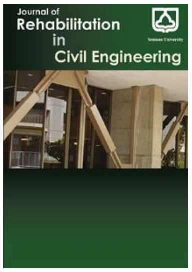
Journal of Rehabilitation in Civil Engineering 5-2 (2017) 32-45



journal homepage: http://civiljournal.semnan.ac.ir/

Evaluating the Performance of Rehabilitated Roadway Base with Geogrid Reinforcement in the Presence of Soil-Geogrid-Interaction

M.I. Khodakarami[1*] and H. Khakpour Moghaddam[1]
1. Faculty of Civil Engineering, Semnan University, Semnan, Iran.

Corresponding author: *khodakarami@semnan.ac.ir*

ARTICLE INFO

Article history:
Received: 29 March 2016
Accepted: 12 April 2017

Keywords:
Geogrid,
Rehabilitated road way,
Pavement settlement,
Soil/load condition.

ABSTRACT

One of the efficient techniques to improve the behavior of the paved road under traffic loads is implementing the geosynthetic material in the sub-base or the soil under the road. In the past years, many researches have been done about this topic, but the study on the effect of soil/load conditions on the performance of the rehabilitated paved road by geogrid in order to investigate the effective parameters on it is still open. In this paper a series of 2D FEM models using the software PLAXIS-2D are carried out to evaluate the effects of soil/load conditions which includes the effect of the subgrade material and load properties (such as modulus of elasticity, Poisson's ratio, drainage conditions, shear strength and the area of load), in the presence of soil-geogrid-interaction. The results showed that the use of a geogrid reinforcement layer decreases the vertical settlement in a soft subgrade surface, and this indicates that the main mechanism of the geogrid is to restrain soils from lateral displacement through interlocking with the particles. In addition, it is concluded that increasing the Poisson's ratio of the subgrade leads to reducing the vertical settlement and increasing the value of modulus elasticity leads to decrease of the vertical displacement, it is also shown that with increasing un-drained shear strength, vertical deflection has also decreased.

1. Introduction

According to the road and geotechnical engineers viewpoint, the problems of soft subgrades and soils are known as one of the main reasons for the difficulty of construction and maintenance of the structures and infrastructures which are placed over the soil. Improving the geotechnical properties of the problematic soils is done by various stabilization methods, these mechanical and chemical stabilization methods includes density treatments (e.g., compaction and preloading), pore pressure reduction techniques or moisture control (such as, dewatering or electro-osmosis), the soil modification (by ground freezing, grouting and cementation stabilization), blending and use of geosynthetics reinforcing (such as geotextiles and geogrid), but most of which may be ineffective and expensive (e.g., for more details see [1, 2]). The use of geosynthetic reinforcement as a ground improvement techniques have been implemented extensively over the last few decades, particularly in pavement and geotechnical engineering. The reinforcement function in reinforced pavement sections includes lateral restraint, increased bearing capacity and tension membrane effect. The idea of reinforced soil has been introduced by the French architect and engineer Henri Vidal in the 1960s and was based on the performance of soil-reinforcement interaction due to tensile strength, frictional and the adhesion properties of the reinforcement on the soft soil [3]. It was also indicated that geosynthetic reinforcement becomes very effective when the deformation in the road or foundation increases due to extending the area which the load affects [4, 5]. Geogrids are one of the most common geosynthetics that are used in transportation engineering, as these reinforcement produce superior interface shear resistance due to interlocking between soil and aperture of the geogrid. The results of experimental, analytical, and numerical studies showed that the geogrid reinforcement in pavement structures can extend the pavement's service life, reduce base course thickness for a given service life and reduce rutting in pavements over soft subgrades [6]. A very good review about effect of geosynthetic reinforcement on pavement foundations is issued in [7]. The reinforcement can absorb additional shear stresses between the subgrade and fill, which improves the load distribution on the subgrade [6], and also if the road is pre-rutted during construction, embedded geosynthetic reinforcement at the roadway layers is distorted and thus tensioned. To better understand and predict the behavior of the reinforced road on the soft subgrade under the traffic load as well as analyzing the reinforcing mechanisms, some studies have been carried out by researchers. The results of these studies showed that the the performance and behavior of the reinforced pavement sections with geosynthetics is improved in terms of stiffness, strength, load bearing capacity and reduced permanent deformations. The researchers concluded that the use of geogrid with higher stiffness has more effect on the improved performance of reinforcement and geogrid has a better performance than geotextile in controlling and reducing the reinforced pavement layers' deformation. The use of reinforcement in test sections leads to enduring more stress than non-reinforced sections in the same strain level.Increased number of reinforcement~~s~~ layers has a significant effect on reducing the shear deformation, especially under the traffic loading in reinforced pavement sections [8-12]. In [8], the effects of the location of the geosynthetic on the performance of reinforced flexible pavement systems are studied. A series of experimental tests have been done for assess of the resilient characteristics of reinforced soils by [9] and development of design methods for geosynthetic reinforced flexible pavements is presented in [10] and under repeated loads, the interface shear growth in a reinforced pavement subject is assessed by [11]. The characteristics and behavior of the geogrids and its related mechanism are presented in [13-16]. Several numerical studies have been conducted to simulate and study the road or reinforced pavement or unpaved road behavior that constructed on the soft subgrade. Generally, the results of these studies indicated that the use of geosynthetic reinforcement increases the load bearing capacity of the road subgrade and causes a 15-20% reduction of the vertical settlement.Additionally the results showed that reinforcing the pavement reduces crack propagation, deformations and lateral strain inside the base and subgrade layers [17-26]. In the numerical simulation of the reinforced soil, the interaction between the reinforcement and soil is very important and complex for designing and analyzing the behavior of reinforced soil and depends on soil and reinforcement properties [27] and in order to simulate two and three dimensional problems when the domain is bounded or unbounded many numerical methods such as finite element method, boundary element method, scaled boundary finite element method and etc. can be used (see, for xample [28-32]), where in this paper the finite element method is implemented in order to achieve the results. The main objective of this paper is to discuss the influence of geogrid in the reduction of vertical deformation of rehabilitated pavements using a 2D finite element analysis. First, the model is calibrated and then the surface deflection is evaluated with respect to various parameters that included elastic modulus, Poisson's ratio, the undrained shear strength of subgrade and the area of load and its effects of the surface settlement of the pavement.

