Journal of Structural Engineering and Geotechnics,

6 (1), 15-22, Winter 2016

Comparison of Geotextile Layers Effects on Static and Dynamic behavior of Pavement

Reza Nazari[a], Rouzbeh Dabiri[*b]

[a]*Department of Geotechnical Engineering, Maraghe Branch, Islamic Azad University, Maraghe, Iran.*
[b] *Department of Civil Engineering, Tabriz Branch, Islamic Azad University, Tabriz, Iran.*

Received 5 December 2015; Accepted 20 March 2016

Abstract

One of the methods for the improvement of soil against the tensile stresses is using the artificial supplements in soil such as metal belts or nets, polymer materials and natural fibers. Technically this method is called the reinforced of soil. When a pavement is located on soft soil, great deformations can occur as a result of the crossing of traffic load in superstructure layers of the body. This can finally lead to the increase in the cost of maintenance and traffic pause in transportation. The main purpose of this study is to explore the effect of geotextile layers place in various depths of the body of pavement layers located on soft soil. For this purpose, models with the identical geometry from the transection of road using Finite Element Method software, PLAXIS were analyzed in two dimensions in which the location and the number of geotextile layers were considered in various depths. In continue, these models have been under static and dynamic loadings due to vehicles and the settlement rate and the lateral deformation of pavement in section has been evaluated. The results show that in static loading, the maximum safety factor of stability is that of layers in which the geotextile exists in the partition between subgrade and embankment layers. Also, between dynamic loading and increasing number of geotextile layers favorable result is not achieved. Although more studies need to be carried out in this area.

Keywords: Static Loading; Dynamic Loading; Pavement Design; Geotextile; Soil Improvement; Traffic.

1. Introduction

From past until now, the weakness of soil against tension stresses, has constrained the researchers to think about using physical or chemical supplements to solve for this weakness. Today this method is applied with more advanced methods and more resistant materials such as metal belts and meshes, polymer materials and natural fibers, and technically is called soil reinforcement. From 1970 until now, geosynthetics have been utilized for the purpose of stabilizing the soil improvement and reinforcing the base layer in pavement design. These materials are placed at the interface of the subgrade and base layer, or inside the base layer in order to improve the operational of road in bearing the definite traffic loads. Such a operational improvement includes the increase in the volume of traffic loads for the base layer with similar thicknesses, or decrease in the thickness of the required base layer for the purpose of bearing the fixed traffic loads volume or a combination of both the increase in transported traffic volume and decrease in thickness. When a path without superstructure is situated on a soft subgrade, great deformations occur as a result of traffic loading of vehicles. Most of the application of geotextile is due to its separation and stabilization in road

Construction. Using them in road construction leads to the development of simultaneous advantages of the four major operations of geotextile including filtration, drainage, reinforcement, and separation. When the materials of base layer and the soil under the base mix together, their effective thickness decreases; therefore, the capacity of bearing decreases. Therefore, using geotextile layers in road decreases the thickness of the required layer in pavement design and increase the bearing capacity. The main purpose of this study is to explore the effect of geotextile layers place in various depths of the body of pavement layers located on soft soil. In cotinue, it will be described.

2. Literature Review

Many researchers have studied the effect of using geosynthetics in the pavement design and increase in the bearing capacity of reinforced soil. Barenbuerg et al. [1] showed that using geosynthetics can severely decrease failure potential in soil and prevent the puncture and pit in sub base resulting from the load of wheels. According to the studies carried out on the main roads of Washington

