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Numerical evaluation to improve low traffic roads behavior using Geosynthetic stabilization through finite element method

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ABSTRACT

In this research, the method of mechanical stabilization of soil using geogrids in the construction of roads with low traffic volume is investigated. When paving low-traffic roads on poor foundations, problems such as over-grooving, increased maintenance costs, and periodic traffic jams can cause problems. Field applications of geogrid reinforcement on top of the weak bed layer can significantly improve the performance of these pathways by reducing permanent vertical deformations and increasing lateral restraint capability, leading to longer pavement service life. Or reduce the thickness of the base layer to withstand the same number of loads. The purpose of this paper is to provide numerical research using two-dimensional finite element (FEM) method, by ABAQUS software, in order to analyze the performance improvement of low-traffic roads armed with geogrid layer. In this research, after verifying the software with a valid article related to the subject of the article, parametric studies have been performed and the effect of the number and distance of reinforcements and the thickness of the base layer on the pavement performance has been investigated. The results show that the use of geogrid layers can reduce the amount of displacements on the surrounding soil surface up to 74% and improve the resistance of the pavement system against permanent deformation.

Keywords: Low Traffic Roads, Geosynthetic Stabilizer, Geogrid, Finite Element Method.

Introduction

About two-thirds or about 30 million kilometers of all roads worldwide are Low-traffic roads. But there is no adequate technology and infrastructure, and this is due to concerns about budget and lack of knowledge and experience of project designers and builders [1]. In Iran, low-traffic roads are designed as the main roads and this wastes national capital. Local institutions often use experimental approaches based on layer coefficients to design the thickness of Hot Mix Asphalt (HMA) for low-traffic roads. such relatively simple experimental approaches are used are not suitable for considering the effects of recycled / modified or non-traditional building materials currently used in sustainable paving; they have also been found to be inefficient in describing modern building materials [2] and [3]. The roads built on a poor subgrade are exposed to problems such as over-grooving and increased maintenance costs, often leading to periodic traffic jams. Applying geosynthetics on a weak subgrade can significantly reduce the performance of permanent vertical deformation and increase lateral inhibition capability [4]. Some studies have been conducted in this field. In a study, Chamani et al. showed that increasing base layer thickness at low quality materials has less effect on fluctuation reduction than high quality materials, and when base layer thickness increased, the fluctuation is reduced through increasing modulus of resilience of the base layer, [5]. Bahak et al. showed that the studied pavements performed well under the existing traffic and environmental conditions and showed that the RHA and lime coated layer is a good alternative to improve the conditions of low traffic roads and preventing RHA disposal will bring environmental, social and economic benefits [6]. In a study, Guo et al. showed that strengthening the geogrid is effective in reducing damage to the subgrade and base, but cannot significantly increase the fatigue life of flexible pavement [7]. Alavi et al. showed that the progress of bottom-up cracking can be accurately detected using an intelligent measuring instrument. Also, the analysis was based on discrete cracking while I was a continuous cracking [8]. The renovation test of low traffic roads using soft asphalt and OTTA sealing technology has been performed by Adrius Vitkus et al. In Lithuania [9]. Mokhberi and Moayedi in a study showed that lime had a good role in strengthening the road bed, Sasobit materials are very effective in reducing the asphalt thickness. The use of geogrid optimal in strengthening the base and sub base layers, but it does not play an effective role in reducing the subsidence of the asphalt layer [10].

Ziari et al. showed that good coordination between experimental results with numerical methods and computer programs was observed and carbon fiber geogrids are capable to absorb 25 to 40% of tensile stresses and strains [11]. Taherkhani et al. showed that with increasing the modulus of geosynthetic elasticity, its effect will increase on pavement responses. It was also found that the effect of geosynthetic displacement on pavement responses depends on its modulus of elasticity.

