Evaluation of the performance of geotextiles using finite element analysis in the settlement results: a case study in Kayseri, Turkey

Hakan Yalçın & Müge K. Akın
Abdullah Gül University, Turkey

Ali Fırat Çabalar
Gaziantep University, Turkey

ABSTRACT: Geotextiles are successfully designated for the reinforcement of soils to solve certain settlement as well as bearing capacity problems in difficult ground conditions. Furthermore, geotextiles are used for the stability of man-made slopes. In this study, the performance of geotextiles for soil improvement is evaluated by considering various geotextile types that have different axial stiffness values. The stiffness values are compared using a finite element method (FEM) based software PLAXIS 2D. As case study, Kayseri Organized Industrial Site in Turkey was chosen for the comparison of these geotextiles for a specific soil profile during analyses. Besides, the FEM based approach is also considered for the settlement, axial force and the effective stress changes during the application of geotextiles. The selected geotextiles are also correlated using scanning electron microscope (SEM) analyses. The results indicated that the axial stiffness (EA) can be considered with the effect on the possible soil settlement and axial force values. The settlement values reduced with increase in stiffness of reinforcement.

Keywords: Geotextiles, FEM, axial stiffness (EA), SEM, Kayseri

1 INTRODUCTION

Today, population growth and trade increase the demand of new construction sites. The existing sites may not have sufficient bearing capacity to carry live and dead loads, because of that reason these sites may not be suitable for various engineering projects. In order to construct effective projects in engineering point of view, the engineer or designer should either discover new construction sites that have suitable ground conditions or choose the optimum soil improvement technique for the poor subsoil. At this point, geosynthetics are commonly used to improve soils over which roadways, railroads, slopes and earth retaining structures will be built. These high strength fabrics are manufactured from polypropylene, designed to give the highest mechanical properties for heavy duty construction projects. The use of geosynthetics in order to improve the performance of foundations has evolved considerably over the last two decades (Sarsby 2007). The road embankment that constructed with geotextiles is more advantageous than non-geotextile reinforcement in point of lifetime, cost and stability (Karagül 2007). The applicability of FEM for analysing geotextile reinforced embankment of soft soil is investigated by (Siaovashnia et al., (2010)). The related study indicated that vertical and horizontal displacement of soil could be reduced with geotextile improvement. Moreover, in order to get higher resistance against tensile forces, the stiffness of geotextile should be increased. The study of Koohyar Faizi et al., (2013) showed that the groundwater table affects maximum settlement directly and increasing geotextile layers provide decreasing in settlement under seismic loads. The value of factor of safety affect the optimum tensile strength of geotextile reinforced embankment (Wulandari and Tjandra 2015).

In this study, geotextile reinforcement is taken into consideration for finite element analysis. Geotextiles that have different axial stiffness values are analysed with the soil conditions of Kayseri Organized Industrial Zone.

It can be stated that axial load capacity, extreme total displacement and extreme effective stress affect the results. Additionally, the FEM using PLAXIS is proved that users can concentrate on the basis of different analyses to choose the optimum scenario for the design purposes.

1.1 *Study Area Properties*

Kayseri is a large and industrialised city in Central Anatolia, Turkey. The city has extinct volcano Erciyes that is 3916 meter tall. The mountain has very significant effect on earth crust and soil structure of Kayseri. It was active 2000 years ago, in the meantime the volcano produced tuff, lava and pyroclastics (Higgins et al., 2015). These materials separated to the region due to chemical and physical dissipation. The basin has sandy, silty, clayey soil and gravel that breaks off from volcanic rocks. In the study area, a total number of 8 boreholes with 15m and one trial pit about 3m depth are excavated for the site investigation. According to these site works, first 2-3m depth is fill material (sand, gravel and andesite blocks) after 3m depth clayey, sandy, silty soils are observed. Standard Penetration Test (SPT) is performed for 1.5m of depth in each borehole.

