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Research paper

Behavior of flexible pavement on swelling subgrade soil reinforced with geogrid

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Abstract: An enormous number of structures and roads are put on expansive subgrade soils and may be exposed to the swelling and shrinkage risk. To prevent the expanding weight of the subgrade layer under loaded pavement, one of the following strategies may be utilized are geogrid layer. Reinforced pavement layers have been propagated in the field of civil engineering because of their profoundly adaptable and diversified use. In this study, axisymmetric models of pavement layers have been created by 2-D Plaxis software and all of these models included geogrid layers at various positions concentrated to research the impact of geogrid on the critical pavement responses. Geogrid was placed at the bottom of asphalt layer, bottom of base layer, tope and middle of the subgrade layer. All models are loaded with incremental contact pressure between 50 and 600 kPa. Analysis processes have been made for all models and the obtained investigation results show a significant effect on pavement behavior when the a geogrid layer was used under various tire pressures. Also, there is an increase in the bearing capacity of a model that includes geogrid at the top and middle of the subgrade layer by about 35% and the resistance of the asphalt layer to deformation and cracking failure was improved.

Keywords: expansive, subgrade, geogrid, repeated load, settlement, asphalt pavement

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1. Introduction

Subgrade which is named formation level is the basis of pavement structure and the significances of it are to prohibit excessive rutting, give great sustenance for all pavement layers above it, limit pavement rebound deflections to acceptable frontiers, and straiten the development of exaggerated permanent deformation in pavement structure during its service life [10]. Subgrade quality has been greatly influencing pavement design, performance, and its service life, wherever road layers have been constructed on bad soils (like expansive soils); bad conditions and unpredictable behavior will be found for all pavement layers above this soil [12]. During recent years, the development of the transportation network has made designer's work so difficult when the location is including areas with many difficulties like expansive or swelling soil. Many plastic types of clay swell considerably when water is added to them and then shrink with the loss of water. Soils that exhibit the greatest volume changes from dry to wet state usually possess a considerable percentage of montmorillonite [6].

2. Expansive soil underneath pavement layers

Light structures (like roads) impacted by expansive soil could not stand against the upward pushing introduced from these expansive soils. Some years beyond the construction, the damage will be obvious and soil below will exert swelling pressure both upwards and laterally. As a result, the subgrade of the road and floor slab is lifted while cracking is normally evident at the road's surface at the same time [14].

The danger from such soils can be eliminated by the technique of soil stabilization where it is a combined term for any physical, chemical, or biological manner or any combination of such methods employed to ameliorate or change definite properties of natural soil to make it avail for meant engineering work [15]. Soil stabilization can be achieved by many techniques (mechanical, chemical, and physical stabilization) to improve the soil strength, workability, durability, and reduce its volume change due to temperature or moisture [13].

Geosynthetics which involve geotextiles, geogrids, and geomembranes are materials used to improve soil conditions; where geotextiles were used to detach the materials, reinforcing, filtering, draining, and/or providing a moisture barrier [7]. By utilizing geotextiles; subgrade clay and subbase separating can be achieved, load-bearing capacity can be increased and fine-grained soil preservation from conveyance and channeling unwanted water away can be done.

3. Expansive soil reinforcement

Reinforcement technique has been used to prevent the movement of soil particles by improving the tensile bond (caused by friction, adhesion, or interlocking) at the soil-reinforcement interface and optimal case can be obtained by rotating the reinforcement in the direction of main principal tensile strains. In clay, the adhesive bond is poor and subject to reduction by the development of positive pore pressure, the possible volume change of some expansive clay minerals, and the aggressive effect of some minerals on metal reinforcement [3].

Several researches have been conducted to investigate the effectiveness of using reinforcement technique to improve soil properties [2, 4, 5, 8, 9, 11]. These researchers found that using reinforcement materials for soil stabilization will improve the properties of soils such as an increase in cohesion, modulus of elasticity, compressibility and displacement.