2. Description of the model

In order to investigate the effect of using geogrids in the unpaved road a series of 63 numbers of models according to Figure 1 are created.

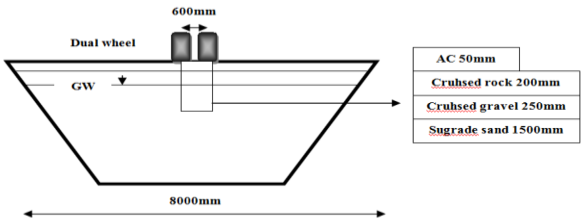


Figure 1. Cross-section of flexible pavement system.

This model has 4 layers with geometrical and mechanical properties as mentioned in Table 1 (e.g., the basic modeling parameters of the flexible pavement system are similar to the research which is done by [33]).

Table 1. Geometrical and mechanical properties of the flexible pavement system layers.

Property	Asphalt	Crushed Rock	Crushed Gravel	Sand
Thickness (mm)	50	200	250	1500
Elastic modulus (MPa)	5400	250	125	75
Poisson's ratio	0.3	0.35	0.35	0.35
Unit weight (kN/m^3)	25	21.2	22	18
Cohesion (kPa)	-	30	20	8
Friction angle (^{0})	-	43	44	36
Dilatation angle (^{0})	-	13	14	6
K_0	1	0.32	0.3	0.42

As the dimension of the road length is greater than the cross-sectional dimension, a two-dimensional plain-strain model was carried out in this study and the mechanical behavior of the pavement layers are modeled using the Mohr-Coulomb's criterion by five parameters related to mechanical properties of these materials: Poisson's ratio, modulus of elasticity, adhesion, friction angle and dilation angle. This model is a proper behavioral and reliable model in explaining the material behavior. The Mohr-Coulomb behavioral model presents the behavior of soil and rock materials with a first order approximation. In these models, geogrid is modeled as an axial element with membrane performance, which will behave elastic and the properties of this geogrid are presented in Table 2.

Table 2. Geogrid properties.

Parameters	**Value**
Geogrid type	BX-1100
Polymer type	Polypropylene
Aperture shape	Rectangle
Aperture size (MD/XD)(mm)	25/33
Rib thickness (mm)	0.75
Junction thickness (mm)	2.8
Tensile strength at 5% strain (kN/m)	
MD	8.46
XD	13.42
Initial modulus (kN/m^2)	
MD	226.4
XD	360.1

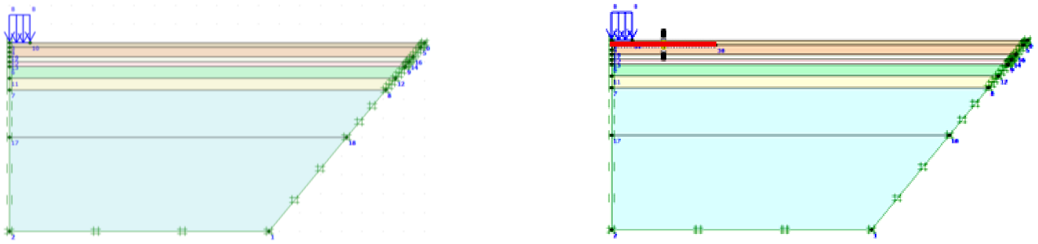
In the finite element model to mobilize reinfrcement resistance and tension membrane properties of the geogrid, in the contact surafce with the soil, the interaction between soil and reinforcement was modeled by interface element.These surface strength factors can be evaluated by:

$$C_{inter} = R_{inter} \times C_{soil} \quad (1)$$

$$\tan(\varphi'_{inter}) = R_{inter} \times \tan(\varphi'_{soil}) \quad (2)$$

$$G_{inter} = (R_{inter})^2 \times G_{soil} \quad (3)$$

where, C_{soil}, G_{soil} and φ'_{soil} are the adhesion, shear modulus and internal friction of the soil, respectively and C_{inter}, G_{inter} and φ'_{inter} are the adhesion, shear modulus and internal friction of the surface contact, also R_{inter} is the strength coefficient of the surface interaction. This parameter is a constant coefficient that varies between 0.01 and 1. The upper limit of this ratio is a sign of weak contact surfaces and is more flexible than the soil. The area that the load applies to the road is selected regarding the vehicle wheels with a length of 0.6 m, for more reality (see, Figure 1). Using the finite element software PLAXIS-2D[34], and because of the symmetry of the model with respect to the center line of the road, a two-dimensional model based on the half of the section (Figure 1) was built by employing the typical 2D elements mesh which is consisted of a series of 752 number of 15-node triangular elements and totally 3530 number of degrees of freedom (see, Figure 2) and the loading is 557 kPa which have been applied onto the road surface at the area with radius of 0.2 m. As it is depicted in Figure 2, the location of the geogrid reinforcement is varied with respect to the surface of the road (this will explain in the next), and moreover, the underground water table is selected in different depth in order to evaluate of the effect of the geogrid reinforcement regarding that.



(a) (b)

Figure 2. Geometry model and boundary conditions of the model; (a) without geogrid and (b) with geogrid reinforcement.

