settlement reaches 112 cm and 18 months later (10.5 years after construction) it becomes 118 cm. It is anticipated that the primary consolidation (where the excess pore pressure has completely dissipated) of the compressible subsoil would be complete after about 163 years, at which the maximum settlement would reach about 169 cm.

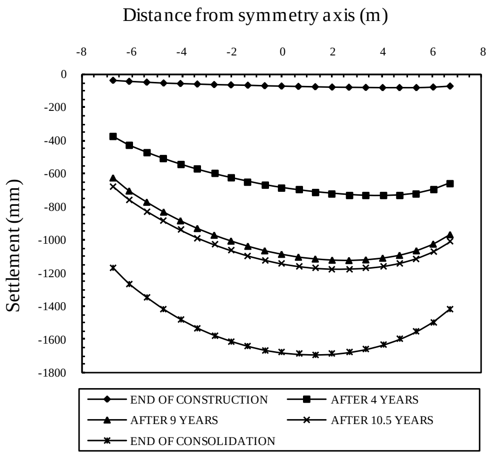

Figure 4. Settlement of embankment surface at each stage

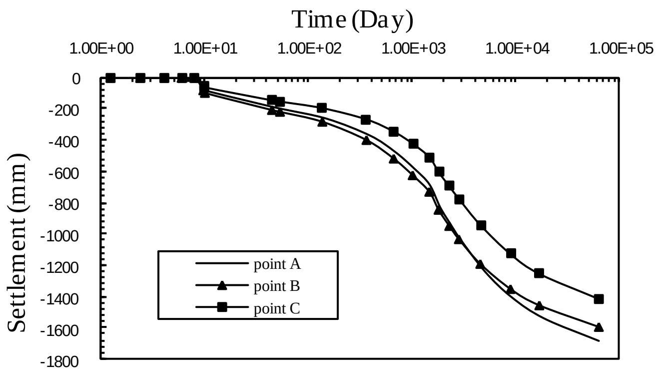

Figure 5. Settlement time-histories of points A, B and C

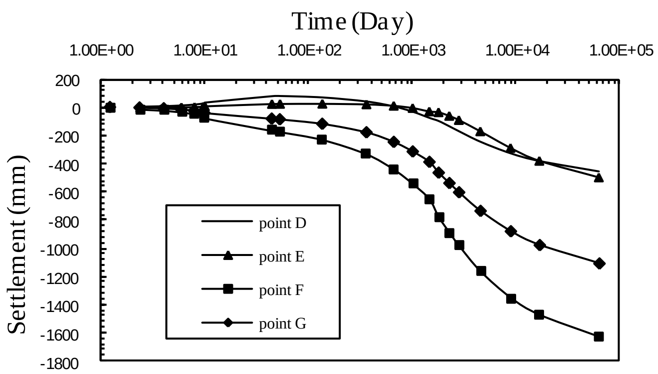

Figure 6. Settlement time-histories of points D, E, F and G

The measured and calculated surface settlements of the embankment are plotted in Figures 7 to 9. According to these plots, the finite element analysis provided a very good estimate of the actual ground settlement. In order to evaluate the effect of geotextile reinforcement, a finite element analysis was carried out by implementing a layer of geotextile at base of the embankment.

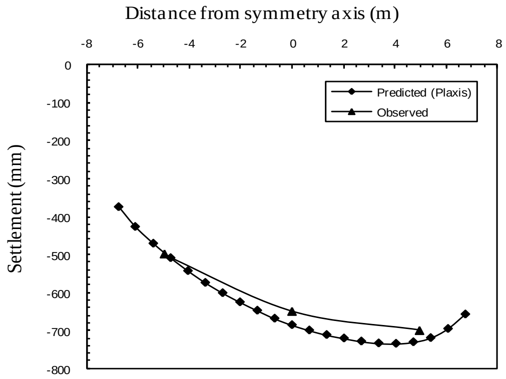

Figure 7. Comparison between results from finite element modeling and measured surface settlement of the embankment for four years after construction

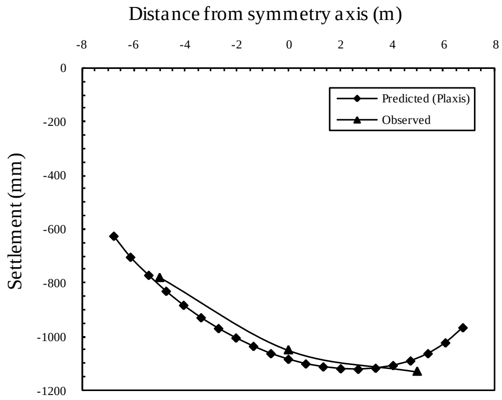

Figure 8. Comparison between settlements obtained from finite element modeling and measured surface settlement of the embankment for nine years after construction

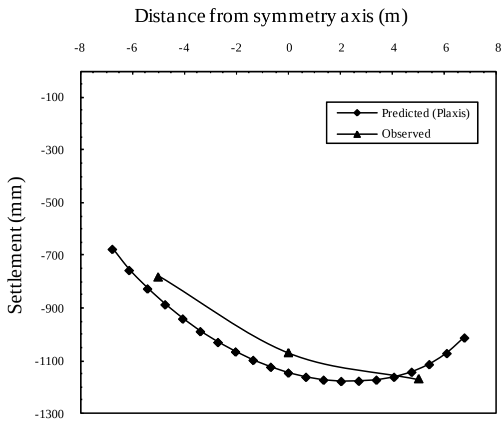

Figure 9. Comparison between results from FEM modeling and observed surface settlement of the embankment ten and half years after construction