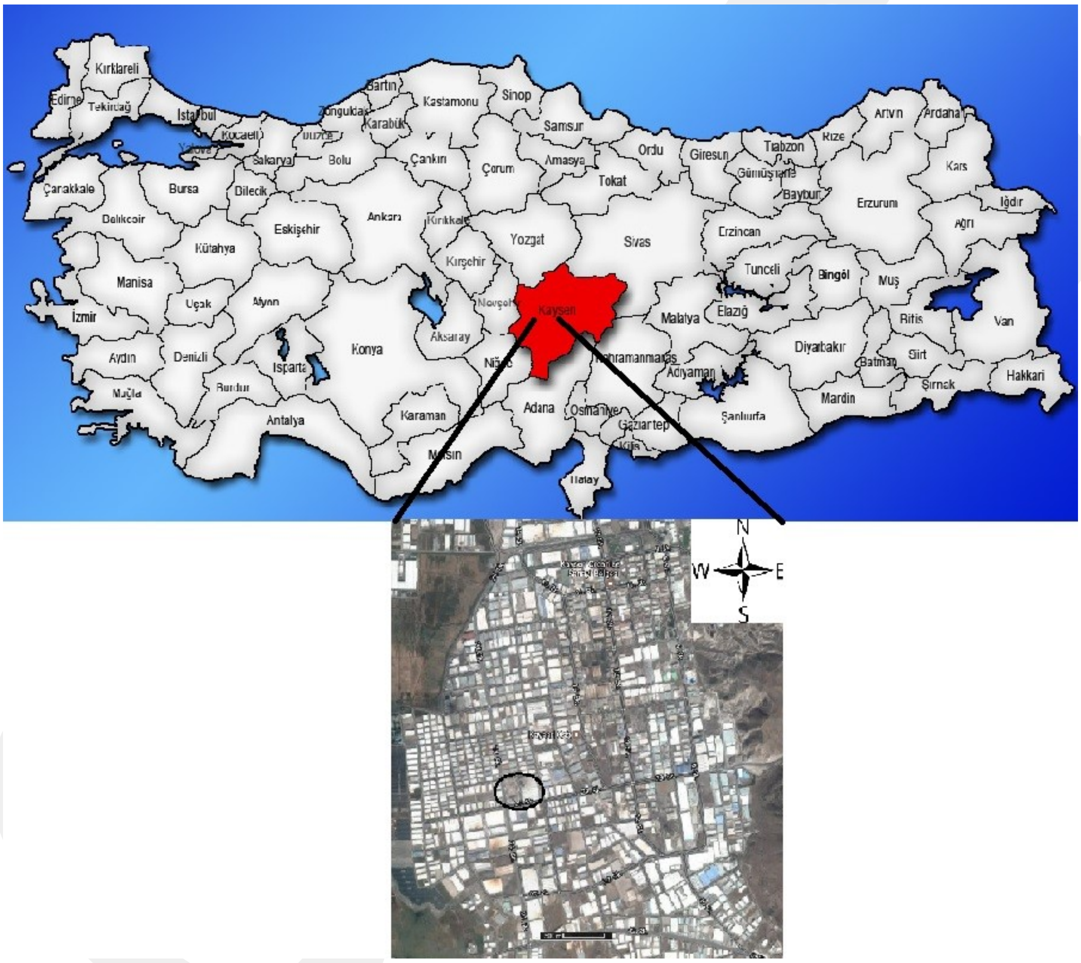

Figure 1. Location map of the study area.

The soil profile is made according to the boring log results. Numerical model and analysis are performed using PLAXIS 2D (Professional version 8, Brinkgreve and Vermeer 1998) .Effective stress and vertical settlement values of the soil profile with and without geotextile are considered in the FEM analyses.

2 MATERIAL PROPERTIES AND GEOMETRY

The roads of industrial sites may have settlement problems due to the soil condition and heavy load traffic. This problem commonly occurs in an area when the soil profile has low strength with low SPT-N values.

Kayseri Organized Industrial site has these kinds of problems. The soil improvement performance of two different types of geotextile are calculated and compared.