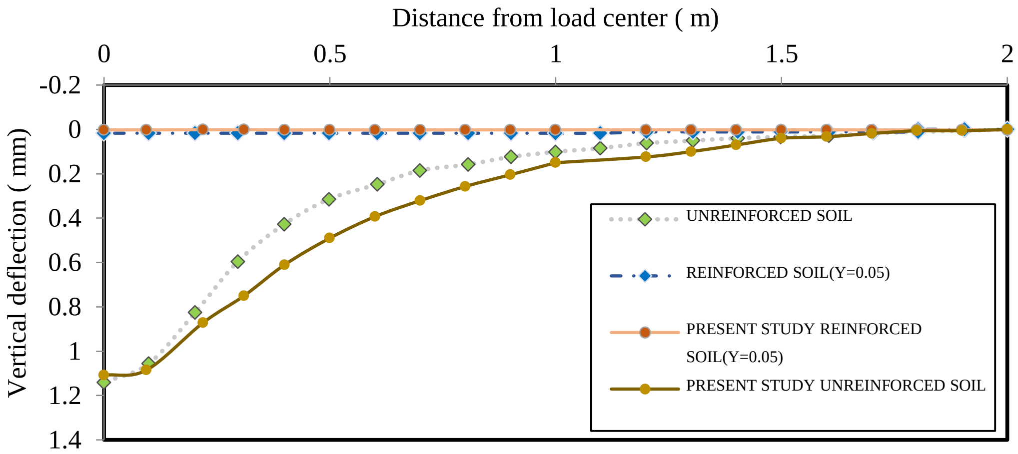


Figure 3. Comparison of the vertical deflections for unreinforced and reinforced FEM model between this study and Ref. [33].

As shown in Figure 2, conventional kinematic boundary conditions are adopted (i.e., roller supports on all four vertical boundaries of the mesh and fixed supports at the bottom of the mesh) for the boundaries of the model which are involved, while the earth and the surface of the road is subjected to the wheel load and is free traction boundary. The strain absorption interlayer system is a soft layer that is located at the bottom of the hot-mix asphalt (HMA) to dissipate the most of the energy. The analyses have been carried out for drained condition without pore water pressure changes. In order to simulate the stress dependency of the modulus of elasticity, the structural layers were divided into sub-layers with the same conditions, but different moduli of elasticity. The reinforced system was modeled with the same properties of the unreinforced model but geogrid reinforcement placed in three different locations to study the effect of geogrid location in tension stress absorption (see, Figure 2b). Figure 3 shows the results from the two-dimensional model which is built in this study by using software PLAXIS-2D according to above model description and are compared with the results which were presented in Ref. [33]. So, with this verification, it is clear that the model works well for both with and without the reinforcement and it would be a suitable base for the parametric study that is the main aim of this paper which is assessing the effects of the load area (Lw), depth level of the embedded geogrid (H), drainage conditions and material properties of the subgrade (ν and E) on the vertical deflection of the pavement. In this regard, four categories of models are studied. The models with name HqLWr are used in order to assess the effect of the load area on the vertical deflection. The models with name UHqCr are used in order to assess the effect of undrained shear strength of the subgrade on the vertical deflection and the models which are named as HqVν and HqEe are used for investigte of the effect of Poisson's ratio and elastic modulus of the subgrade, respectively, on the vertical deflection, where, in these models, q and r are the mentioned values of the embedded depth of the geogrid and length of the applied load, c is undrained shear strength, ν is Poisson's ratio and e is elastic modulus of the subgrade and also the geogrid was placed under the asphalt layer with q= 0.05, 0.25 m and also located under sub-base layer (q = 0.5 m).

3. Results and discussions

According to the models which have been described in the previous section, 63 numbers of models have been built and regarding that, effects of each under study parameter is evaluated on the pavement settlement. In order to study the effect of the load length, 18 models with various specimen that are used and are named as HqLWr, where q and r are mentioned the embedded depth of the geogrid and length of the applied load, respectively; for example, H0.05LW0.2 introduce a model with 0.05 m embedded depth of the geogrid and 0.2 m length of loading, in this study, the length of load area (LW) has been chosen equal to 0.2, 0.4, 0.5, 1.0, 1.1, 1.2 and 1.5 m.

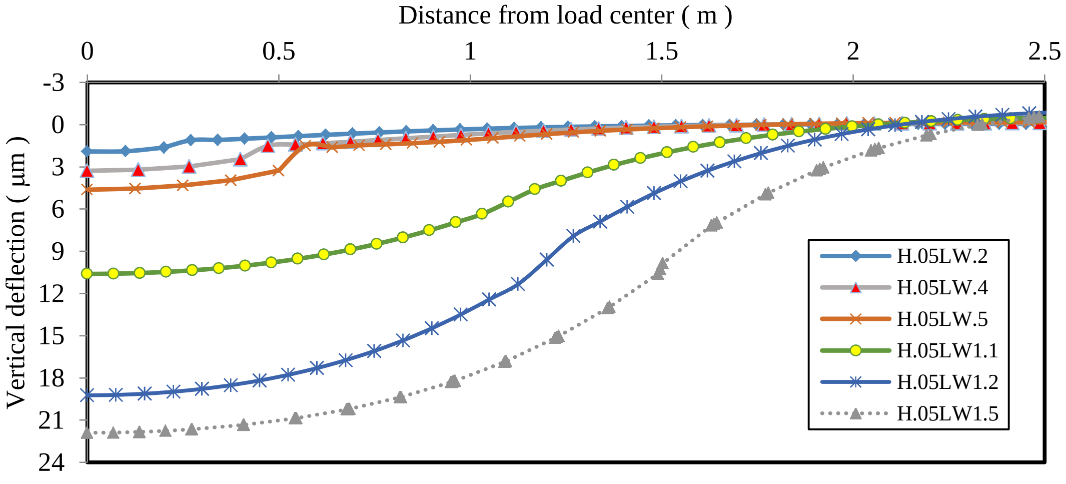


Figure 4. Vertical deflection of the pavement for various length of load area when the reinforcement is placed at q=0.05m.