4. Research objective

The research aims to evaluate the settlement of the pavement layers on expansive subgrade soil under moisture effect with and without the possibility of using different types and numbers of geogrid reinforcement layers to reduce these changes under heavy traffic load. The evaluation is done by using numerical analysis through the software (PLAXIS 2D) to find the effect of reinforcement geogrid layers on the behavior of expansive subgrade soils.

5. Finite element model

Numerous external and internal factors affect the performance of asphalt pavement; traffic load is one of these factors (act as an external factor) that affect the pavement performance over time [8]. 2-D PLAXIS software version 2018 V 6.4 used in this study to create a flexible pavement model. The model consists of four layers: asphalt concrete surface layer, crushed gravel base layer, granular subbase layer placed on expansive subgrade layer. All model layers are exposed to repeated cycling load with 0.1 second loading period. The estimation of model responses (unreinforced and reinforced) has been evaluated under a repeated cycling load (25, 50, 100, 200, 400, and 600) kPa as uniform pressure applied on a circular area (radius 0.3 m) with a frequency of 10 Hz which is corresponding to 0.1 seconds duration; the duration time between two subsequent axles is assumed to be 0.2 seconds. Besides, the asphalt and geogrid layers were modeled as linear elastic materials whereas the base and the subbase layers were modeled using the Mohr–Coulomb model.

An axisymmetric model, shown in Figures 1 and 2, was utilized in the analysis using 15 node structural solid elements with medium refinement. Simulating a circular loading by 2-D PLAXIS software may take too much time in the computational analysis process. Therefore, an axisymmetric model was chosen in this research as a replacement to the full sketch model.

Alex 2000 indicted that "the nodal radial strains were assumed to be negligible at approximately 10 times R (radius of the loaded area) from the area applied wheel load and the nodal stresses and displacements were assumed to be negligible at 20 times R below the pavement surface". Therefore, the model scale was set at 10 m for width and length dimension, and 2.6 m thickness. The base of the model was restricted from the movement by fixing it in both the vertical and horizontal directions while the edges were restricted from the horizontal movement only. Also, the side and bottom boundaries are assumed to be impermeable to ensure no flow is allowed through these portions.

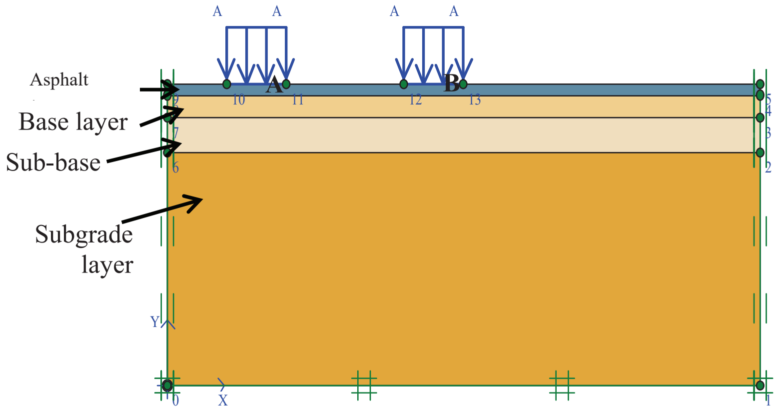


Fig. 1. Finite element axisymmetric model for unreinforced pavement

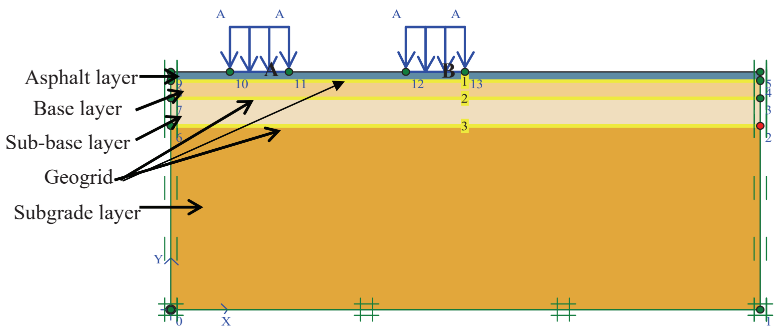


Fig. 2. Finite element axisymmetric model for reinforced pavement

The material parameters used for innovator models are shown in Table 1 whereas Table 2 shows the mechanical properties of geogrid reinforcement.