Analyzing roads pavement and their constituents is always of great importance due to better understanding of their behavior under different conditions and leads to a better understanding and thus a more accurate relationship. Asphalt concrete pavement, as one of the largest infrastructure components in different countries of the world, is a complex system that is faced with several layers of different materials, with different combinations of irregular traffic loads and changing environmental conditions. Therefore, making a realistic forecast of the long service life of asphalt pavements is one of the challenging tasks of pavement engineers. this study aims to model and numerical analysis of low traffic roads stabilized with geosynthetics using finite element software and to obtain diagrams to better understand the behavior of these roads and finally providing some suggestions to use geosynthetics. The specific objectives of this research are:

1- Investigating the effect of geosynthetic stabilization on the performance of low traffic pavement

2- Evaluating the effect of geosynthetic distance from the asphalt surface on the response of low traffic pavement

Methodology and Validation

In this study, finite element method through ABAQUS software is used to evaluate the numerical evaluation as accurately as possible. The studied variables include the number of geosynthetic stabilization (1, 2 and 3 layers), the distance of geosynthetic stabilization (25, 50 and 75 mm) and the height of the soil for geosynthetic stabilization (300 mm), respectively. The examined modes are presented in Table (1). The values mentioned has been selected according to studies conducted by Calvarno et al. (2017) on application of geosynthetic stabilization [4]. Figure (1) shows the geometric position of the geosynthetics.

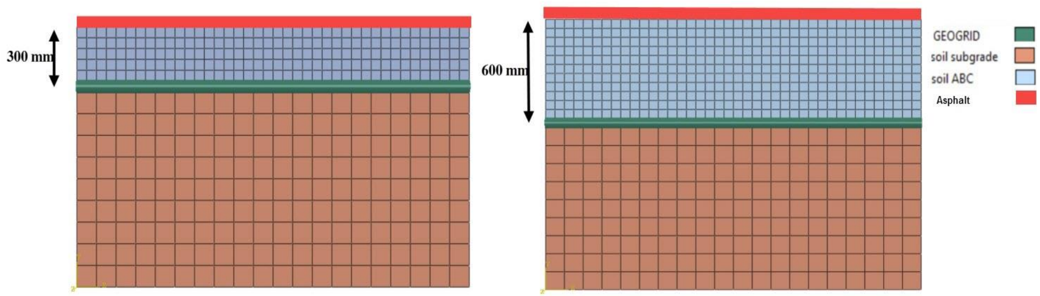

Figure 1: The Geometric Position of the Geosynthetics.

Table 1: Parameters studied

state	Number of geosynthetic layer	Geosynthetic distance (mm)	Geosynthetic stabilizing soil height (mm)	Abbreviation
1	----	----	300	No retrofit - H:300
2	1	25		FRP-N:1-S:25- H:300
3		50		FRP-N:1-S:50- H:300
4		75		FRP-N:1-S:75- H:300
5	2	25		FRP-N:2-S:25- H:300
6		50		FRP-N:2-S:50- H:300
7		75		FRP-N:2-S:75- H:300
8	3	25		FRP-N:3-S:25- H:300
9		50		FRP-N:3-S:50- H:300
10		75		FRP-N:3-S:75- H:300
11	----	----	----	No retrofit - H:600
12	1	25	600	FRP-N:1-S:25- H:600
13		50		FRP-N:1-S:50- H:600
14		75		FRP-N:1-S:75- H:600
15	2	25		FRP-N:2-S:25- H:600
16		50		FRP-N:2-S:50- H:600
17		75		FRP-N:2-S:75- H:600
18	3	25		FRP-N:3-S:25- H:600
19		50		FRP-N:3-S:50- H:600
20		75		FRP-N:3-S:75- H:600

In this study, three materials have been used to define the materials, subgrade, surface soil and geosynthetic layer. The properties of the materials are given in Table (2).

Table 2: Characteristics of materials and behavioral models in the study [4]

Material	Models and Parameters	Thickness (m)	E(MPa)	υ
ABC Subgrade	Drucker – Prague $\beta = 40°$ و $P_t = 20KPa, \psi = 10°$	0.30 0.60	50	0.35
Geogrid	Elastic- Linear	0.003	400	0.30
Pavement bed	Drucker – Prague $\beta = 10°$ و $P_t = 10KPa, \psi = 0$	0.90	10	0.42
Asphalt surface	Time hardening	0.1	950	0.41

explicit dynamic analysis was used to analyze the studied models. In order to apply the loads on the subgrade according to the study of Calvarano et al. (2017), the Point Load test has been used [4]. All the considered models are built on a rigid bed and the boundary conditions under the wall are fixed. The soil surface is also flexibly modeled to record horizontal deformations. In the present study, soil and formwork elements of C3D8R type were selected. The eight-node linear rectangular prism elements are reduced by integration method. These elements have three degrees of freedom in each node in three directions, which defines a total of 24 degrees of freedom for each element. The number of elements is 460 and the number of nodes is 538. The mesh dimensions in the subgrade are equal to 10 mm and in the surface are equal to 5.