Axisymmetric model and 15-node elements are used in the calculations. Global coarseness was set to ‘’ coarse ‘’ for the calculations, because it is adequate as a first approach in most cases. The material properties of the sandy and clayey layers and the interfaces are shown in Table 1. The road model is planned as two lane road with a vertical distributed load is 40 kN/m^2. The slope of the embankment is 1.5:4 (V:H). Firstly, the analysis is made without improvement. Secondly, analysis is performed using geotextile A. Finally, the last analysis is performed using geotextile B. The EA value of geotextile B is 2250 N/m. These values are provided or/and calculated by the manufacturer during the production process. Figure 2 shows PLAXIS model of the road construction.

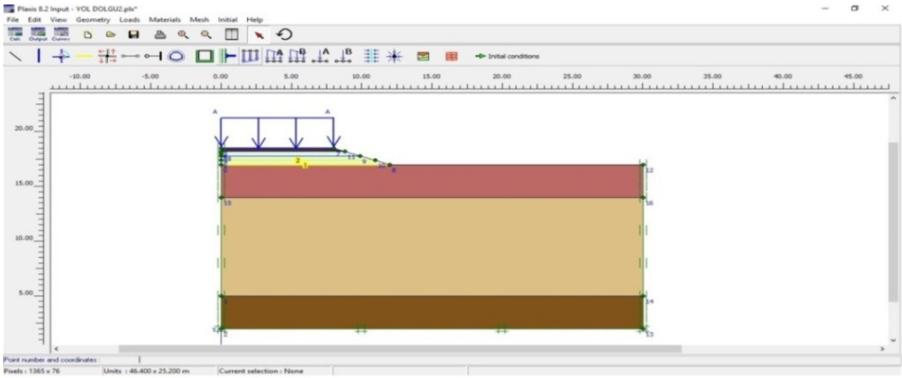

Figure 2. PLAXIS model of the road construction

Standard fixities are used for boundary conditions and ground water table (in this case 6m) is defined in the calculations. 40 kN/m^2 distributed load is applied along the road (8 m).

Table 1. The material properties of the sandy and clayey layer, and the interfaces

Parameter	Symbol	**Pavement**	**Fill material**	**Clay**	**Silty Sand**
Unsaturated unit weight	γ_{unsat} (kN/m^3)	24	18	16	18
Saturated unit weight	γ_{sat} (kN/m^3)	-	20	18	19
Cohesion	c (kN/m^2)	-	5	15	10
Internal friction angle	ϕ °	-	15	5	20
Dilatancy angle	Ψ	-	0	0	0
Poisson's ratio	ν	0.12	0.2	0.33	0.2
Permeability in x direction	k_x (m/day)	-	1	0.0001	3.056
Permeability in y direction	k_y (m/day)	-	1	0.0001	3.056
Modulus of elasticity	E_{50} kN/m^2	1.5E+06	20000	2000	10000
Material type	-	Non-Porous	Drained	Drained	Drained
Material model	-	Linear Elastic	Mohr Coulomb	Mohr Coulomb	Mohr Coulomb

2.1 *Geotextile properties*

The geotextile A has 0.9 mm thickness and it includes slightly less polypropylene ($(C_3H_6)_n$) than other geotextile (geotextile B) specimen which has 1.3 mm thickness. Also, the EA value of geotextile A is 1250 N/m and modeled as elastic while the EA value of geotextile B is 2250 N/m.

2.2 *SEM images of Geotextile specimens*

The grab tensile test is performed using geotextile specimens with an extension rate 300 mm/min. Deformed geotextile A and B specimens for the microscope images, are taken after grab tensile test. Undeformed and deformed geotextile specimens are seen in Figures 3 – and 4 respectively.

Figure 3. Undeformed geotextile specimen

Figure 4. Deformed geotextile specimen

Scanning Electron Microscope (SEM) is a powerful magnification tool that utilizes focused beams of electrons to obtain sample's surface and structure. The SEM analysis of this research was made by Zeiss Supra 55 at Advanced Technology Research and Application Center in Mersin University. Deformed and undeformed geotextile-A and geotextile-B specimens scanned with SEM. The SEM images of geotextile A and geotextile B are shown in Figures 5-6 and Figures 7-8, respectively.

