



Settlement Analysis of Geosynthetics Reinforced Embankments

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ABSTRACT

Geosynthetics have been used in many construction and environmental projects in recent years, and the use of geosynthetic products as an effective element is increasing. These materials, as reinforcement, can solve the problems of building heavy structures and roads on weak soils without the need for excavation or filling, foundation, and sub-foundation operations. In this study, using different number and type of geosynthetic materials with two types of soil profiles in different layers of these soils, settlement of these soil layers are investigated. The road superstructures consist of three layers. Different geosynthetic are modeled with the finite element program, PLAXIS, to examine the modeling results. By application of Geogrids as different layers of the road, the amount of settlement decreases significantly. It can be seen that the most reduction occurs in application of three geogrids in soil profile though the total displacement decreases by increasing the number of geogrids. On the other hand, it can be concluded that application of geotextiles does not affect the settlement regardless of the layer numbers. Moreover, it can be concluded that the order of soil layers does not have any significant effect on the settlement rate.

Introduction

Due to critical problems of soft soils such as low bearing capacity and high settlement, there are different methods of strengthening the soils for soft soils which include mechanical and chemical improvement of soils. These methods generally increase the resistance and load-carrying capacity. This reduces the potential for soil swelling and shrinkage. On the other hand, natural fibers have been used for a long time to overcome the weakness of soils against tensile stress, and today, with the development of various sciences, polymeric materials such as geosynthetics are used. Geogrid and geotextile lead to an increase in their use in ground structures, increase in bearing capacity, and decrease in the volume of ground treatments, rapid application, and compatibility with the natural environment [1]. By increase in the tensile strength of the geotextile reinforcement, the safety factor increases [2]. Since displacement does not have a significant effect on increasing the tensile strength of the geotextile, this parameter has been neglected in determining the optimum tensile strength of the geotextile [3]. Several authors have investigated the effect of geosynthetics on soil layers. Using the case of two layers of geogrids, Bayram concluded that the amount of settlement in the thinner section was reduced by 4.01 mm. Although the filling thickness was decreased by 42.5 cm, it was observed that the amount of settlement

decreased [4]. In another study, use of pavement geogrids of flexible roads and the output results with the PLAXIS 2D program showed the beneficial effects of the axial stiffness of the geogrids in the base layer and the interfacial strength of materials of different thicknesses on the vertical surface deformation. Vertical surface deformation did not decrease much when using a geogrid [5]. Studies on the slope reinforced with geosynthetic material depicted that reinforced slope is safer and gave better settlement and shear stress results [6]. The desired improvement has not been achieved in the single geosynthetic reinforced state under the foundation. A relatively more load-sitting behavior was exhibited in models with multiple reinforcements (N = 2 and 3) [7]. Unlike the properties of geotextiles, environmental factors (the environmental pressure at which the experiments are conducted) can affect test results, especially at normal pressures, the effect of other factors is reduced [8]. Later on, it was shown that Geogrid increases the stability of the road and extends the life of the road and offers economical solutions in terms of cost. On the other hand, the decrease in the filling thickness shortens the construction period [9]. It was shown that undrained shear strength increases when geotextiles are used [10]. Moreover, Geosynthetics prevent the separation of soil layers and provide soil drainage. It provides long and short-term stability in the use of geosynthetics in fill foundations, limits different settlements, and can prevent

slumping [11]. It was also proven that Geogrids, first of all, provide the compression of the foundation layers and then they increase the strength [12]. The use of geogrids applied in the upgrading process has provided economical, fast, stable and useful, and functional solutions [13].