*Corresponding Author Email: rouzbeh_dabiri@iaut.ac.ir

D.C., Christofer and Holts [2] examined the operation of the separation of geosynthetics surrounded in silty sand between the base and sub base of the road and consequently could increase the California Bearing Ratio (CBR) from below 3 to 4.4. Yamanouchi [3] reported that using geotextile causes the stress to spread throughout soil and increase bearing capacity. This influence is significant. Roa et al. [4], Shetty [5],Charan and Gopal Ranjan [6] and Canceli et al. [7] described the results of the experiment series (laboratory tests) (saturated and unsaturated CBR) on silty sand reinforced with polypropylene textiles random distributed. The results of experiments showed that the CBR quantity of soil increased significantly by the increase in the amount of polymer fibers. The amounts of CBR increase in saturated and unsaturated soil by 3% increase in the amount of fibers (weight of fibers) were 175% and 125% respectively. Benson and Khire [8] proved that when the disposable wastes were used for reinforcement, CBR and scant modulus of sand increase. Cancelli et al. [8], Benson and Khire [9] analyzed the results of full-scale experiments on cobblestones reinforced with various cross sections of geogrids in saturated silted clay having the CBR quantity of about 1% to 8%. The results of the experiment showed that the layers which were accompanied by geogrids layer produce the best results of base reinforcement for sub-base soil having CBR ≤ 3%. Montanelli et al. [9] by placing geogrids between gravel base layer and sand sub base layer showed that the amount of vertical sinking under loading decreases by the increase in the amount CBR of sub base. Fanin and Sigurdsson [10] , Holtz and Black [11], Al-Qadi and Chair [12] in large-scale researches by doing a series of large-scale experiments concluded that by using unwoven small cashmere geotextiles, the minimum groove depth is created and these materials separate subgrade layer and sub layer well. Giroud and Noiray [13] concluded that the bearing capacity of superstructure soft bed in non-reinforced stat is q= $(\boldsymbol{\pi})$ cu and in reinforced state is equal to maximum bearing capacity, i.e. q_p= $(\boldsymbol{\pi}+\mathbf{2})$ cu. cu is the shear resistance of clay without drainage. Giroud and Noiray by defining the ratio of bearing capacity in the form of maximum bearing in reinforced state to non-reinforced state suggested the increase in bearing equal to 1.6. Also similar studies have been performed by Steward et al. [14] , Miligan et al. [15]. In these methods the increase in the bearing quantity in reinforced state to non-reinforced state has been suggested as 1.7, 1.8 and 2 respectively. In this study in addition to surveying the stress-strain function of geotextiles, a series of improved CBR experiments are conducted on the reinforced and non-reinforced superstructure and the obtained results are compared. Among the domestics works carried out are the works by Makarchian and Eliasi [16] which have examined the influence of unwoven small cashmere geotextiles on the bearing of super structured road upon soft clay layer and under sand layer using PLAXIS software. Also Khodadadi and Fakhri [17] have conducted laboratory experiments about the function of geotextile and geogrids in the increase of the fatigue life of asphalt concrete pavements. Hajek etal. [18] and Moayedi et al. [19] evaluated effects of geogrid layers locations in paved road Improvement. They observed tension stress absorption increases with shifting the geogrid towards the top of the pavement and attains the highest values when the geogrid is placed between asphalt layer and base layer in model.

3. Finite Element Analysis

In this study, for evaluating the geotextile layer effects in bearing capacity of pavement body under statically and dynamic loading due to traffics, based on Iran Code 234, cross section models observed in figure (1). The properties of materials in the layers of road section used in PLAXIS software model is observed on table 1 and geotextile layer properties is observed in Table 2. In a way that in each model the depth of the placement of geotextile layer has been considered differently. For modeling the geotextile model was considered as a 5 nodes linear part with the axial hardness of 10000 kN/m and with the interaction factor between geotextile and the environs soil in intersection elements were used 0.6 for expressing the interaction.

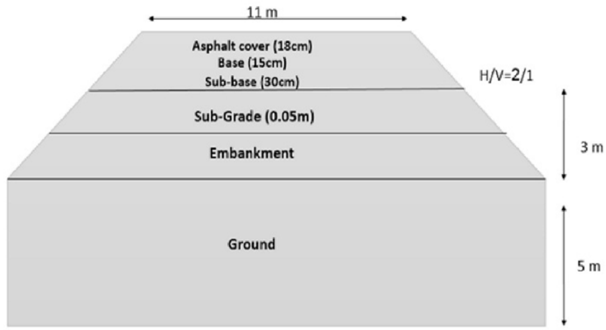

Figure 1. The section of road pavement in this study [20]

Table 1. Properties of materials in pavement layer [20]

parameters	C (kPa)	φ (Degree)	γ_d (kN/m3)	γ_{st} (kN/m3)	E (kPa)	ν
Ground (CL)	10	22	16	18	12500	0.35
Embankment (CL)	15	32	18	20	105000	0.3
Subgrade (SW-SC)	12	34	18	20	115000	0.3
Sub-base (SW-SC)	5	36	19	20	125000	0.3
Base (GW-GC)	5	40	19	20	160000	0.3
Cover (Asphalt)	-	-	23	-	2.5e7	0.15

Table 2. Properties of geotextile layer [20]

Properties	Values
Weight (g/m^2)	163
Thickness (mm)	0.9
Static puncture (CBR-test) N	2200
Dynamic cone drop (mm)	28
Tensile strength(kN/m)	15
Elongation at peak stress (%)	45-55

The Mohr-Coulomb model behavior was used for modeling of the soil materials in pavement layer at PLAXIS program and for asphalt layer elastic liner behavior assumed. Based on hand book of program for the simulation of behavior of geotextile layer in models, geogrids element with linear elastic behavior was used. Also, for incorporate the interaction of geotextile layer and soil. Interface element was used. Due to the symmetry of the model geometry, half of the cross section has been modeled according to figure (2). It should be noted that analyses in models performed in plain strain.