Figures 10 to 14 compare settlements on the embankment surface both with and without the reinforcing geotextile layer. According to these figures, the inclusion of the geotextile reinforcement does not provide any improvement at the end of the construction as settlement primarily occurs as a result of embankment deformation. After construction, however, geotextile provides tensile stiffness to the subsoil that reduces the long-term (absolute and differential) settlement. For example, according to Figure 11, a 36% reduction in embankment surface settlement is observed four years after construction. Figure 12 further shows 47, and 33% settlement reduction at the left and right sides of the embankment, respectively after nine years from the end of construction. At 10.5 years after construction, the reductions in settlements slightly reduce to 40, and 30% at the left and right sides of the embankment, respectively. At the end of the primary consolidation that occurs 163 years after construction, Figure 14 shows that the effectiveness of the geotextile reinforcement in reducing settlement has significantly decreased to about 10%. We anticipate that this was because of 1) slippage and larger strains at the soil-geotextile interface, 2) settlement of the deeper strata that were less affected by the geotextile reinforcing effect. So in effect a geotextile distributes the load more uniformly and reduce differential settlement.

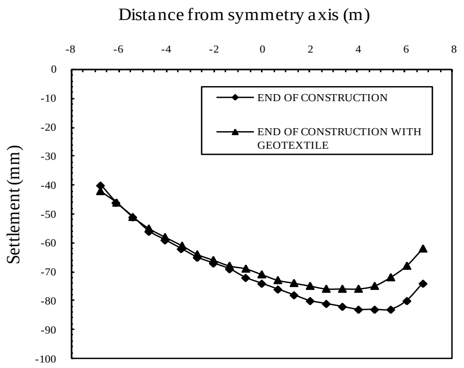

Figure 10. Comparison between surface settlement of embankment with and without geotextile at the end of the construction.

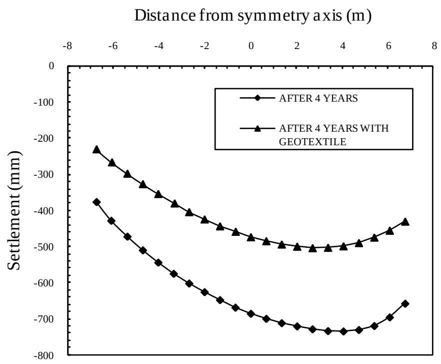

Figure 11. Comparison of embankment surface settlement with and without geotextile, for four years after construction.

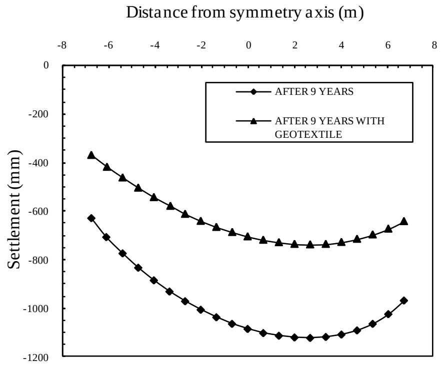

Figure 12. Comparison of embankment surface settlement with and without geotextile for nine years after construction.

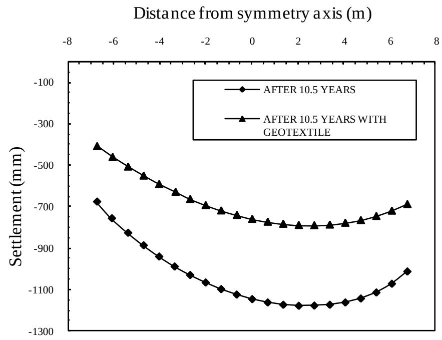

Figure 13. Comparison of embankment surface settlement with and without geotextile, for ten and half years after construction.

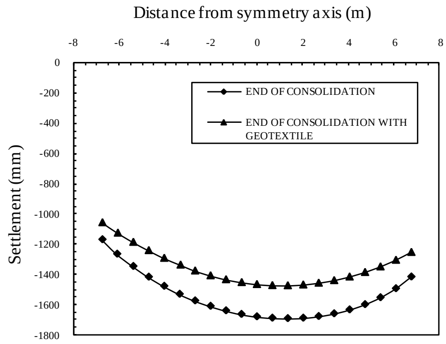

Figure 14. Comparison of embankment surface settlement with and without geotextile, for the end of consolidation.

5 SUMMARY AND CONCLUSION

In this study, the settlement of Shahid Klantari highway embankment was estimated using finite element numerical analysis. Numerical analyses were performed for without and with a geotextile layer at the base of the embankment in order to investigate the effect of using geotextiles for ground surface settlement. The results of the finite element analyses were in good agreement with the ground settlements measured on the actual embankment. This motivated further research to investigate the influence of geotextile as a reinforcing element in the embankment, using the finite element method. The results indicated that geotextile reinforcement could have significantly reduced the absolute and differential settlements of the Shahid Kalantari highway embankment. However, with elapsed time the effectiveness of geotextile for settlement reduction could reduce and potentially reach that of the unreinforced soil.

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