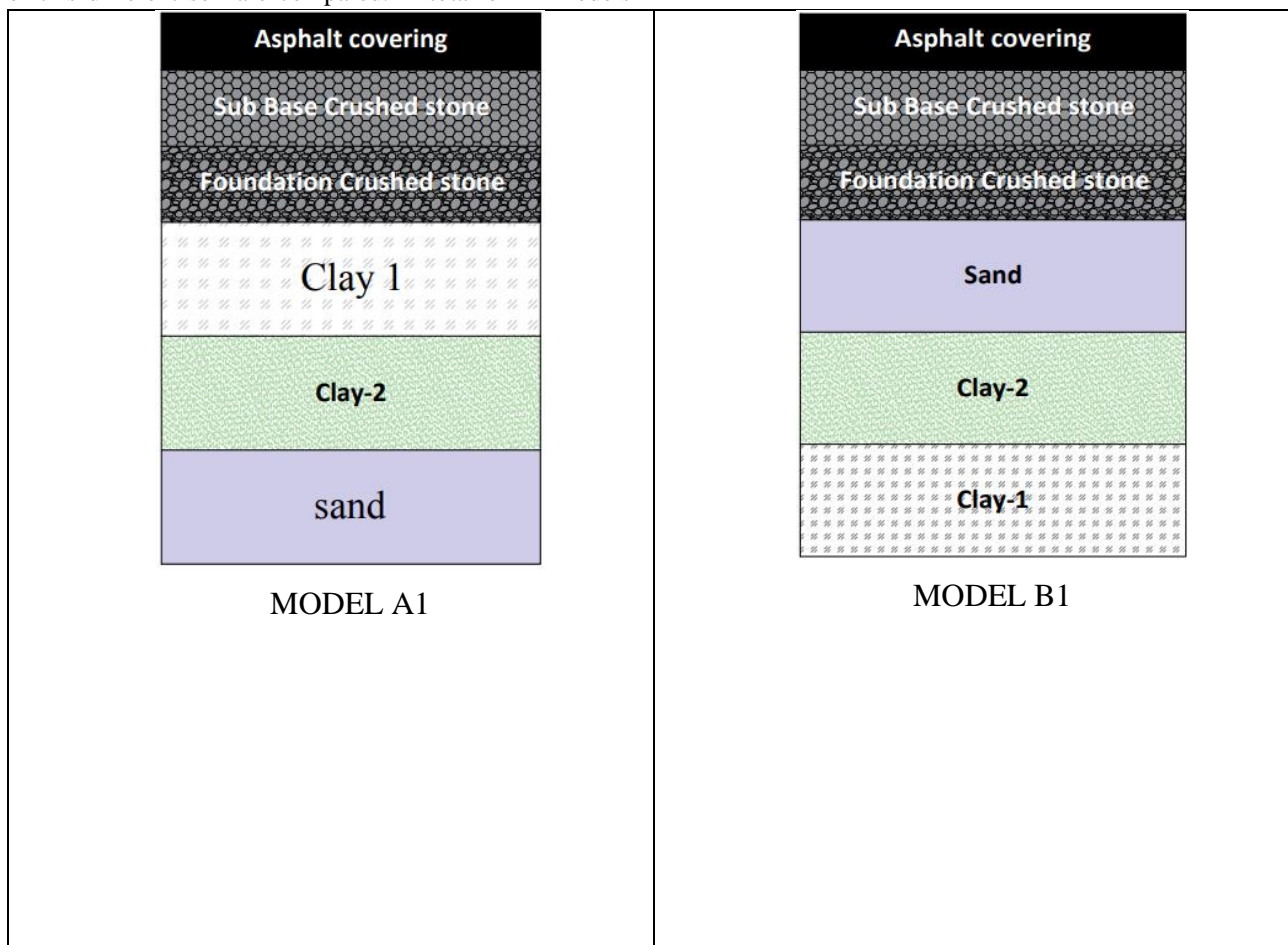
In the above mentioned studies, limited number of layers were investigated. Moreover the effect of soil types and the impact of layer orders in settlement has not been investigated carefully. Furthermore, the impact of the number of the geosynthetic layers on the settlement of soft soils is missing. This study aims to highlight these shortcomings.