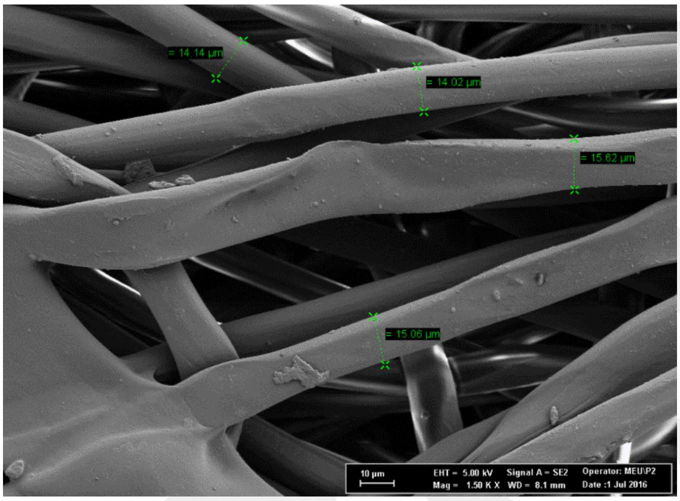

Figure 5. The SEM image of geotextile-A (undeformed)

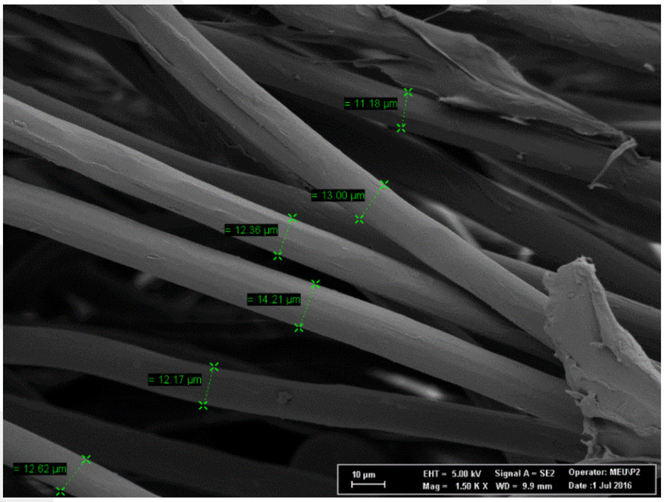

Figure 6. The SEM image of geotextile-A (deformed)

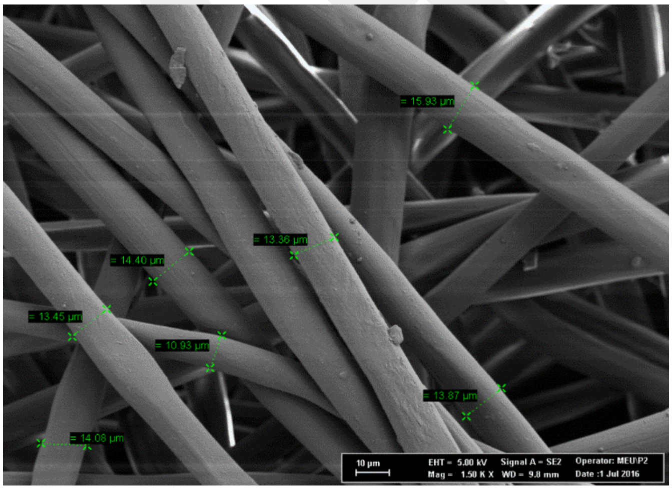

Figure 7. The SEM image of geotextile-B (undeformed)