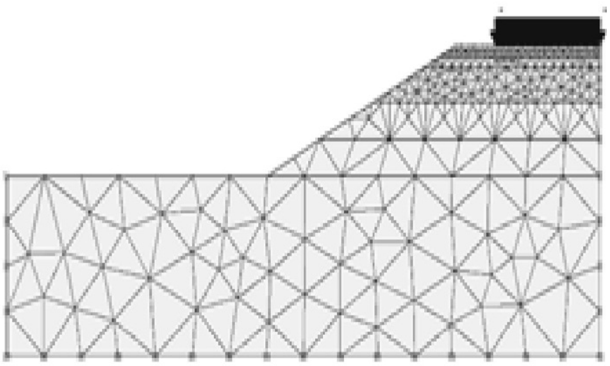

Figure 2. Finite element model of road pavement section in this study.

For static loading of model 30 kPa uniform load has been used for the purpose of maximum load resulting from vehicles which is according to the by-code 234 [21] of the periodical of Program and Budget Organization of Iran. According to the conducted studies the dynamic load of vehicles is 50 to 80 percent greater than static load. Therefore, road traffic creates vibratory force with the base frequency of 50 to 200 Hz (regarding the vehicle type). The Dynamic load has been considered in the form of a harmonic sinusoidal function with the base frequency of 100 Hz and 50 kPa in this study. Table 3 illustrates the models used in this section.

Table 3. Spesifications of models in this Study

Model	Place of Geotextile	Number of Geotextile layers	Base Frequency (Hz)	Loading Amplitude (kN/m)
1	No Geotextile	1	100	50
2	Under Cover	1	100	50
3	Between Base	1	100	50
4	Base-SubBase	1	100	50
5	Between SubBase	1	100	50
6	SubBase-SubGared	1	100	50
7	Between Subgrade	1	100	50
8	Subgrade-Embankment	1	100	50
9	Between Embankment	1	100	50
10	Embakment-Ground	1	100	50
11	Model 8 & 10	2	100	50
12	Model 6 & 10	2	100	50
13	Model 4 & 10	2	100	50
14	Model 7 & 8 & 10	3	100	50

3. Results and Discussion

3.1. The effect of geotextile layer position

Based on Table 3, static loading performed on models. The first model is non-reinforced and 6 positions have been considered for geotextile layer in pavement body. Lateral and vertical deformation evaluated in analyses. Figure 3 shows the percent level of the decrease in the lateral deformation of each model compared to the model which has the maximum lateral deformation among all models, so that the model with zero percent changes represents the model with maximum (critical) lateral deformation. According figure 3, it can be seen that models 1, 2 and 3 have the maximum lateral deformation. In the other words, the position of geotextile layer between the bottom of asphalt and the middle of base layer no effect to reducing lateral deformation. In contrast, the position of geotextile within the embankment layer leads to the decrease in the maximum lateral deformation up to about 4%.

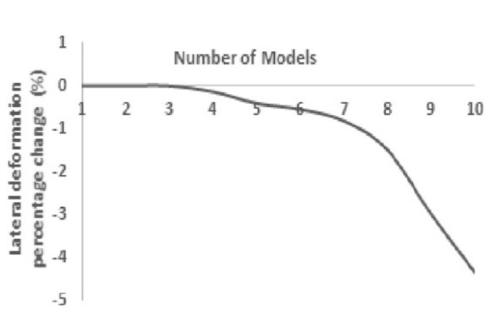

Figure 3. The maximum lateral deformation percent change the studied models.

Also, figure 4 shows the changes in the percent of decrease in vertical deformation of each model can be observed compared to the model having the maximum vertical deformation among all models. Therefore, the model with the change of zero percent represents the model with maximum (critical) vertical deformation. It can be found that models no.1 and no.2 have the greatest vertical deformations. In the other words that the position of geotextile layer between asphalt and base layer no effect to decrease vertical deformation. Although, the position of geotextile within embankment and subgarde decreases the maximum vertical deformation approximately up to 7%.