In order to validate the simulation method used in the study, a geosynthetic stabilization method conducted by Calvarano et al. (2017) was used and finite element method was used for simulation.

Table 3: Comparison between Displacement Resulting from Finite Element Models of the Present Study with Calvarano Study

Error Percent	Maximum displacement in Calvarano Study	Maximum displacement in this study
1.92	-3-10×5.772	-3-10×5.883

Findings

The outputs for each finite element model are presented separately. These outputs include displacement history, strain and stresses contours, respectively. In these diagrams, the displacement unit is in millimeters and the stress unit is in Pascal. The maximum outputs of the analysis of each of the studied models are determined and finally compared with each other. In order to evaluate the outputs, in each section, bar diagrams are presented with the aim of comparing the performance of different states so that the parameters in the present study such as the number of geosynthetic stabilization (1, 2 and 3, respectively). Layer) the distance of the geosynthetic stabilization (25, 50 and 75 mm) and the height of the soil for the placement of the geosynthetic stabilization (300 mm) can be evaluated.

1. The Effect of Geosynthetic Stabilization Number in The Studied Models

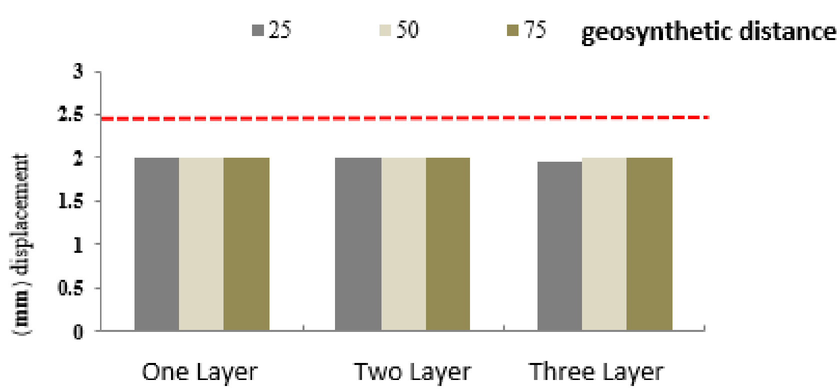

Figure 2: Comparison of The Maximum Displacement Created for Investigating the Number of Geosynthetic Stabilization Layers (Soil Height 300 Mm)

According to Figure (2) in the soil with a height of 300 mm and in the case of 3 stabilizing layers with a distance of 25 mm, the least amount of displacement has been observed; The displacement corresponding to the three-layer geosynthetic retrofitting mode with a distance of 25 mm has been reduced by about 3% from the single-layer and two-layer modes. On the other hand, by comparing the displacement values corresponding to the geosynthetic retrofitting modes with the non-geosynthetic mode (red dashed line), it can be seen that the use of geosynthetic layers can reduce the displacement values. The incidence should be spread on the peripheral surfaces of the soil so that in soils with a height of 300 mm in the best case, a reduction of 19% and 27% can be observed, respectively.

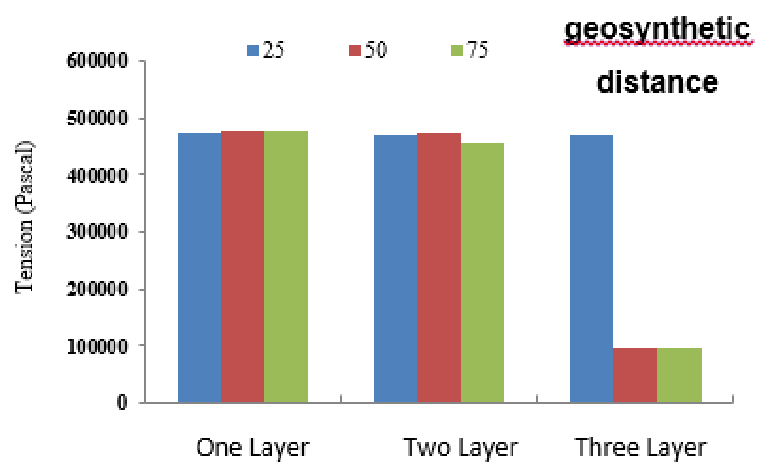

Figure 3: Comparison of The Maximum Tension for Investigating the Effect of Number of Geosynthetic Stabilization Layers (Soil Height 300 Mm)

As shown in Figure (3), when three layers of geosynthetic stabilization are used, the least amount of stress is observed; so that, the difference between the lowest stress in the case of three layers of geosynthetic stabilization with soil height 300 mm compared to one and two geosynthetic stabilization layers is equal to 80 and 79%, respectively. geosynthetic layers can reduce the stresses on the soil surface so that in soils with a height of 300 mm in the best case can reduce the stresses by 84%, respectively.