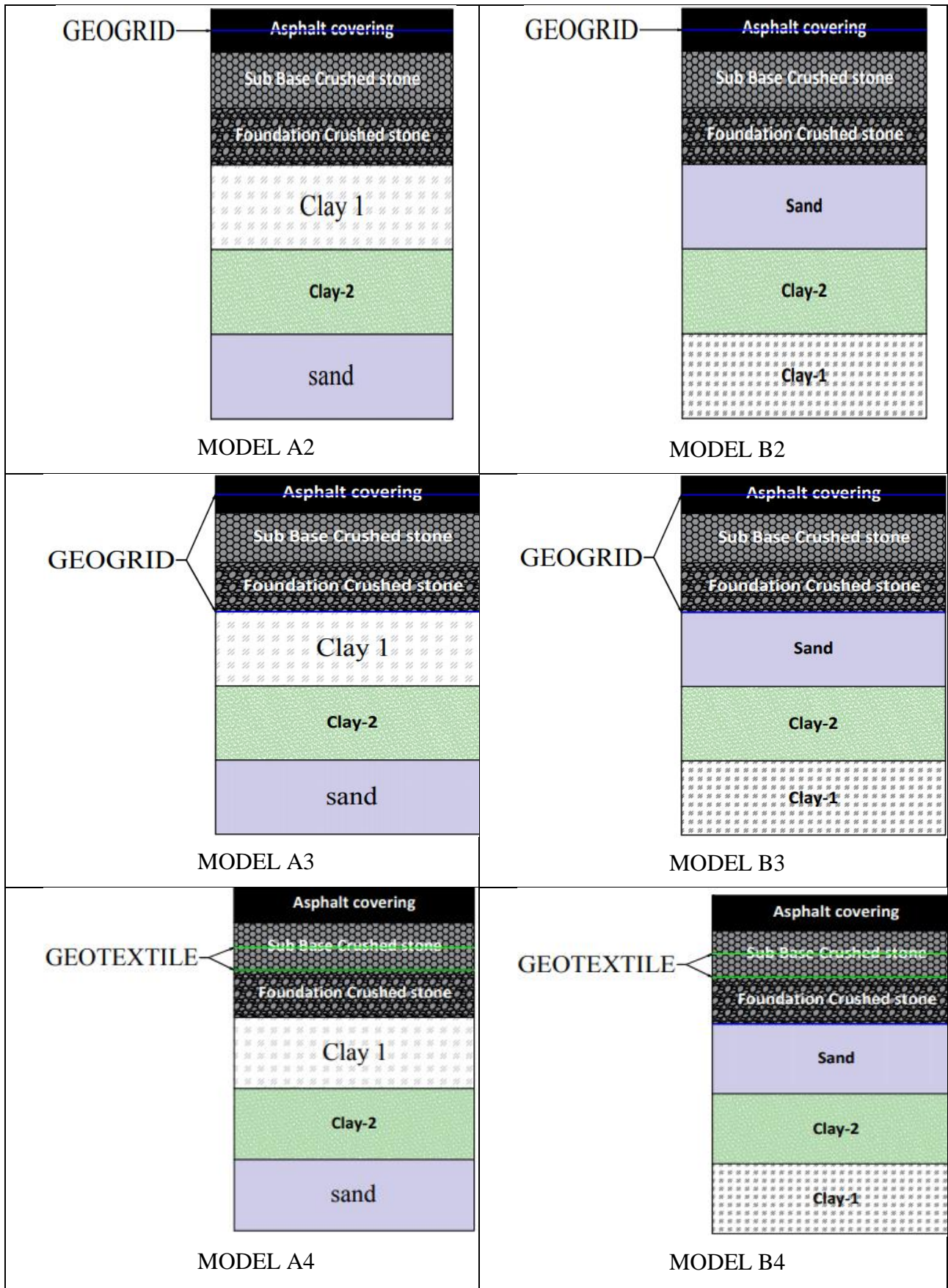
Materials and method

Material models

In this study, different soil profiles and geosynthetic materials have been studied. With a generally uniform cross-section, loading scheme, and a large extent in the z-direction, the plane strain model is suitable for implementation. Normal stresses are fully considered in the z-direction, but displacements and strains are assumed to be zero. A 15-node mesh is considered in this study. The difference between soil profiles depends on how accurately the soil has to be stressed in its mechanical behavior. The design for each model defines the relationship between stress and strain in the material. In the models, different layers with two different soil types are used as asphalt, foundation, sub-base, and ground sub-base. Using different geosynthetic materials as shown in Figure 1, the settlements of this different soil are compared. A total of 14 models

were formed on these two soils and analyzed with the PLAXIS program. The road width is 7.30 and a two lane road with a shoulder width of 1m for each lane has been chosen [14, 15]. Pavement slope (2-3%) and shoulder slope (2-3%) are selected [15]. These models were named as model A1 (with no geosynthetics, two clay liners and one sand), model B1 (no geosynthetics used, sand layer under the foundation), model A2 (single layer geogrid in the middle of asphalt), model B2 (single layer geogrid in the middle of asphalt), model A3 (middle of asphalt, sand and two layers of geogrid used between subbase), model B3 (middle of asphalt, two layers of geogrid between sand and subbase), model A4 (middle of foundation, two layers of geotextile between foundation and subbase), model B4 (middle of foundation, foundation and two layers of geotextiles are used between the sub-base), model A5 (single layer geogrid is used in the middle of the foundation), model B5 (single layer geogrid is used in the middle of the foundation), A6 (mid-asphalt, between asphalt and foundation, between foundation and sub-base, sub-base and Geogrid was used in four layers between clay), B6 (mid-asphalt, between asphalt and foundation, between foundation and sub-base, between subbase and sand), A7 (asphalt and foundation, a Geogrid and geotextile are used in two layers between the foundation and clay in two layers, the middle of the foundation, the two layers between the foundation and the subbase), B7 (between the asphalt and the foundation, the subbase and the sand, two layers of geogrid and the middle of the foundation, two layers of geotextile between the foundation and the subbase are used).