Figures 4-6 show the variation of the settlement of the reinforced pavement along horizontal direction for each model with a different length of the load area. Figure 4 represents the surface deformation caused by changes in the loading area when the reinforcement is located at the depth of 0.05 *m* from the surface. As it can be observed, by increasing the loading length from 0.2 to 1.5 *m*, the maximum settlement is increased from 2.5 to 22.5 micrometers which is almost greater around 9 times.

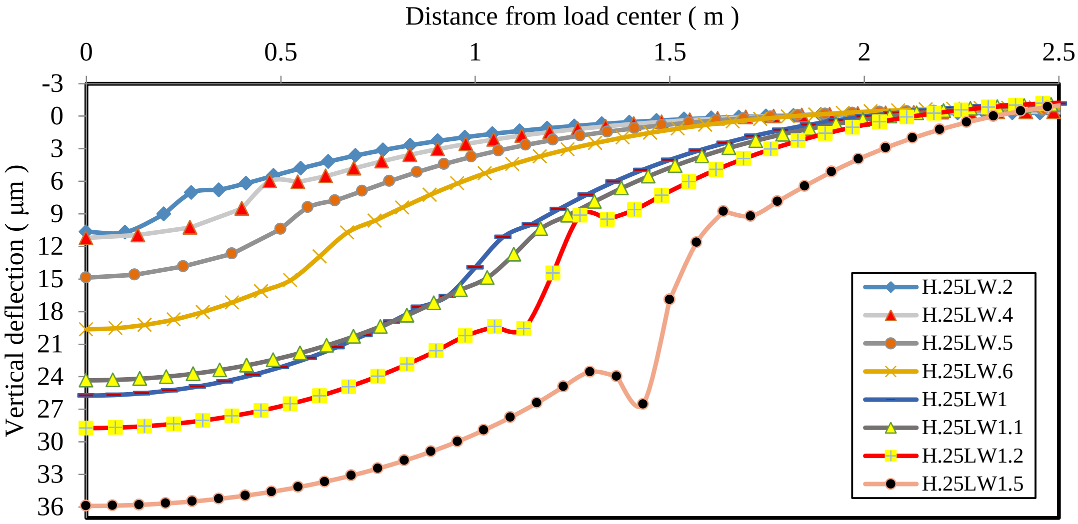


Figure 5. Vertical deflection of the pavement for various length of load area when the reinforcement is placed at *q*=0.25 *m*.

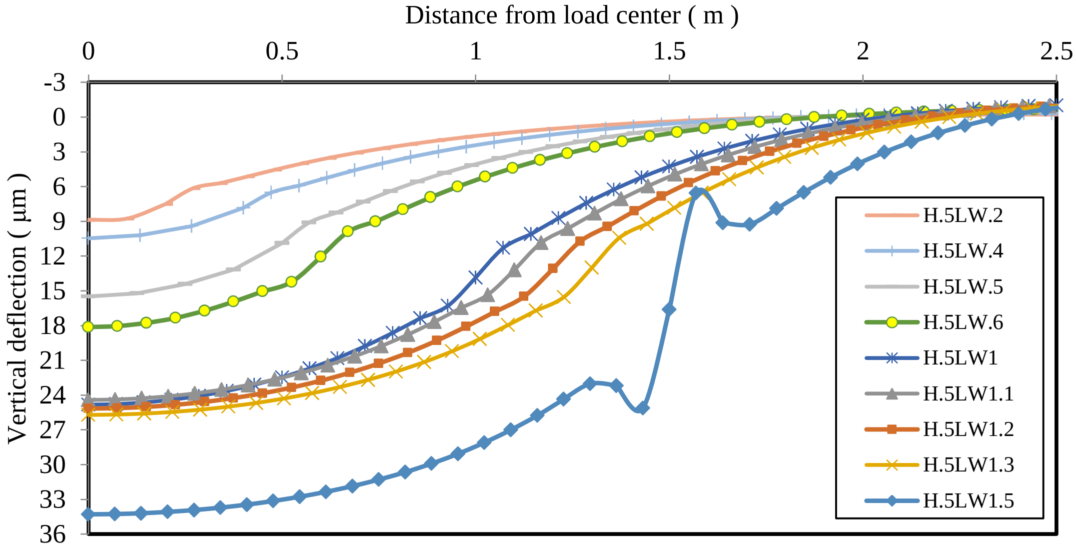


Figure 6. Vertical deflection of the pavement for various length of load area when the reinforcement is placed at *q*=0.5 *m*.

Figure 5 shows how the vertical deflection of the pavement surface varies when the geogrid reinforcement is placed at the depth of 0.25 meters from the surface. From this figure, it is noticeable that increasing the loading length from 0.2 to 1.5 *m*, the maximum settlement increases from 10 to 35 micrometers which becomes almost 3.6 times greater. In Figure 6, the variation of the surface deformation caused by changes in the loading length is depicted when the reinforcement is at a depth of 0.5 meters from the surface, it can be observed that by increasing the loading width from 0.2 to 1.5 *m* the maximum settlement is increased from 9 to 34 micrometers which is almost 3.77 times greater. As it can be observed in Figures 4-6, by increasing the length of the loading area, the settlement increased but the changes in the settlement were different by increasing the location depth of embedded geogrid. When the geogrid is close to the loading surface, deformation and settlement are lower but the lowest changes in the settlement have occurred for geogrid with the burial depth of 0.25 *m* which seems to be the optimal geogrid burial depth to reduce the effect of increased loading on the deformation.