2. The Effect of Geosynthetic Stabilization Distance in The Studied Models

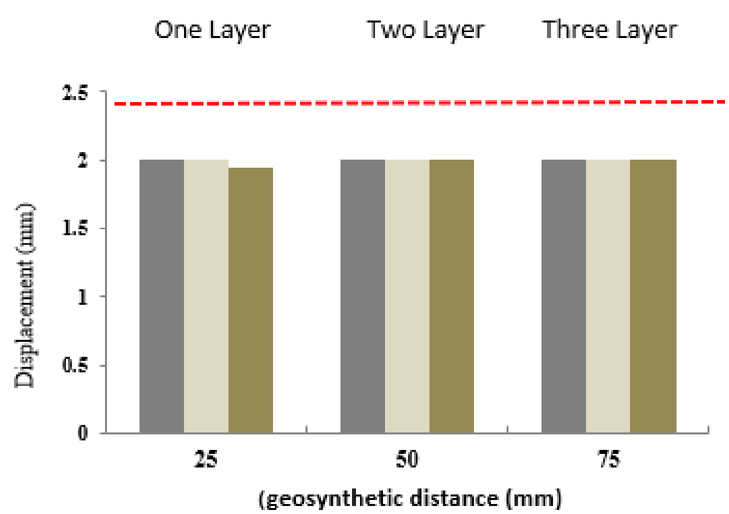

Figure 4: Comparison of The Maximum Displacement for Investigating the Effect of Geosynthetic Stabilization Distance (Soil Height 300 Mm)

According to figure (4), as the distance between the geosynthetic retrofitting increases, the displacement of the subgrade pavement does not change significantly; In other words, with 3 times the distances between geosynthetics (from 25 to 75 mm), the subgrade displacement for both considered heights has not changed significantly. Therefore, it is more economical to use geosynthetics at 75 mm distances in terms of displacement.

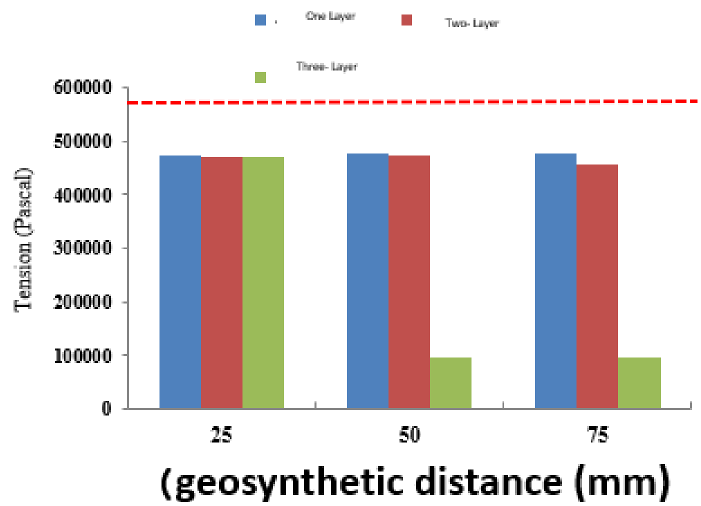

Figure 5- Comparison of The Maximum Tension Created for Investigating the Effect of Geosynthetic Stabilization Distance (Soil Height 300 Mm)

As can be seen, in soils with a height of 300 mm, increasing the distance between the geosynthetic stabilization has a very significant role in reducing the stresses; For example, the corresponding stress is increased at 80% in the case of using three geosynthetic layers with a distance of 75 mm compared to corresponding value with a distance of 25 mm.

3. The Effect of Geosynthetic Stabilizing Soil Height on the Studied Models

As shown in Figure (6), the maximum road displacement is reduced by the addition of geosynthetics. Also, as can be seen, the displacement changes slightly when the distance between the geosynthetics changes. In a way, a change in the height of the geosynthetics has little effect on the performance of the complex.