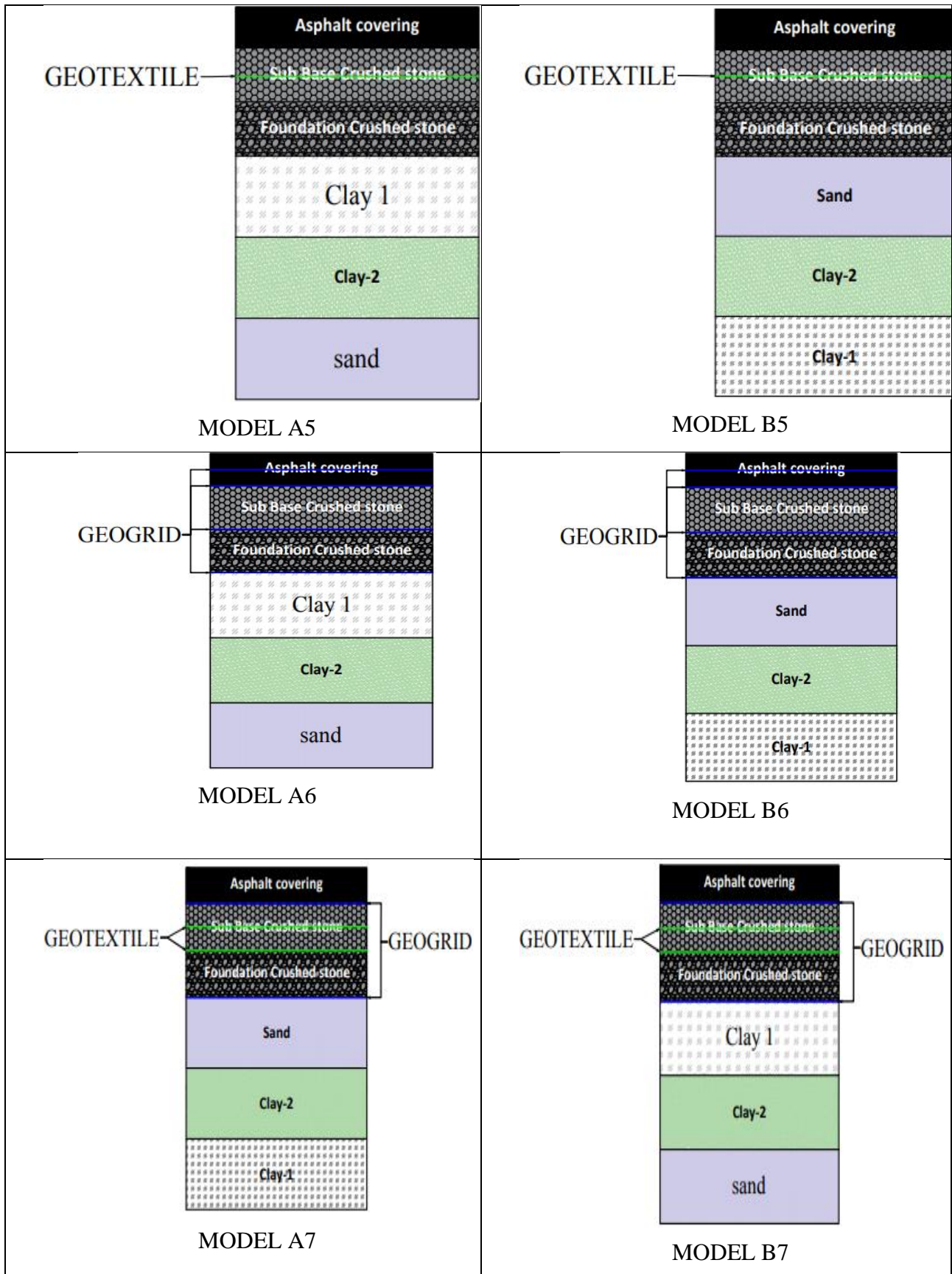


Figure 1. Cross section of two types of soil (A, B)

(Linear isotropic elasticity) model

The Linear Elastic soil model is the simplest stress-strain relationship found in PLAXIS. This model has only two input parameters, Young's modulus, E, and Poisson ratio, ν . Such a model is not suitable for explaining the complex behavior of the soil but is suitable for modeling larger structural members and bedrock layers.

Mohr-Coulomb model

Mohr-Coulomb is an elastic-plastic model containing five input parameters, E and ν for soil elastic, ϕ and c for soil plasticity, and angle. It is recommended to use Mohr-Coulomb for the evaluation of initial deformations. This is because other advanced models need more ground data than

Mohr-Coulomb. Mohr-Coulomb model has been well able to model soil behavior [16] and the full plastic floor behavior is done with this model.

Features of Geosynthetics

Geogrids are thin structures that have normal stiffness but no bending stiffness. Geogrids can only handle tensile forces and do not compress. These objects are often used to model ground reinforcements. Geogrids are modeled using "geogrid" elements that have only one (axial) degree of freedom at each node and cannot handle compression forces. The material and geometric properties used in modeling the geogrid are given in Table 1.

Table 1. Geogrid and geotextile properties

Parameter Name	Symbol	Unit	Value	Reference
Geogrid	EA	kN/m	1×10^5	[17]
Geotextile	EA	kN/m	10×10^5	[5]

Geogrid and Geotextile Layout and Functions in Road Coverings

Geogrid and geotextile are used from geosynthetic materials. These materials are as shown in figure 2 for road pavements [24].

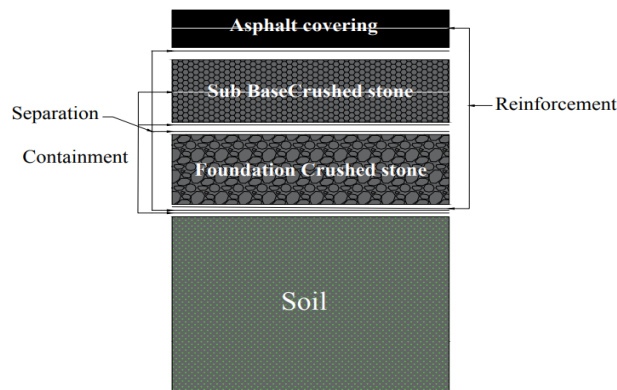


Figure 2. The purpose of the distribution of geosynthetic materials on the road [24]

These are on different soils, different layers of soils with different numbers of different materials were used in Figure 2 and examined with the PLAXIS program.