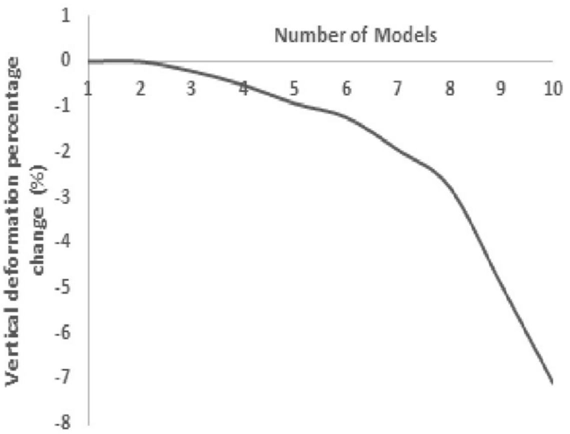

Figure 4. The maximum vertical deformation percentage change the studied models.

Figure 5 shows the increase percentage of safety factor of stability of each model compared to model having the minimum safety factor of stability among all models, so that the model with changes of zero percent represents the model with minimum safety factor of stability. Of course it should be mentioned that the safety factor of stability of all models is higher than the extent required (safety factor of one). According to the figure 5, the maximum safety factor stability relates to models in which geotextile layer is located within the subgrade layer and embankment and the maximum stability relates to the position of geotextile layer at the bottom of embankment which not only increases the safety factor but also decreases vertical and lateral deformations.

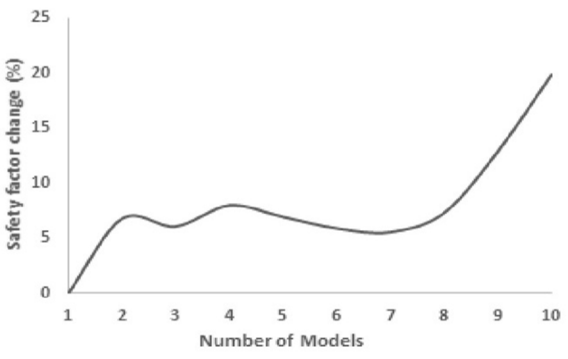

Figure 5. Percentage change in safety factors in the studied models.

In continue, at dynamic analysis the variations of maximum vertical settlement and lateral deformation of pavement design under the dynamic loading and the safety factor of stability of road body were evaluated. The dynamic loading on the asphalt layer was applied harmonic with the frequency of 100 Hz and maximum domain of 50 kN/m at the period of 0.1 of second. Load was performed vertically in central part of pavement cover. Figure 6 shows geotextile layer effects on vertical settlement in all of models. Diagrams observe that with increasing time effect of harmonic loading, vertical settlements in models show rising trend. Also, within the period of 0.02 second vertical settlement is almost the same in all diagrams but with continuing time loading the difference among curves increases. Model no.10 has minimum settlement than other models.

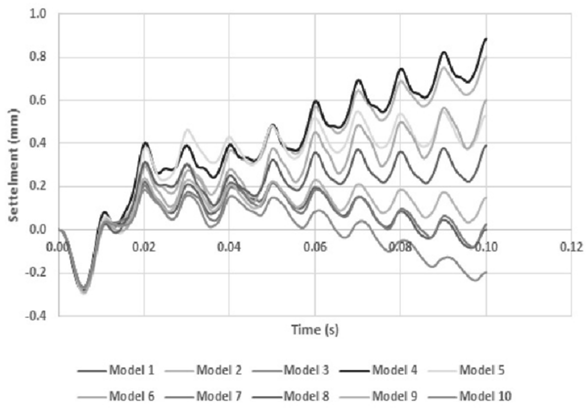

Figure 6. Effects of Geotextile layers position on vertical settlement in all of models at time loading

Figure 7 shows the changes percentage of the maximum vertical settlements history of each model in comparison to the maximum vertical settlement of non-reinforced model (model no.1). Based on results, all models except model 5 have led to the decrease in the maximum vertical settlement compared to non-reinforced model. Nonetheless, the maximum changes are related to models no.10 and no.8 including 8.99% and 8.22% decrease in vertical settlement respectively.

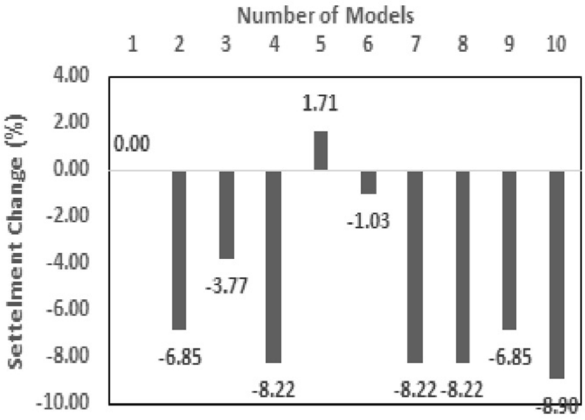

Figure 7. Percentage variations of maximum vertical settlements in all of models

As can be seen in Figure 8, the changes percentage of lateral deformation has increased which demonstrates the influence of geotextile layer in the decrease of lateral deformation. The placement of geotextile layer in model 5 has led to the increase in lateral deformation but in other models the maximum value decrease is related to models no.10 and no.8 with respectively 15.82% and 15.31%. It is mentioned that in this diagram variations percentage of maximum lateral deformation of models in comparison to non-reinforced model (model no.1).