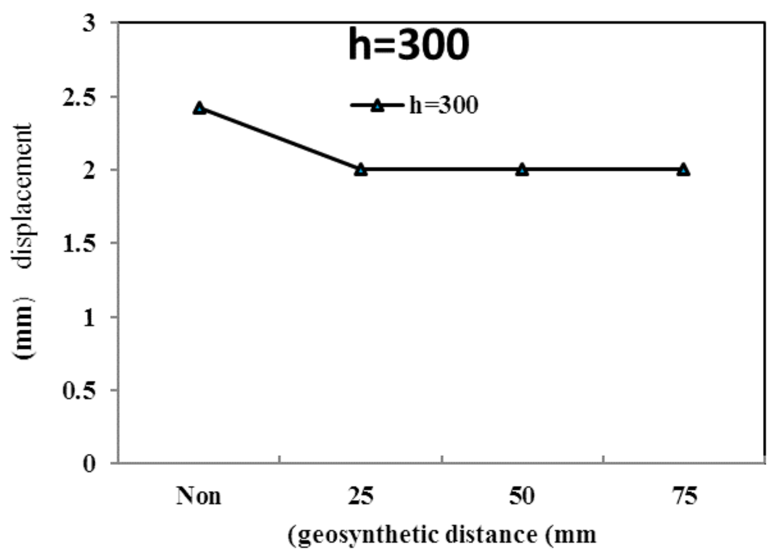

Figure 6- Comparison of The Maximum Displacement for Investigating the Effect of Geosynthetic Stabilization Soil Height (1-Layer Geosynthetic)

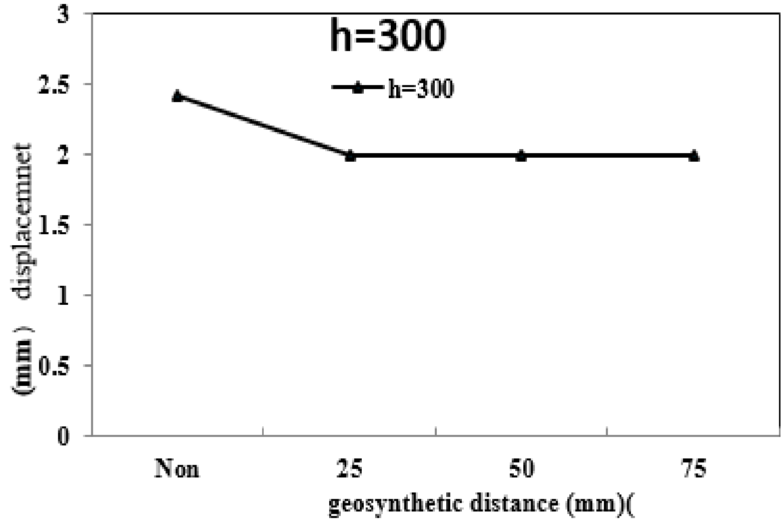

Figure 7- Comparison of The Maximum Displacement for Investigating the Effect of Geosynthetic Stabilization Soil Height (2-Layer Geosynthetic)

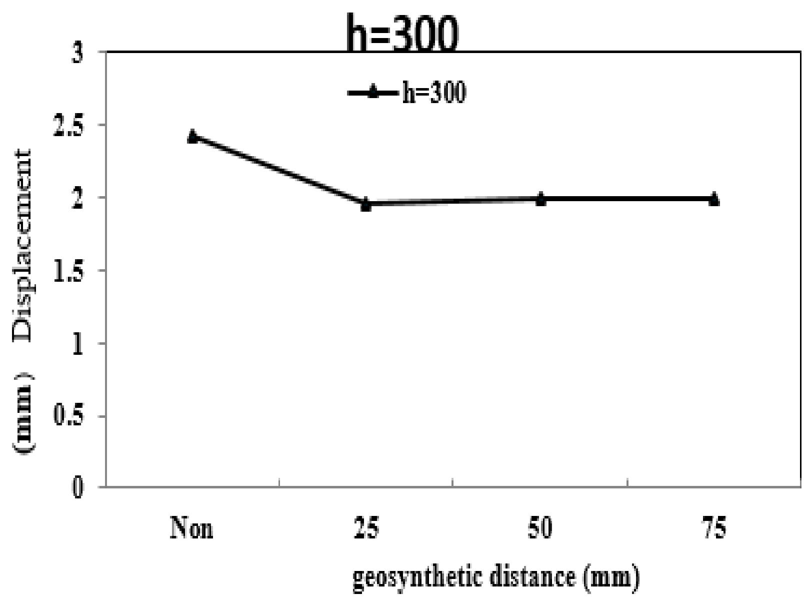

Figure 8- Comparison of The Maximum Displacement for Investigating the Effect of Geosynthetic Stabilization Soil Height (3-Layer Geosynthetic)

According to Figures (7) and (8) where the maximum displacement created with the aim of investigating the effect of geosynthetic stabilizing soil height with two and three layers compared, it can be seen when the geosynthetic distance is 25 mm. In most cases, less displacement is observed than other cases.