3.1. Effect of undrained shear strength of the subgrade on the vertical deflection

In order to study the effect of the undrained soil properties, 15 models with various specimen that are used and are named as UH*q*C*c*, where *q* and *c* are the mentioned values of the embedded depth of the geogrid and undrained shear strength. For example, UH0.5C30 introduce a model with 0.5 *m* embedded depth of the geogrid and undrained shear strength equal to 30 *kPa*. In this study, undrained shear strength (C) has been chosen as 30, 50, 100, 150 and 200 *kPa*. The results of the assessment of the effect of the undrained shear strength are captured in Figures 7-9 for different location of the embedded geogrid reinforcement. These figures show that with increasing undrained shear strength, the vertical deflection decreases. Figure 7 presents the changes of the surface settlement with respect to the every shear strength of the soil within the range of 30 to 200 *kPa* when the geogrid is buried at the depth of 0.05 *m* from the ground surface. According to this figure, it can be seen that by reducing more than 80 percent of subgrade strength, the surface settlement is increased from 1.2 to 3.2 micrometers (e.g., this is around 2.6 times rather than C=30 *kPa*). In Figure 8 the variation of the surface settlement compared to the changes in shear strength of the soil within the range of 30 to 200 *kPa* when the geogrid is buried at the depth of 0.25 *m* from the pavement surface and consequently, it is shown that by reducing more than 80 percent of subgrade strength, the surface settlement is increased from 10 to 30 micrometers (around 3 times greater). Figure 9 depicts the changes of surface settlement compared to the changes in shear strength of the soil within the range of 30 to 200 *kPa* when the geogrid is buried at the depth of 0.5 *m* from the ground; in these conditions, by reducing more than 80 percent of subgrade strength, the surface settlement is increased from 10 to 25 micrometers (2.5 times greater). Consequently from these figures, it can be observed that the amount of settlement is influenced by the subgrade strength and when the geogrid is buried at the depth of 0.05 *m* from the ground, the settlement is lower and when geogrid is buried at the depth of 0.5 *m* from the ground, the settlement changes caused by shear strength have been minimal.

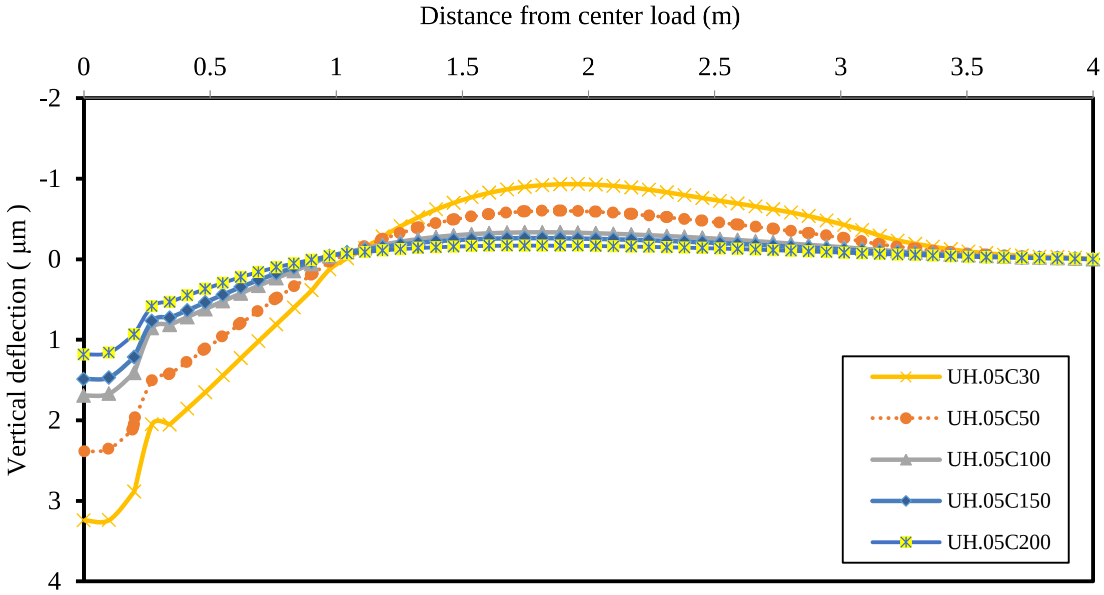


Figure 7. Vertical deflection of the pavement for various undrained shear strength of the subgrade when the reinforcement is placed at *q*=0.05 *m*.

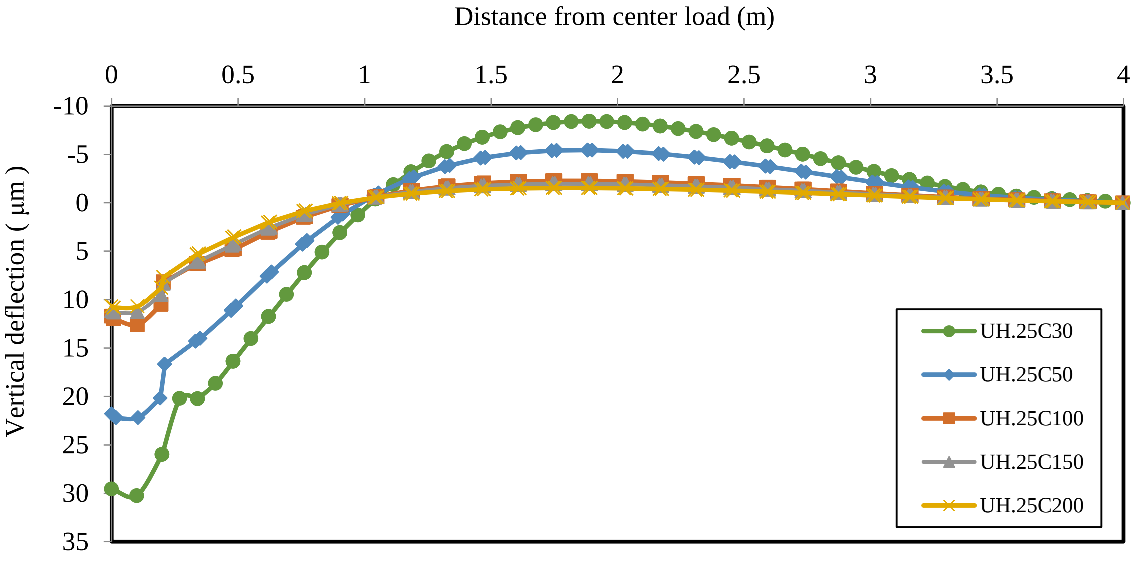


Figure 8. Vertical deflection of the pavement for various undrained shear strength of the subgrade when the reinforcement is placed at *q*=0.25 *m*.