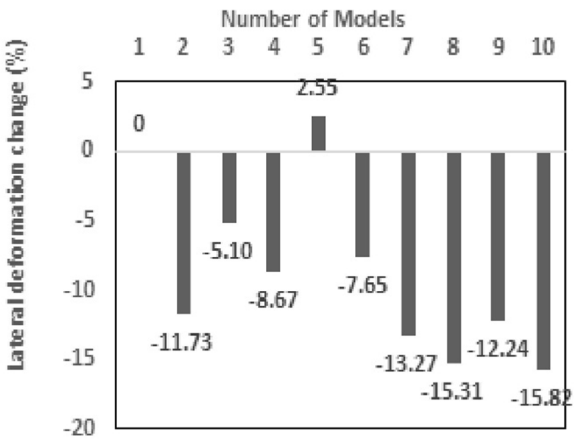

Figure 8. Percentage variations of maximum lateral deformations in all of models

Figure 9 shows the changes percentage of safety factor in comparison to model no.1 (non-reinforced model). The use of geotextile layer in all models results in the increase of safety factor of stability, so that the maximum increase relates to models 10 and 8 with respectively 38.96% and 29.44% increase in the safety factor compared to non-reinforced model.

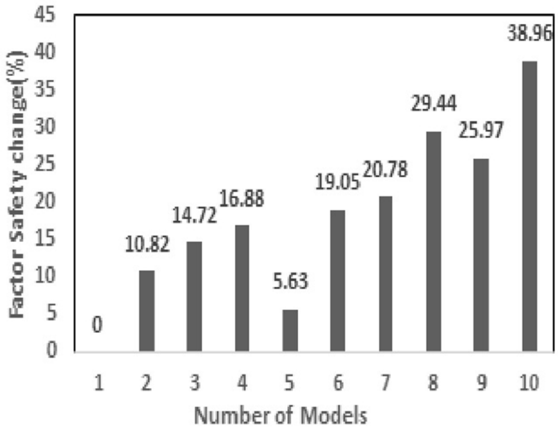

Figure 9. Percentage variations of safety factor in all of models

3.2. The effect of geotextile layer number

In this section of study, effect of 2 and 3 geotextile layers in cross section of pavement body assessed. The characteristics of models include no.11, 12, 13 and 14 which is illustrated in table 2. The amount of lateral deformation and vertical settlement of pavement cover in static and dynamic loading has been evaluated. Table 4 shows the maximum lateral deformation, vertical settlements and the safety factor of stability in each model under static loading.

Table 4. Results of analyses models under static loading

Model	Placement of Geotextile	Maximum Lateral Deformation (mm)	Maximum settlement (mm)	FS
10	Embakment-Ground	7.05	9.04	3.44
11	Model 8 & 10	6.99	8.90	3.22
12	Model 6 & 10	7.05	9.03	3.40
13	Model 4 & 10	7.06	9.08	3.23
14	Model 7 & 8 & 10	6.96	8.81	3.23

As can be seen in Table 4, minimum values of lateral deformation and vertical settlement are happen in model no.14. Figure 10 and figure 11 respectively show variations of percentage of the lateral deformation of models no.10 to no.14 in comparison to the non-reinforced model (model no.1) and the changes in percentage of vertical sinking of models no.10 to no.14 in comparison to non-reinforced model (model no.1).