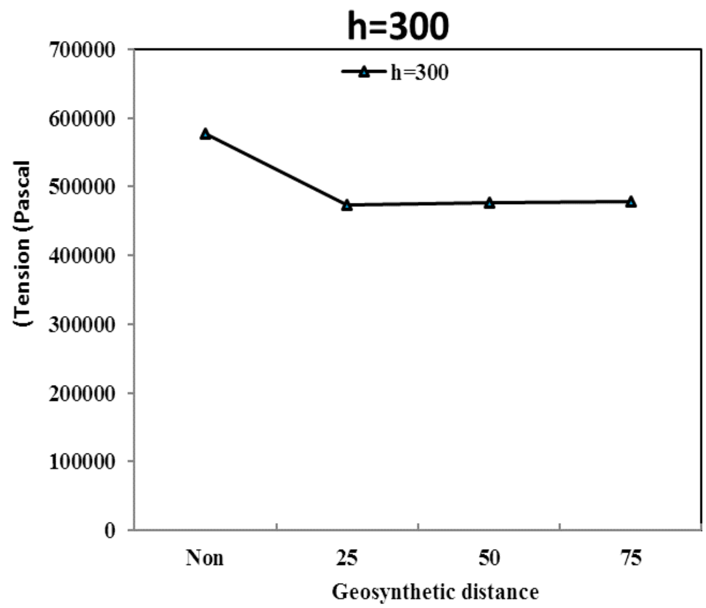

Figure 9- Comparison of The Maximum Tension for Investigating the Effect of Geosynthetic Stabilization Soil Height (1-Layer Geosynthetc)

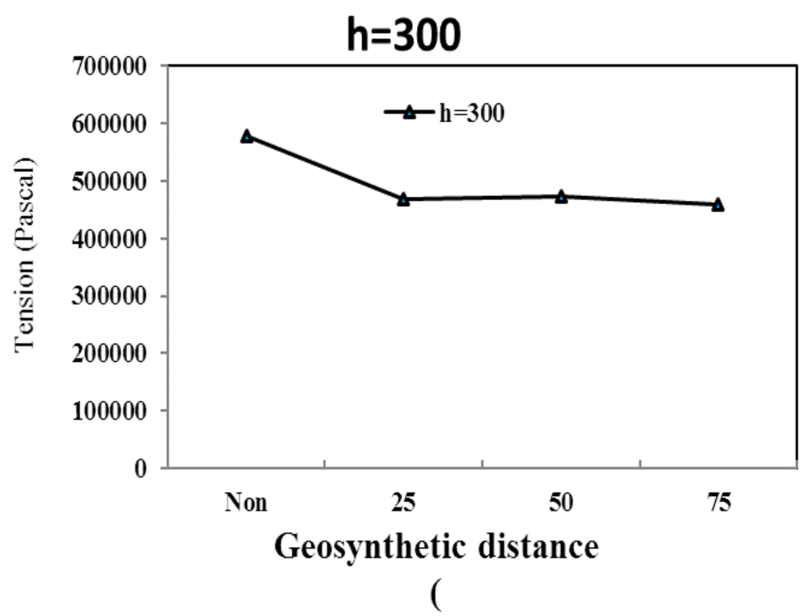

Figure 10- Comparison of The Maximum Tension for Investigating the Effect of Geosynthetic Stabilization Soil Height (2-Layer Geosynthetc)