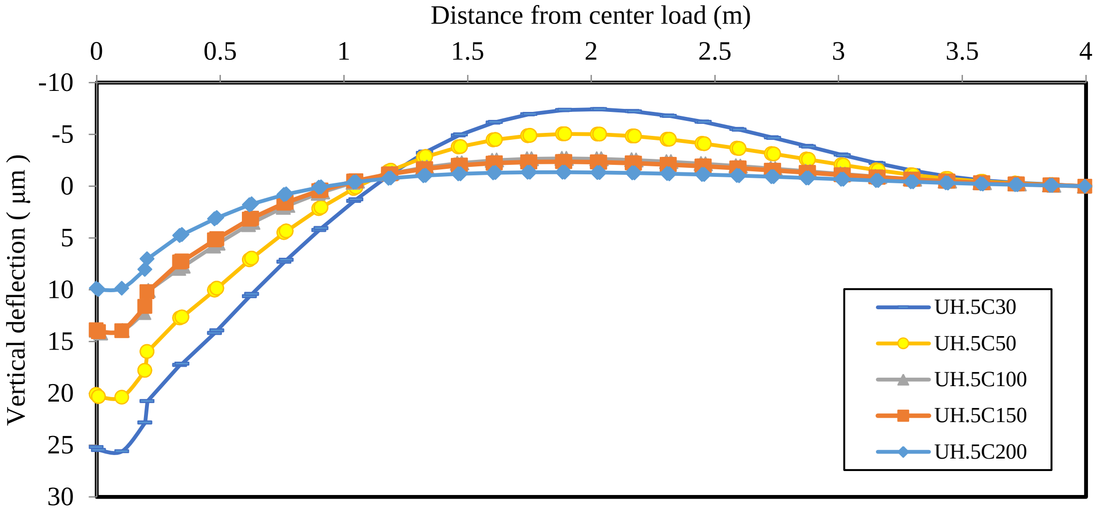


Figure 9. Vertical deflection of the pavement for various undrained shear strength of the subgrade when the reinforcement is placed at *q*=0.5 *m*.

3.2. Effect of Poisson's ratio and elastic modulus of the subgrade on the vertical deflection

In order to study the effect of Poisson’s ratio of the subgrade, 15 models with various specimen that are used and are named as H*q*Vν, where *q* and *ν* are the mentioned values of the embedded depth of the geogrid and Poisson’s ratio of the subgrade. For example, H0.25V0.3 introduce a model with 0.25 *m* embedded depth of the geogrid in a subgrade with Poisson’s ratio equal to 0.3. Also, In order to study the effect of modulus of elasticity of the subgrade, 15 models with various specimen that are used and are named as H*q*E*e*, where *q* and *e* are the mentioned values of the embedded depth of the geogrid and modulus of elasticity of the subgrade. For example, H0.25E55 introduce a model with 0.25 *m* embedded depth of the geogrid in a subgrade with modulus of elasticity equal to 55 *MPa*; in this study, the Poisson’s ratio of the subgrade (*ν*) has been chosen equal to 0.3, 0.35, 0.4, 0.45 and 0.49 and the elastic modulus of the subgrade is 45, 55, 65, 75 and 85 *MPa*. It is seen from the results which are depicted in Figure 10, that with increasing Poisson's ratio from 0.3 to 0.49, the vertical deflection will decrease around 27%. Figure 11 shows that with increasing subgrade elastic modulus, from 45 MPa to 85 Mpa vertical deflection will decrease around 48.8%.

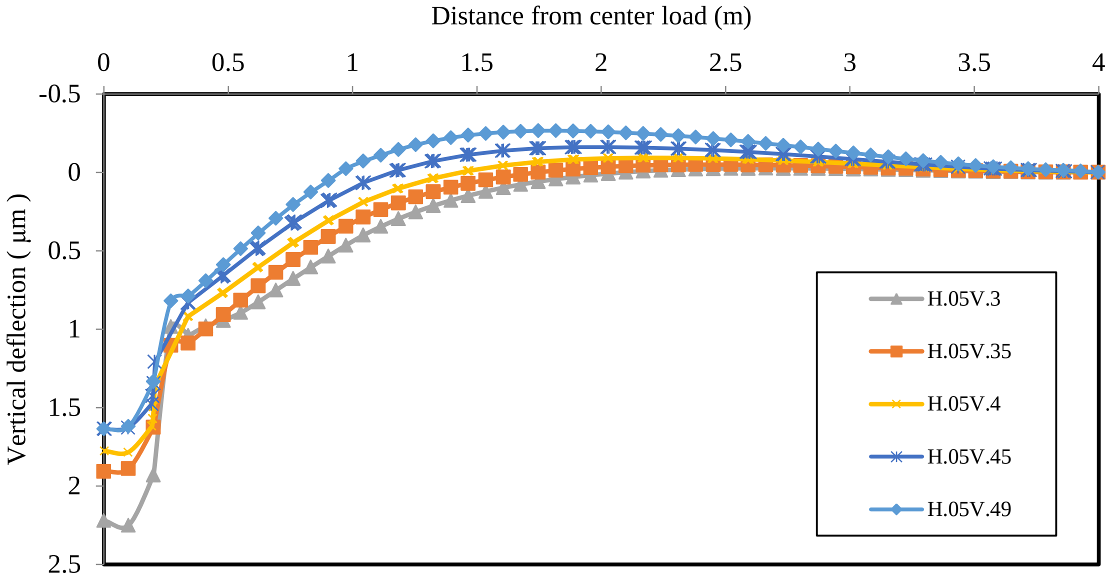


Figure 10. Variation of vertical surface deflection along horizontal direction for the models with various Poisson's ratios of the subgrade when the reinforcement is located at *q*=0.05 *m*.