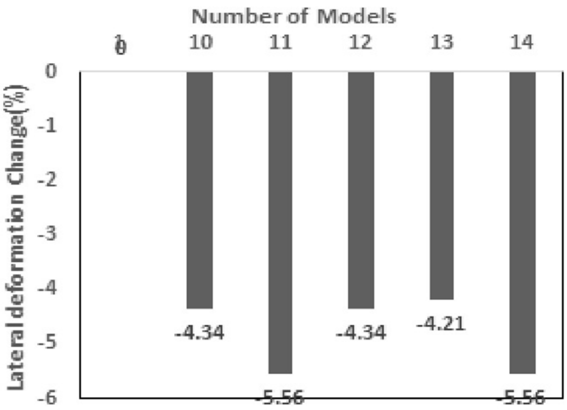

Figure 10. Percentage variations of maximum lateral deformations in all of models

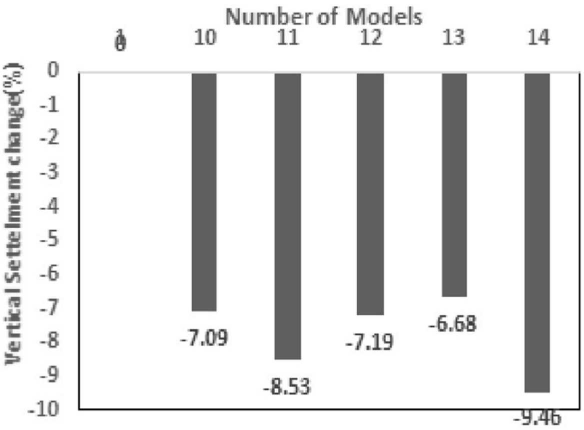

Figure 11. Percentage variations of maximum vertical settlements in all of models

It can be observed in figures mentioned above, in static loading, with increase in the number of layers influences the placement of geotextile layers in models no.11 and no.14 more and causes 5.56% decrease in lateral deformation. Also 8.53% and 9.46% in vertical settlement respectively. Therefore, with regard to economic advantage, model no.11 can be selected as the effective model in the arrangement of geotextile layers under static loading. In continue, for evaluating number of geotextile layer effects on lateral deformation and vertical displacement of pavement body under dynamic loading, Similar to the previous section, according to the diagram below, with the increase in applied harmonic load, the vertical settlement differences in all models increase, so that all diagrams is almost the same within the period of 0.02 second. Although, at later times the difference among curves increases.

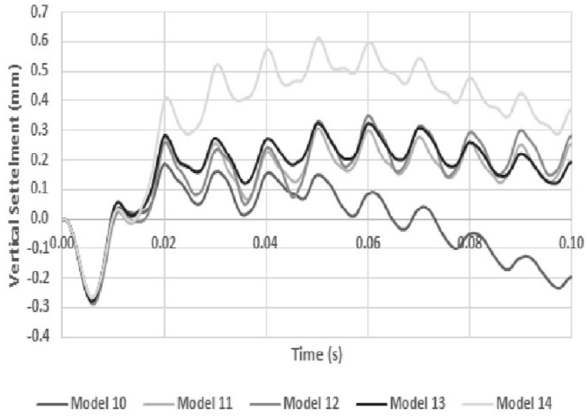

Figure 12. Effects of geotextile layers number on vertical settlement in all of models at time loading

The percentage the changes of maximum vertical settlement of each model in comparison to the maximum of the same parameter in non-reinforced model (model no.1) have been plotted in figure 13. As can be seen that the highest percentages of vertical settlement in the diagram related to the history of models no.11 and no.14 are about 9.25% and 8.90%.

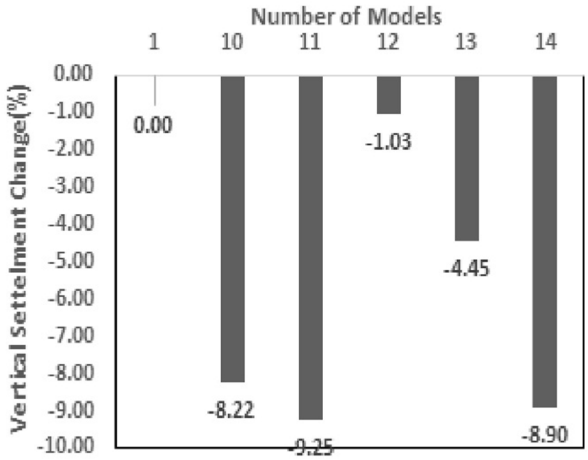

Figure 13. Percentage variations of maximum vertical settlements in all of models under dynamic loading

The percentage variations of the maximum lateral deformations in comparison to non-reinforced model (model no.1) have been plotted in figure 14. According to this figure, the highest percentage of the increase in lateral deformation relates to models no.14 and no.11 by 17.35% and 15.82% respectively.