Loading Areas and Quantity

In the loading section, a vehicle weighing 29000 kg has been selected which corresponds to 6 tire loads. In this study, each tire transfers a load of 246.2 kN/ m² to the ground [18].

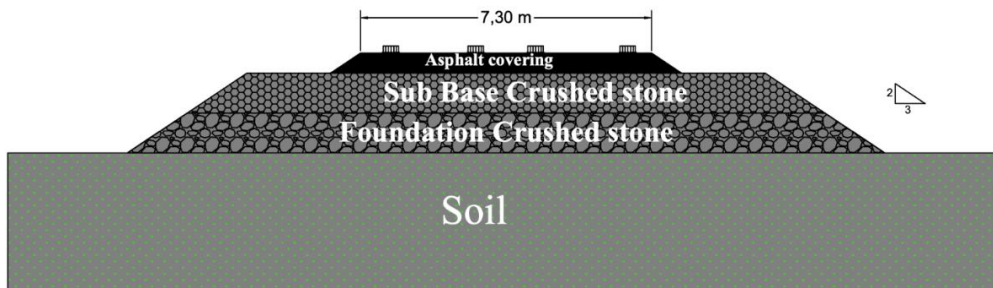


Figure 3. Width of the road, and loading areas

Soil Properties Used in Plaxis

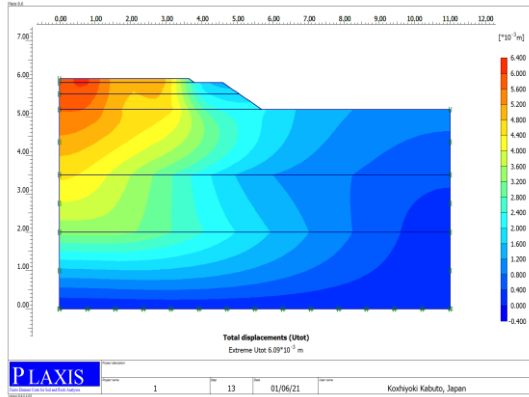
Mohr-coulomb model is accepted as a first order approximation of real soil behavior. This elastic- perfect plastic model requires five basic input parameters: Young's modulus (E), Poisson ratio (ν), cohesion (c), friction angle (ϕ) and dilatation angle (ψ). In table1, all parameters (including ground, sub-base, foundation , and asphalt properties) used in modeling are given.

Table 2. soil, subbase, foundation and asphalt Parameter properties

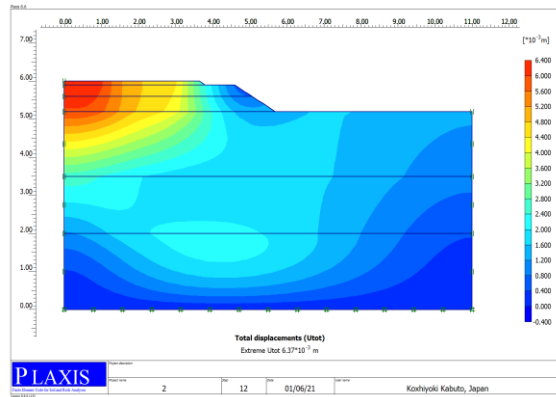
Parameter	Symbol	Asphalt coering	Sub Base Crushed stone	Foundation Crushed stone	Sand	Clay-1	Clay-2
Material model		LE	MC	MC	MC	MC	MC
Behavior type		No drain	Drained	Drained	Drained	No drain	No drain
Dry unit weight [kN/m ³]	γ_{unsat}	23.5	20	22	18	19	20
Wet unit volume weight [kN/m ³]	γ_{sat}	-	22	24	21	20	22
Permeability in X direction [m/day]	k_x	-	1.000	1.000	5×10^{-3}	0	0
Permeability in Y direction [m/day]	k_y	-	1.000	1.000	5×10^{-3}	0	0
Young's modulus [kN/m ²]	E_{50}	120×10^5	100×10^3	120×10^3	25000	1.4×10^4	7.5×10^4
Poisson ratio [-]	ν	0.3	0.35	0.35	0.35	0.2	0.2
Cohesion [kN/m ²]	C	-	30	20	0.025	10	20
Angle of internal friction [°]	ϕ	-	43	44	40	25	25
Angle of Dilatation [°]	Ψ	-	13	14	10	0	0
Reference	-	[22]	[19]	[20]	[23]	[21]	[21]

Discussion and conclusions

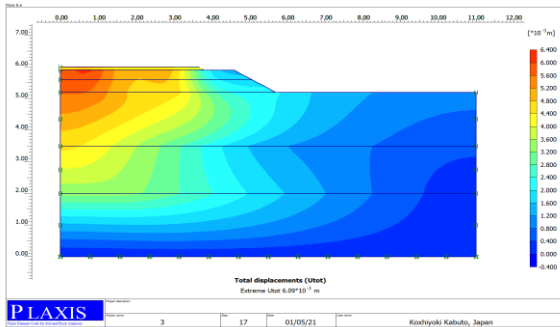
In this study, the beneficial effects of using different layered geosynthetics are investigated. Modeling was analyzed with the PLAXIS program used in the study. The output results show the beneficial effects of the axial stiffness of geosynthetics in the base layer and the interface strength of materials with a different base layer thickness on settlement, as it is shown in the figures.