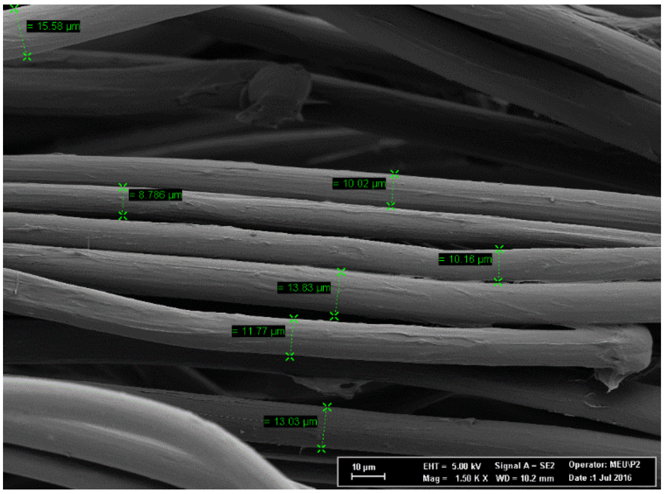

Figure 8. The SEM image of geotextile-B (deformed)

When these SEM images are compared, applied tensional load (extension rate 300 mm/min) cause to thinner polypropylene fiber diameters.

Also, the undeformed geotextile images have complex structure, but immediately after the loading, the structures become fairly straight. In addition, polypropylene fiber diameters of deformed geotextile-B is thinner than geotextile-A, because it has bigger EA value than geotextile-A and this provides more load carrying capacity.

3 GEOTEXTILE REINFORCEMENT ANALYSES

3.1 *The effect of geotextile EA value against the extreme total settlement*

The first analysis of the model is performed without improvement and according to this analysis extreme total displacement is 20.72 cm. Secondly, geotextile-A is used for the calculations. Deformed mesh and vertical settlement value without improvement can be clearly seen in Figure 9. Effective compaction depth is found about 40 cm. Also, the construction period of 2 days is considered for each layer in order to simulate the actual conditions of geotextile layers for stage construction analyses. In the final analysis geotextile-B is used as a ground improvement technique. Figure 10 shows deformed mesh and extreme total displacement of geotextile-B.

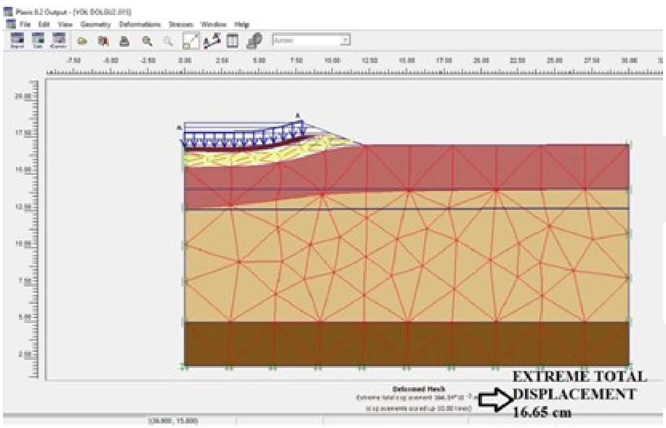

Figure 9. Analysis result of geotextile-A

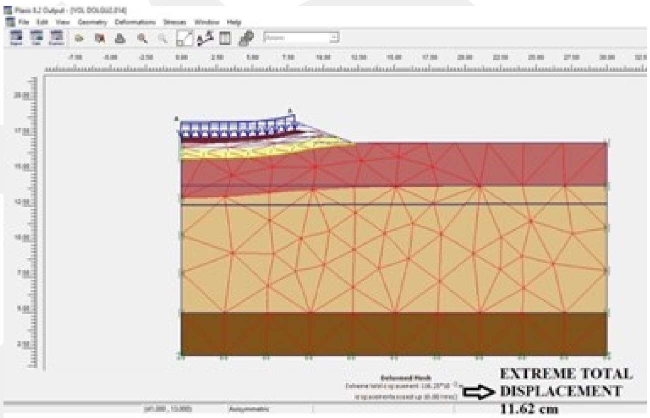

Figure 10. Analysis result of geotextile-B

According to the extreme total displacement results, using geotextile-A is partly successful but not enough, ground improvement with geotextile-B may be more efficient. In addition, phi/c reduction analysis is performed against slope stability problems in the road embankments. It is concluded that slopes are secure against failure depending on the analyses, because anchoring the ends of geotextiles at the slope and overlapping the layers provide resistance against slope failure.