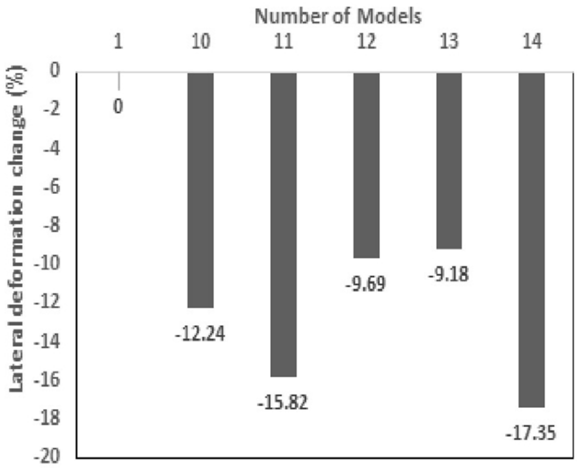

Figure 14. Percentage variations of maximum lateral deformations in all of models under dynamic loading

In continue, the percentage changes of safety factor compared to model no.1 (non-reinforced model) in figure 15. The use of geotextile layer in all models results in the increase of safety factor stability, so that the maximum increase relates to model no.11 equal to 50.65% compared to non-reinforced model.

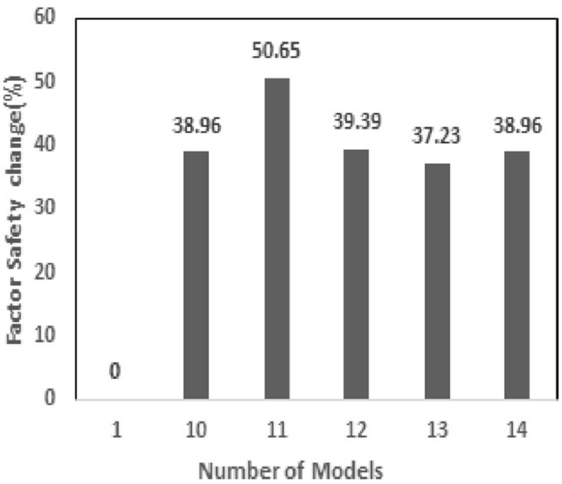

Figure 15. Percentage variations of safety factor in all of models under dynamic loading

It can be concluded that by the increase of the number of layers in general, the favorite result will not be obtained, so that model no.11 with 2 geotextile layers has more decrease in the changes of vertical settlements and safety factor in comparison to model no.14. Therefore, the position of geotextile layers under embankment and under subgrade has better technical and economic justification.

4. Discussion and Conclusion

According to the results obtained of the analyses can be expressed as follows:

1- In static loading, models no.1, no.2 and no.3 have maximum lateral deformation, which means that the placement of geotextile layer within the bottom of asphalt layer to the midpoint of base layer leads to no change in the decrease of lateral deformation. But the placement of geotextile within embankment layer results in the decrease of lateral deformation approximately up to 4% compared to non-reinforced model. Also, models no.1 and no.2 have the maximum vertical displacement. It means that the placement of geotextile layer within the bottom of asphalt to base layer doesn't lead to any change in the decrease of vertical displacement. But the placement of geotextile within the distance of subgrade layer and embankment results in the decrease of the vertical displacement approximately up to 7% than to non-reinforced model.
2- In dynamic loading, the maximum changes percentage vertical displacement relates to models 10 and 8 including respectively 8.99% and 8.22% decrease in it than to non-reinforced model. In these models geotextile layer is within the embankment.
3- In dynamic analysis of one layered models, maximum decrease in vertical displacement relates to models no.10 and no.8 with respectively 15.82% and 15.31% decrease compared to non-reinforced model. In these models geotextile model is within the scope of embankment. Also maximum decrease percentage of lateral deformation relates to models 14 and 11 by 17.35% and 15.82% respectively and the use of geotextile layer in all models leads to the increase in the safety factor of stability, so that maximum increase relates to models 11 equal to 50.65% compared to non-reinforced model.
4-In dynamic time history loading, the maximum decrease percentage of vertical displacement relates to models no.11 and no.14 about 9.25% and 8.90% respectively.
Therefore, the results analyzes show that in static loading state, maximum safety factor of stability relates to models in which geotextile layer is placed within the distance of subgrade layer and embankment, so that vertical displacement and lateral deformation decrease. Also, with increasing in the number of layers is more effective than to the arrangement of geotextile layers and results indicate that to decrease of 5.56% in lateral deformation, 8.53% and 9.46% in vertical displacement. So, with considering the economic advantage, model no.11 can be selected as the effective model in the arrangement of geotextile layers. In dynamic loading condition, with increase in the number of geotextile model no.11 with 2 geotextile layers has more decrease in the lateral deformation and safety factor compared to model no.14. Finally, by comparing static and dynamic loading it can be concluded that the placement of geotextile layers under embankment and under subgrade has better technical and economic justification and by using geotextile, the changes of the results of dynamic loading analysis are more than static loading, although more extensive studies have to be conducted on this area.