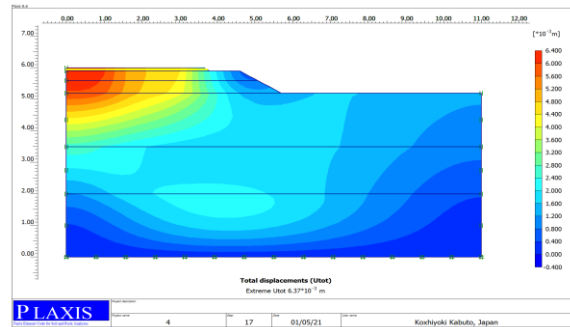
Model A1



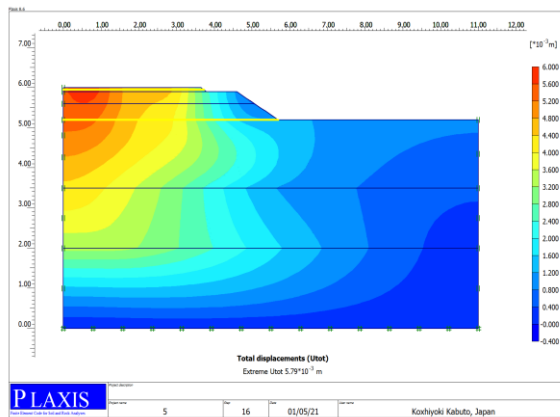
Model B1



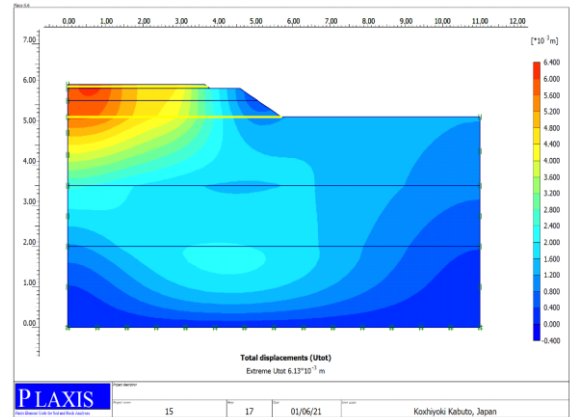
Model A2



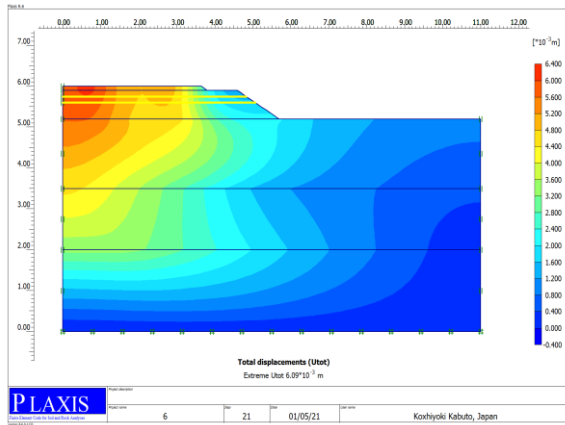
Model B2



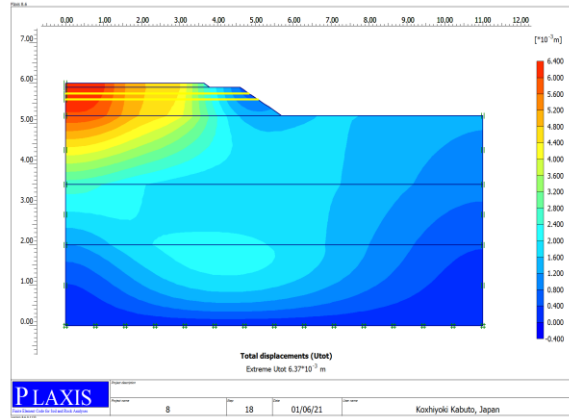
Model A3



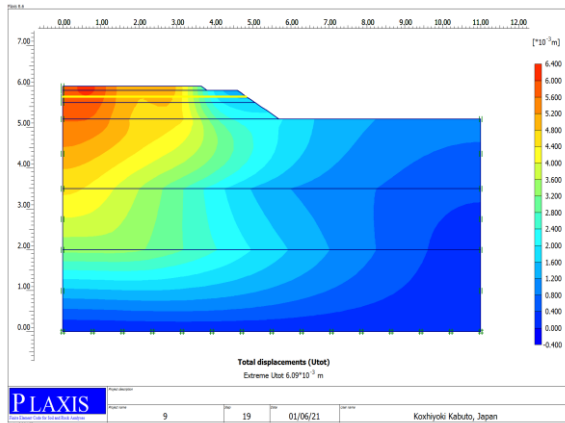
Model B3



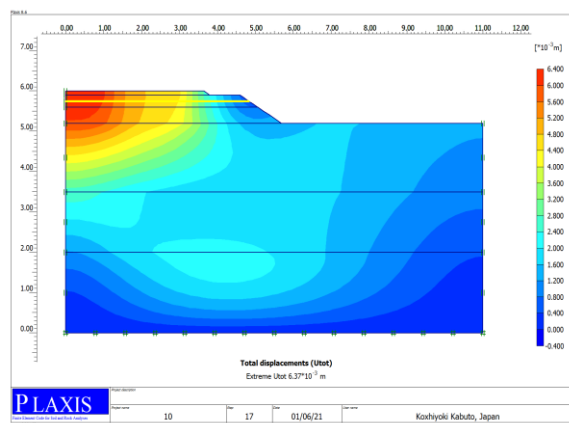
Model A4



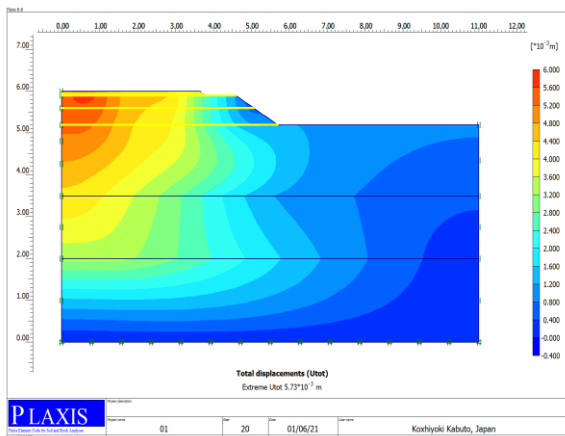
Model B4



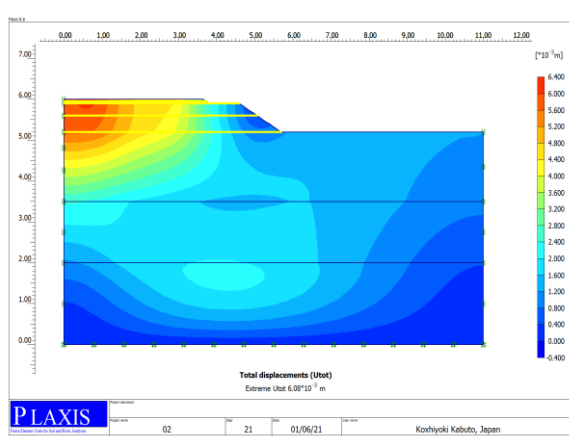
Model A5



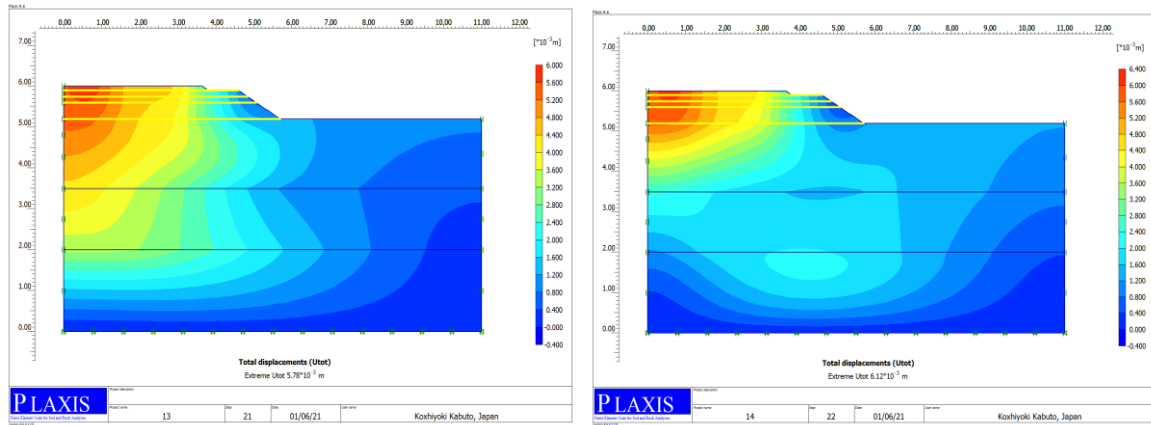
Model B5



Model A6



Model B6



Model A7

Model B7

Figure 4. Results of sitting in PLAXIS

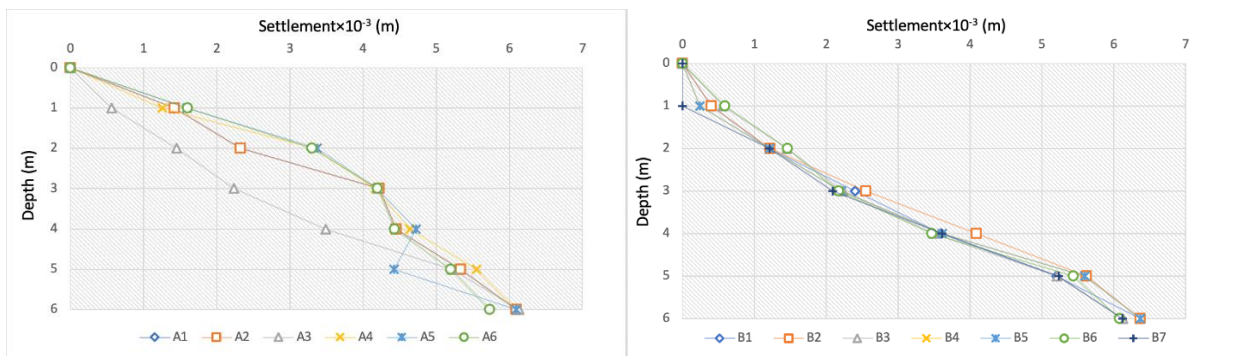


Figure 5. Settlement of different profiles with respect to depth

Results were determined for various parameters different for each model. These models are modeled without geogrid, using one or more layer geogrid, one or more layer geotextiles and these two products together in different layers. The two tires applied in these models transfer the a load of each tire to 246.2 kN/m² of force. The model (A1) and model (B1) are shown in Figure 4 (A1, B1), which shows the total settlement results obtained without using geosynthetic materials. The settlement amount for model A1 is 6.09×10⁻³m and for model 2 the total displacement is 6.37×10⁻³ m. By comparison of these two models, it can be revealed that the order of sand clay liners have insignificant effect on the settlement of the embankment. Model (A2) and model (B2) are formed applying a single layer geogrid depicted in Figure 4. This means that two tires applied in the same models transfer the load of each tire 246.2 kN /m². In Figure 4, the seating amount for model A2 is 6.09×10⁻³m and for model B2 the total seating is 6.37×10⁻³m. Comparison of A1.B1 with A2 and B2 shows that in case of using a single layer of geogrid, the settlement does not change. In