3.2 *The effect of geotextile EA value against the axial load*

The axial load capacity of geotextiles is crucial for the carrying applied loads. The geotextile-A 1st layer (the bottom part) has axial load 7.47 kN/m and 2nd layer (the upper part) has axial force 4.36 kN/m. This means bigger part of load is carried by lower geotextile-A. The axial force values of geotextile-A are presented in Figures 11- and 12.

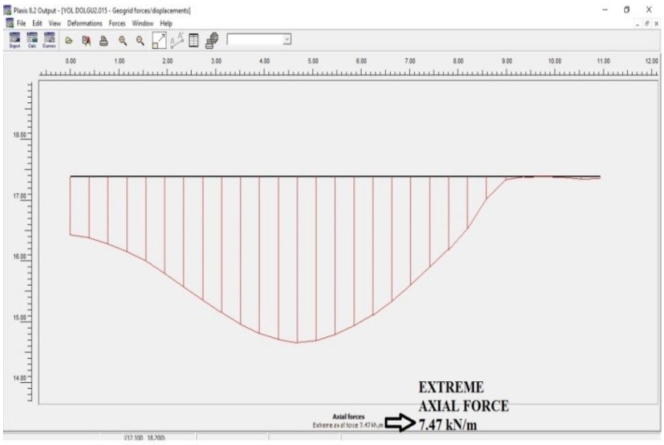

Figure 11. Axial force value of geotextile-A (1st layer)

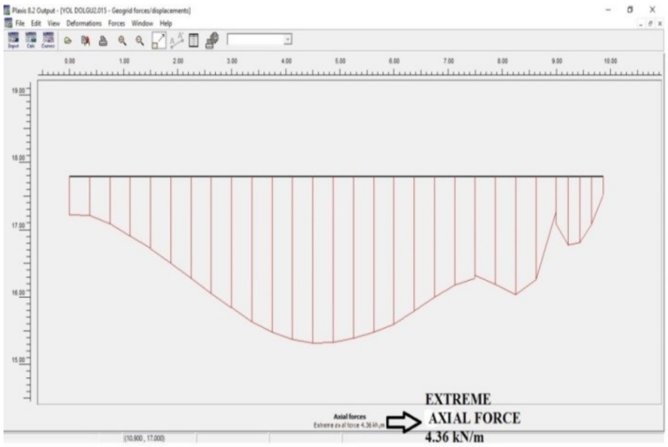

Figure 12. Axial force value of geotextile-A (2nd layer)

The axial force value of geotextile-B for 1st layer is 10.19 kN/m and for 2nd layer is 7.06 kN/m. Axial force values of geotextile-B are shown in Figures 13- and 14. The bigger part of load is carried by lower geotextile-B as given for geotextile-A.

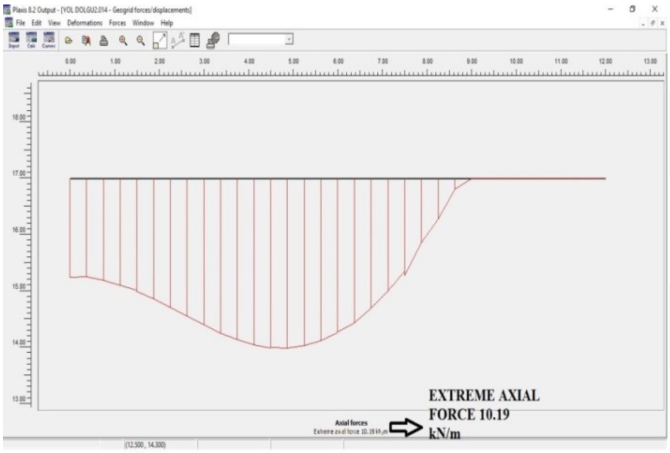

Figure 13. Axial force value of geotextile-B (1st layer)