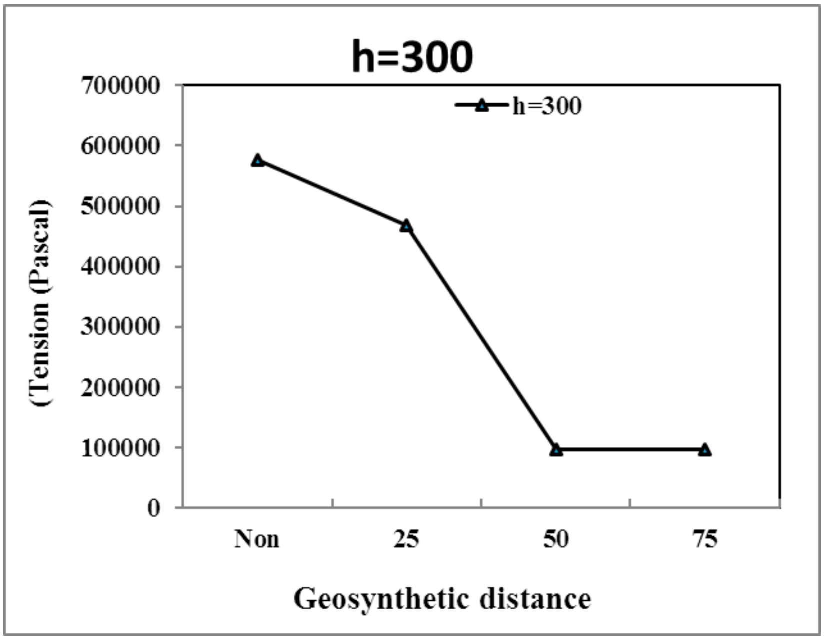

Figure 11- Comparison of The Maximum Tension for Investigating the Effect of Geosynthetic Stabilization Soil Height (3-Layer Geosynthetc)

According to Figures (9) to (11), when one and two layers of geosynthetics is used, the stresses in the models whose soil height is 300 mm have increased; However, in models where three geosynthetic layers are used and their distances are considered to be 50 and 75 mm, soil height has no effect on the stresses.

4. Investigation of The Displacement in The Studied Models for Investigating The Depth Of Geosynthetic Placement

Figure (12) compares the displacements in the studied models in order to investigate the effect of geosynthetics stabilizing soil height. As can be seen, the displacement decreased with increasing geosynthetic depth.

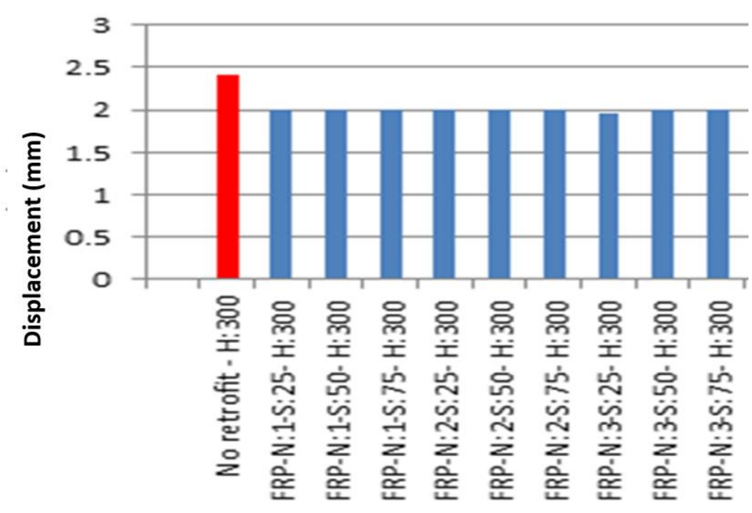

Figure 12- Comparison of The Displacement in the model aims to Investigate the Effect of Geosynthetic Stabilization Soil Height
Displacement (mm)

5- Reviewing the Load (Upper and Lower Strains)

In this section, the most optimal mode in terms of stress and displacement was selected out of 20 models studied was re-simulated under light and heavy loads in the case of geosynthetic retrofit mode without retrofitting. In this case, three geosynthetic layers at distance of 75 mm are applied and the height of the stabilized soil is equal to 300 mm. In order to apply light and heavy loads, Table 10-1 of Journal 234 has been used. For this purpose, to apply light and heavy loads, the loads corresponding to the pickup vehicle (1 ton) and heavy truck (19 tons) were used, respectively.