model (A3) and (B3) models, the amount of double layer geogrid settlement is formed as in Figure 4. In this way, the settlement amount appears to be a descent. In Figure 4, the settlement amount is calculated as 5.79×10⁻³ m for model A3 and 6.13×10⁻³ m for model B3. It can be concluded that if the two upper layers are clay, double layer is more effective than the sand as the upper layer. Model (A4) and (B4), double layer geotextile settlement amount was formed as in Figure 4. The amount of seating is calculated as 6.09×10⁻³ m for model A4 and 6.37×10⁻³ m for

model B4 which does not have any effect with regard to the original case (A1 and B1). In (A5) and (B5) models, the total displacement for single layer geotextile is formed as in Figure 4. The settlement amount for model A5 was calculated to be 6.09×10⁻³m and model B5 to 6.37×10⁻³ m. In (A6) and (B6) models, the amount of settlement in the four-layer geogrid situation was formed as in Figure 2. The settlement amount for Model A6 is 5.73×10⁻³m and for model (B6) the total displacement is calculated as 6.08×10⁻³ m. It is clear that increase in the number of geogrids has a effective impact in reduction of settlement though the rate of reduction decreases in application f four geogrid layers. For models (A7) and (B7), the total displacement for two-layer geogrid and two-layer geotextile is 5.78×10⁻³ m and for model (B7) the total displacement is 6.12×10⁻³ m.

Figure 5 (a) and (b) compares and summarizes the settlement rate at different layers of the soil at point x=0 using geogrids and geotextiles.

Modeling results

Considering the applied analysis, finite element software – PLAXIS- is capable of modeling the infrastructure of the paths appropriately. Analysis were performed using plane strain model. In plane strain, the strains out of plane (z-direction) are assumed as zero, therefore the depth of the model is set as zero. In these models, geosynthetics (geogrid and geotextile) are applied in different depths, different layers and different geosynthetic numbers according to the placement. Geosynthetic materials have been given a

suitable solution to strengthen the sub-base and foundation in clay and sandy soils. The results obtained when using geosynthetic material in the foundation and subbases of the roads are presented as follows:

At the moment of the load transferred by the two tires of the vehicle, the first layer of clay soil was found to have less settlement than the first layer of sandy layer.

After application of geosynthetics in different layers of the road, the safety count decreased significantly, M_{sf} decreased. There is no effect on the use of single layer geotextiles and geogrids in models.

In the use of two-layer geogrid in models, the total displacement shows a decrease of 4.926% compared to the use of no geosynthetics. Application of geosynthetics seems to have no effect on the settlement reduction in all the cases.

Application of four-layer geogrid decreases the settlement, though the rate of reduction is not as severe as the case of 3 geogrids decrease. It can be concluded that the formation and order of layers with different soil types (clay and sand) does not have any significant effect on the settlement rate.

Ethics committee approval and conflict of interest statement

There is no need to obtain permission from the ethics committee for the article prepared

There is no conflict of interest with any person / institution in the article prepared

Authors' Contributions

Mohammad Salem NOORI : Analysis, and interpretation of data, drafting of manuscript

Kaveh DEGHANIAN: Conceived the original idea, supervised the project, critical revision

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