References

[1] Barenbuerg T., Wu J.T.H. & Bender A. (1994). Bearing Capacity of Rectangular Footings on Geogrid-Reinforced Sand. Journal of Geotechnical Engineering, 120 (12), 2083-2099.

[2] Christofer, G. V. and Holts, G. V. S. (1990). Pavements. Tata McGraw Hill, New Delhi, 283-306.

[3] Yamanouchi, T. (1982). Resent Developments in the Use of Synthetic Geofabrics and Geogrids. Proceeding of a Symposium on Resent Developments in Ground Improvement Techniques, Bangkok, 205-224.

[4] Rao, G. V., Gupta K. K. and Singh, P. B.(1989). Laboratory Studies on Geotextiles as Reinforcement in Road Pavement, Proceedings of the International Workshop on Geotextile, Bangalore, 1**,** 137-143.

[5] Shetty, K. R. and Shetty, P. P. (1989). Reinforced Soil layers in Pavement Construction., Proceedings of the International Workshop of Geotextile, Bangalore, 1, 177-183.

[6] Gopal, Ranjan and Charan, H. D. (1998). Randomly Distributed Fiber Reinforced Soil—the State of the Art., Journal of the Institution of Engineers (India), 79, 91-100

[7] Cancelli, A., Montanelli, F., Rimoldi, P. and Zhao, A. (1996). Full Scale Laboratory Testing on Geosynthetics Reinforced Paved Roads', Proceedings of the International Symposium of Earth Reinforcement, japan, 573-578.

[8] Benson, C.H. and Khire, M.U, (1994). Reinforcing Sand with Strips of Reclaimed High-Density Polyethylene. Journal of Geotechnical Engineering, 121, 838-855.

[9] Motanelli, F., Zhao, A. and Rimoldi, P. (1997). geosynthetics Reinforced pavement system: testing and design, Proceeding of Geosynthetics, 97, USA, 1-16.

[10] Fannin, R.J. and Sigurdson, O., (1996). Field Observations on Stabilization of Unpaved Roads with Geosynthetics, Journal of Geotechnical Engineering, 122(7), 544-553.

[11] Holtz, R.D., Black, P.J., (1999). Performance of Geotextile Separators Five Years after Installation, Journal of Geotechnical and Geoenvironmental Engineering, 125(5), 404-412.

[12] Al-Qadi, I.L. and Chair, E.V., (2003). Eight-year of Field Performance of a Secondary Road Incorporating Geosynthetics at the Sub-grade- Base Interface., Transportation Research Board and National Research Council, Washington, D.C. 3, 3453-3468.

[13] Giroud, J.P. and Noiray, L., (1981). Geotextile Reinforced Unpaved Road Design. Journal of Geotechnical Engineering, 107(9), 1233-1254.

[14] Steward, J., Williamson, R. and Mohney, J., (1977). Guidelines for the Use of Fabrics in Construction and Maintenance of Low- Volume Roads., US Department of Agricultural Forest Service, Portland, Oregon, Report No. FHWA- TS, 78-205.

[15] Milligan, G.W.E., Jwell, R.A., Houlsby, G.T. and Burd, H.J., (1989). A New Approach to Design of Unpaved Roads. Ground Engineering. 9(1), 37-42.

[16] Makarchian Elyasi, (2009)., Geotextile effect in increasing bearing capacity of pavement design., 8th international conference in civil engineering, iran, 120-135 (in persian).

[17] Khodadadi A., Fakhri M.(2005). Geosynthetic effect on the fatigue life of asphalt pavements. Journal of Transport, 2, 137-144.

[18] Hajek, J.J., Blaney, C.T., Hein, D.K. (2006). Mitigation of highway traffic-induced vibration. Annual Conference of the Transportation Association of Canada Charlottetown, Prince Edward Island, Session on Quiet Pavements: Reducing Noise and Vibration.

[19] Moayedi H., Kazemian S., Prasad A. and Huat B. B. K. (2009). Effect of geogrid reinforcement location in paved road improvement. Electronic Journal of Geotechnical Engineering, 14, 1-11.

[20] Nazari R. and Dabiri R. (2015). Study of stabilization of road with geosynthetics (Geotextile), Msc thesis in geotechnical engineering, Department of civil engineering, Islamic Azad University, Maraghe Branch, 138. (In persian).

[21] Code No.234. (2003). Iran highway asphalt paving code, Minstery of roads and transportation research and education center, 1-197.