Table 4: Classification of Vehicles and Axle Specifications and Their Weight [15]

Total weight (Ton)	Rear axel		Middle axel		Front axel		Wheel arrangement	No. Axel	Kind of vehicle
	Weight (Ton)	Kind	Weight (Ton)	Kind	Weigh t (Ton)	Kind			
2	1	Simple			1	Simple		2	Car
3	2	Simple			1	Simple		2	Pickup
6	3	Simple			3	Simple		2	Minibus
9	6	Simple			3	Simple		2	Bus
15	9	Simple			6	Simple		2	Lightweight two-axle truck
19	13	Simple			6	Simple		2	Heavy two-axle truck
26	20	Compound			6	Simple		3	Three-axle truck
36	10+10	Simple	10	Simple	6	Simple		4	Four-axle truck
32	16	compound	10	Simple					
40	18	compound	16	compound	6	Simple		5	Five-axle truck
40	24	compound	10	Simple	6	Simple		5	Five -axle truck

Table 5: Maximum Values of Outputs of the Studied Models For Investigating The Amount of Loading

Model	Displacement (mm)	Strain	Tension (kPa)
Light Load (Without Retrofitting)	1.8	0.000195	92170
Light Load (Geosynthetic Retrofitting)	1.8	0.000195	92170
Heavy Load (Without Retrofitting)	6.35	0.000796	299500
Heavy Load (Geosynthetic Retrofitting)	6.10	0.003088	145100

In Table (5), the maximum output of the analysis of the studied models with the aim of investigating load has been compared. As can be seen, the displacement corresponding to the heavy load mode is 3.52 times lighter than the corresponding load. Also, the strain corresponding to the heavy load mode is 4.08 times the strain corresponding to the light load mode. On the other hand, the stress corresponding to the heavy load mode is 3.24 times the stress corresponding to the light load mode.

Also, according to Table (5), adding geosynthetic layers in the case of heavy load application has reduced the displacement by 4% and the created stress by 51%.

Another issue that can be mentioned according to Table (5) is that the type of soil selected in the state without retrofitting had enough resistance that can show a good response to light loads; In other words, it can be stated that there was no need for light load retrofitting for the studied soil; This issue was also observed in the study of the obtained displacements for all models in the previous section. However, the response of subgrade retrofitting with geosynthetic was different in heavy load and this difference is quite clear in Table (5).

Conclusion

In the present study, in order to investigate the numerical evaluation of the improvement the low traffic behavior roads using geosynthetic stabilization by finite element method, finite element method through ABAQUS software is used. The studied variables include three geosynthetic stabilization (1, 2 and 3 layers), three geosynthetic stabilization distances (25, 50 and 75 mm) and two soil heights for geosynthetic stabilization (300 mm), respectively. The range of values is selected according to studies conducted by Calvarno et al. (2017) on the use of geosynthetic stabilization. The validation of the finite element method used was performed by Calvarano et al. (2017) and a good agreement was observed between the laboratory and numerical results.

The results showed that in the soil with a height of 300 mm and when 3 stabilization layers with a distance of 25 mm were used, the least amount of displacement was observed; The displacement corresponding to the three-layer geosynthetic retrofitting mode with a distance of 25 mm has been reduced by about 3% from the single-layer and two-layer modes. The use of geosynthetic layers can lead to a reduction in the amount of displacements on the peripheral subgrade, so that in soils with a height of 300 mm in the best case can be reduced by 19%, respectively. When using three layers of geosynthetic stabilization, the least amount of stress occurs so that the difference between the lowest stress in the case of three layers of geosynthetic stabilization with a soil height of 300 mm compared to one and two layers of geosynthetic stabilization. The use of geosynthetic layers can reduce the amount of stresses on the subgrade, so that stresses reduction at 84% can be observed in soils with a height of 300 mm. by increasing the distance between the geosynthetic retrofitting, the displacement of the pavement subgrade does not change significantly; In other words, with 3 times the distances between geosynthetics (from 25 to 75 mm), the amount of subgrade displacement for the considered height has not changed significantly. Therefore, it is more economical to move the use of geosynthetics at 75 mm distances in terms of displacement. In soils with a height of 300 mm, increasing the distance between the geosynthetic stabilization has a very significant role in reducing the stresses; For example, when 3 geosynthetic layers with a distance of 75 mm is applied, the stress is 80% less than distance of 25 mm. Maximum road displacement are reduced by adding geosynthetics. Displacement values change slightly, When the distance between the geosynthetics changes. In other word, change in the height of the geosynthetic has little effect on the performance. The displacement corresponding to the heavy load mode is 3.52 times the displacement corresponding to the light load mode. Also, the strain corresponding to the heavy load mode is 4.08 times the strain corresponding to the light load mode. On the other hand, the stress corresponding to the heavy load mode is 3.24 times the stress corresponding to the light load mode. Addition of geosynthetic layers in the case of heavy load application has reduced the displacement by 4% and the stress by 51%.

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