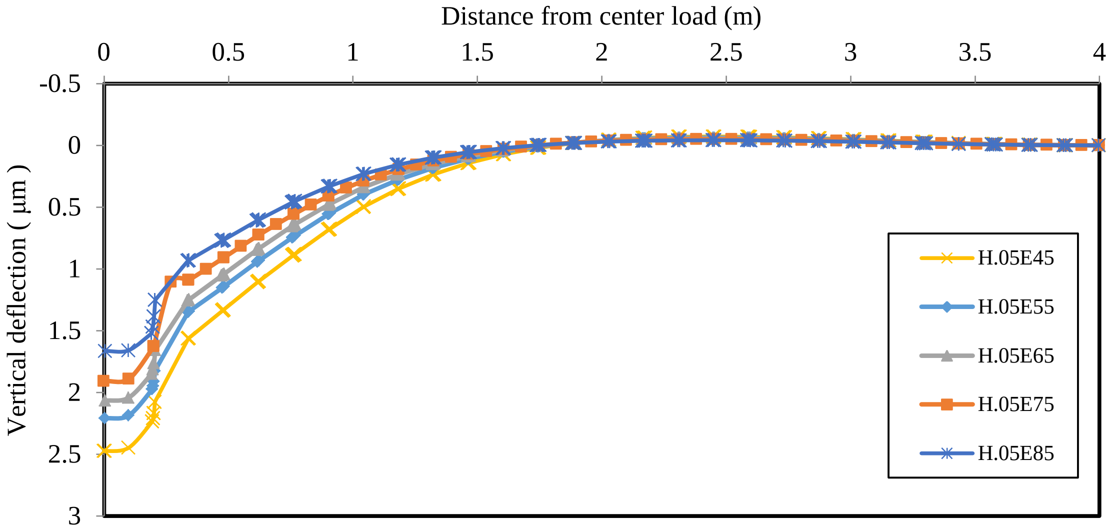


Figure 11. Variation of vertical surface deflection along horizontal direction for the models with various elasticity moduli of the subgrade when the reinforcement is located at *q*=0.05 *m*.

4. Conclusions

In this paper, a numerical 2D model using FEM software PLAXIS-2D is developed in the presence of soil-geogrid-interaction in order to evaluate the effective parameters on the performance of the rehabilitated pavement. Based on the results of this study, the following remarks can be concluded that increasing of the Poisson's ratio and elasticity modulus of the subgrade leads to a reduction of the vertical deflection. In addition, the surface settlement will decrease when the undrained shear strength is greater amount but this reduction is a function of the depth level that the geogrid reinforcement is embedded. This study showed that with increasing the length of the load area, vertical settlement have grown, but more deflection will be increased by increasing the embedded location depth of the geogrid. In general, it is noticeable that the behavior of the rehabilitated roadway is strongly affected by the parameters studied in this paper and in practical cases these should be considered.

REFERENCES

[1] Borges, J.L.,Cardoso, A.S.(2001). "Structural behaviour and parametric study of reinforced embankments on soft clays." Computers and Geotechnics,Vol.28, Issue 3,pp. 209-233.

[2] Daud, N.N., Yusoff, Z and Muhammed, A.(2015). "Ground Improvement of Problematic Soft Soils Using Shredded Waste Tyre."The Sixth Jordanian International Civil Engineering Conference (JICEC06).

[3] Gu, J.(2011). "Computational modeling of geogrid reinforced soil foundation and geogrid reinforced base in flexible pavement." A Dissertation Submitted to the Graduate Faculty of the Louisiana State University and Agricultural and Mechanical College in partial fulfillment of the requirements for the degree of Doctor of Philosophy, Hebei University of Technology.

[4] Kazimierowicz-Frankowska, K.(2007). " Influence of geosynthetic reinforcement on the load-settlement characteristics of two-layer subgrade." Geotextiles and Geomembranes, Vol.25, Issue 6,pp. 366-376.

[5] Zornberg, J., Gupta, R.(2010)."Geosynthetics in pavements: North American contributions." in Theme Speaker Lecture, Proceedings of the 9th International Conference on Geosynthetics, Guarujá, Brazil.Vol.1,pp.379-400.

[6] Hufenus, R.,Rueegger,R .,Banjac,R., Mayor, P.,Springman, S.M.,Bronnimann,R.(2006). " Full-scale field tests on geosynthetic reinforced unpaved roads on soft subgrade." Geotextiles and Geomembranes.Vol. 24,Issue1,pp. 21-37.

[7] Jenner, C. and Paul.J .(2000). " Lessons learned from 20 years experience of geosynthetic reinforcement on pavement foundations." Proceedings of the 2nd European Geosynthetics Conference. Vol.1: Mercer Lecture, Keynote Lectures, Geotechnical Applications.

[8] Perkins, S.W., Ismeik,M and Fogelsong, M.(1999). " Influence of geosynthetic placement position on the performance of reinforced flexible pavement systems." Conference:Geosynthetics '99: Specifying Geosynthetics and Developing Design Details, Vol. 1.

[9] Moghaddas-Nejad, F. and Small, J.(2003). " Resilient and Permanent Characteristics of Reinforced Granular Materials by Repeated Load Triaxial Tests." Geotechnical Testing Journal, Vol. 26, No. 2, pp. 152-166, https://doi.org/10.1520/GTJ11324J. ISSN 0149-6115.

[10] Perkins, S.W.,Cheristopher, B.,Eli L,C.(2004).“Development of design methods for geosynthetic reinforced flexible pavements.” Final report prepared for the US Department of Transportation Federal Highway Administration, Washington, DC, FHWA Report Reference Number DTFH61-01-X-00068.

[11] Perkins, S.W., Svanø, G.(2006). “Assessment of Interface Shear Growth from Measured Geosynthetic Strains in a Reinforced Pavement Subject to Repeated Loads.” Eighth International Conference on Geosynthetics, J. Kuwano and J. Koseki eds., Vol.3, pp. 813-816, Yokohama, Japan.