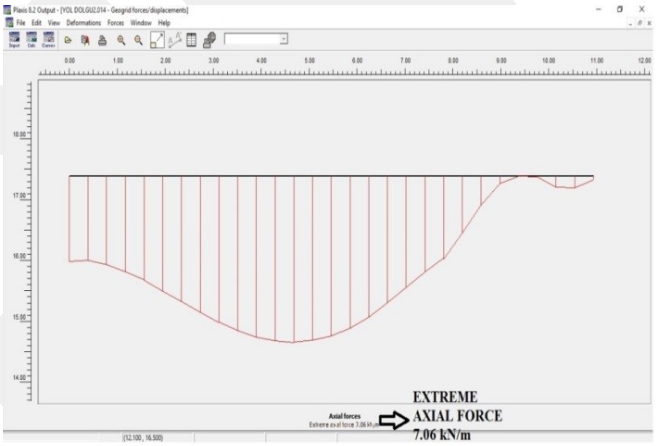

Figure 14. Axial force value of geotextile-B (2nd layer)

The PLAXIS analysis results of the soil model before and after the improvement are presented in Table 2.

Table 2. PLAXIS model analysis results of geotextiles

Type of result / **Improvement**	Extreme total displacement (cm)	Effective stress (kN/m^2)	Extreme axial force (kN/m)	
Without improvement	20.72	-192.11	-	
Geotextile-A (EA)=1250 kN/m	16.65	-196.03	1st layer	7.47
			2nd layer	4.36
Geotextile-B (EA)=2250 kN/m	11.62	-194.75	1st layer	10.19
			2nd layer	7.06

4 CONCLUSION

The present study is designed to be performed the ground improvement performance of geotextile using FEM based software PLAXIS. Obtained results from the study are summarized below;

1) When extreme total displacement values are compared, increasing axial stiffness value (EA) of geotextile has positive effect against settlement values.
2) The higher the EA of geotextile, the higher the ability to resist tensile forces. The EA of geotextile increases the difference between strain in top and bottom of the geotextile layer, therefore larger tensional force is considered for the reinforcement.
3) Minimizing the embankment dimensions provides lower construction cost and it is time saving.
4) Anchoring the ends of geotextiles at the slope and overlapping the layers provide resistance against slope failure.
5) There is no significant relationship between effective stress and EA values.

REFERENCES

Sarsby, Robert W., ed. Geosynthetics in civil engineering. Woodhead Publishing, 2007.

Karagül B. Ç. (2007). Highway embakment stabilization with using geogrid. MSc Thesis, İstanbul Teknik University, İstanbul.

Faizi, K., Armaghani, D. J., Kassim, A., and Lonbani, M. (2013). Evaluation of geotextiles on embankment settlement under seismic Load. Electron. J. Geotech. Eng, 18, pp.439-449.

Siaovashnia, M., Kalantari, F., and Shakiba, A. (2010). Assessment of geotextile reinforced embankment on soft clay soil. In The 1st International Applied Geological Congress, Iran pp. 1779-1784.

Wulandari P.S., Tjandra D., Analysis of Geotextile reinforced road embankment using PLAXIS 2D, 5th International Conference of Euro Asia Civil Engineering Forum (EACEF-5)

Li, G. X., Chen, Y., & Tang, X. (Eds.). (2009). Geosynthetics in Civil and Environmental Engineering: Geosynthetics Asia 2008 Proceedings of the 4th Asian Regional Conference on Geosynthetics in Shanghai, China. Springer Science & Business Media.

Higgins, M., Schoenbohm, L. M., Brocard, G., Kaymakci, N., Gosse, J. C., & Cosca, M. A. (2015). New kinematic and geochronologic evidence for the Quaternary evolution of the Central Anatolian fault zone (CAFZ). Tectonics, 34(10), pp. 2118-2141.

Brinkgreve, R. B. J. (Ed.). (2002). PLAXIS: Finite Element Code for Soil and Rock Analyses: 2D-Version 8:[user's Guide]. Balkema