[12] Nair, A.M., Latha. G.M. (2014).“Large Diameter Triaxial Tests on Geosynthetic-Reinforced Granular Subbases. Journal of Materials in Civil Engineering.” Vol. 27,Issue 4, DOI: http://dx.doi.org/10.1061/(ASCE)MT.1943-5533.0001088

[13] Nazzal,M.(2007).“Laboratory characterization and numerical modeling of geogrid reinforced bases in flexible pavements.” Ph. D. Dissertation, Louisiana State University, Baton Rouge, LA.

[14] Al-Qadi, I., Dessouky, S.H.,Kwon, J and Tutumluer, E.(2008). “Geogrid in flexible pavements: validated mechanism.”Transportation Research Record: Journal of the Transportation Research Board, Issue 2045,pp. 102-109. http://dx.doi.org/10.3141/2045-12.

[15] Henry,K.S.,William,D.,Joshua,C.,Humphrey,D and Barna,L.(2009).“Structural improvements of flexible pavements using geosynthetics for base course reinforcement.” Final Report, ERDC/CRREL TR-09-11, DTIC Document.

[16] Pasquini, E., Bocci,M.,Ferroti, G and Canestrari, F. (2013).“Laboratory characterisation and field validation of geogrid-reinforced asphalt pavements.”Journal Road Materials and Pavement Design. Vol.14, Issue 1, pp. 17-35.

[17] Chan, F., Barksdale, R.D. and Brown, S.F. (1989).“Aggregate base reinforcement of surfaced pavements.” Journal of the Geotextiles and Geomembranes.Vol. 8, Issue 3, pp. 165-189. https://doi.org/10.1016/0266-1144(89)90002-2.

[18] Miura, N.,Sakai, A and Taesiri,Y.(1990). “Polymer grid reinforced pavement on soft clay grounds.” Journal Geotextiles and Geomembranes. Volume 9, Issue 1: pp. 99-123.

[19] Wathugala, G., Huang, B and Pal,S.(1996). “ Numerical simulation of geosynthetic-reinforced flexible pavements.”Transportation Research Record: Journal of the Transportation Research Board, Volume 1534 ,DOI: 10.3141/1534-09. pp. 58-65.

[20] Leng, J., Gabr, M.(2005). “ Numerical analysis of stress–deformation response in reinforced unpaved road sections.”Journal of the Geosynthetics International .Volume12,Issue2: pp. 111-119. DOI: 10.1680/gein.12.2.111.61187.

[21] Kwon, J.,Tutumluer,E and Kim,M.(2005). “ Development of a mechanistic model for geosynthetic-reinforced flexible pavements.”Journal of the Geosynthetics International.Volume 12,Issue 6: pp. 310-320. DOI: 10.1680/gein.2005.12.6.310.

[22] Siriwardane, H., Gondle, R and Kutuk, B.(2010). “ Analysis of flexible pavements reinforced with geogrids.” Journal of the Geotechnical and Geological Engineering. Volume 28, Issue 3: pp. 287-297.

[23] Nazzal, M.D., Abu-Farsakh, M.Y. and Mohammad,L.N.(2010). “ Implementation of a critical state two-surface model to evaluate the response of geosynthetic reinforced pavements.” International Journal of Geomechanics. Volume 10, Issue 5: pp. 202-212.

[24] Benmebarek, S., Remadna, M.S. and Belounar, L.(2013). “ Numerical modeling of reinforced unpaved roads by geogrid.” The Online Journal of Science and Technology. Volume 3,Issue 2,pp,109-115.

[25] Hussein, M.G.,Meguid, M.A.(2013). “Three-Dimensional Finite Element Analysis of Soil-Geogrid Interaction under Pull-out Loading Condition.” in Geo Montreal, S, Montreal, Quebec.

[26] Huang, W.C.(2014). “ Improvement evaluation of subgrade layer under geogrid-reinforced aggregate layer by finite element method.” International Journal of Civil Engineering. Volume 12, Issue 3: pp. 204-215.

[27] Palmeira, E.M.(2009). “Soil–geosynthetic interaction: Modelling and analysis.” Geotextiles and Geomembranes. Vol. 27,Issue 5, pp. 368-390.

[28] Khaji, N. and Khodakarami, M.(2012). “A semi-analytical method with a system of decoupled ordinary differential equations for three-dimensional elastostatic problems.” International Journal of Solids and Structures. Vol. 49,Issue 18,pp. 2528-2546.

[29] Khodakarami, M. and Khaji, N.(2011). “Analysis of elastostatic problems using a semi-analytical method with diagonal coefficient matrices. Engineering Analysis with Boundary Elements.” Vol. 35,Issue 12,pp. 1288-1296.

[30] Khodakarami, M. and Khaji,N.(2014). “ Wave propagation in semi-infinite media with topographical irregularities using Decoupled Equations Method.” Soil Dynamics and Earthquake Engineering. 65,pp.102-112. http://dx.doi.org/10.1016/j.soildyn.2014.06.006.

[31] Khodakarami, M., Khaji, N and Ahmadi, M.(2012). “Modeling transient elastodynamic problems using a novel semi-analytical method yielding decoupled partial differential equations.” Computer Methods in Applied Mechanics and Engineering. Volumes 213–216, pp. 183–195, http://dx.doi.org/10.1016/j.cma.2011.11.016.

[32] Mirzajani, M., Khaji, N and M. Khodakarami, M.I.(2015). “A new global nonreflecting boundary condition with diagonal coefficient matrices for analysis of unbounded media.” Applied Mathematical Modelling.Vol.40,Issue4,pp.2845–2874. http://dx.doi.org/10.1016/j.apm.2015.09.083.

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

[34] PLAXIS. Reference manual, 2D – version 9.0, PLAXIS. Delft, Netherlands: Delft University of Technology; 2008.