Table 1. Pavement materials properties

Layer type	Asphalt	Base	Sub-base	Subgrade
Model	Linear elastic	Linear elastic	Mohr coulomb	Mohr coulomb
Thickness (m)	0.1	0.2	0.3	2
Dry density (kN/m^3)	22	20	17	18
Saturated density (kN/m^3)	–	22	19	21
Young modulus (kPa)	1 200 000	100 000	50 000	2000
Cohesion (kN/m^2)	–	1	5	80
Friction angle (degree)	–	43	39	8
Poisson's ratio	0.35	0.3	0.3	0.15
Permeability, kx, ky (m/sec)	–	1.16×10^{-5}	5.78×10^{-6}	1.16×10^{-8}

Table 2. Geogrid materials properties

Geogrid type	G1	G2	G3	G4
Model	Geogrid	Geogrid	Geogrid	Geogrid
Elastic axial stiffness (KN/m)	1000	450	200	90
Poisson ratio	0.25	0.25	0.25	0.25

6. Results and analysis

6.1. Load – settlement

Figure 3 illustrates the vertical displacement for point A and B at the surface and under the center of load under an applied pressure of 600 kPa for unreinforced pavement model in dry and saturated conditions. It can be noticed that the settlement decreased as the water table is lowered and this effect appears clearly when the pressure exceeds 400 kPa as shown in Table 3. The reduction rate in settlement about 14.58% and 11.02% for points A and B, respectively when the soil is dried, this may be due to the strength properties of swelling soil in the dry condition.

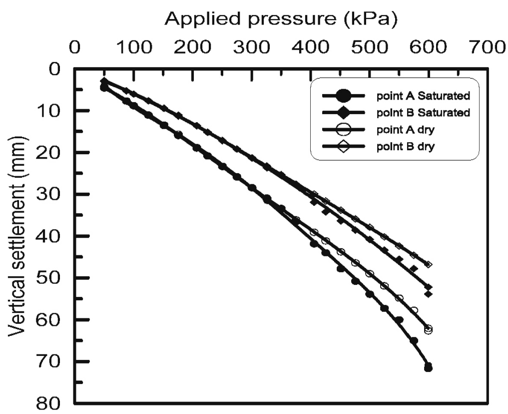


Fig. 3. Load – settlement relationship for unreinforced pavement in dry and saturated conditions

Table 3. Settlement value for points a and b

condition	settlement (mm)	
	A	B
Dry	62.54	46.72
Saturated	71.66	51.87

The inclusion of a geogrid also acts to increase the bearing capacity of subsurface aggregates. By transferring part of the shear stresses induced in the subsurface to the geosynthetic, which is able to accept tensile forces and distribute them over a large area. Use of geogrid reinforcement in a pavement system ensures a long-lasting pavement structure by reducing excessive deformation and cracking.

6.2. Effect of number of geogrid layers

The effect of geogrid layers numbers is illustrated in Figure 4 which shows the vertical surface settlement at point A under 600 kPa applied pressure in saturated conditions. The geogrids are placed under the asphalt layer while the others are placed under the base and subbase layers. It can be noted that the vertical settlement value is affected by geogrid layers and the maximum reduction is shown in the reinforced model of three-geogrid layers; as well as this conductance will be led to a decrease in the settlement in the subgrade layer also. Also, similar values have been found in models of one and two-geogrid layers.

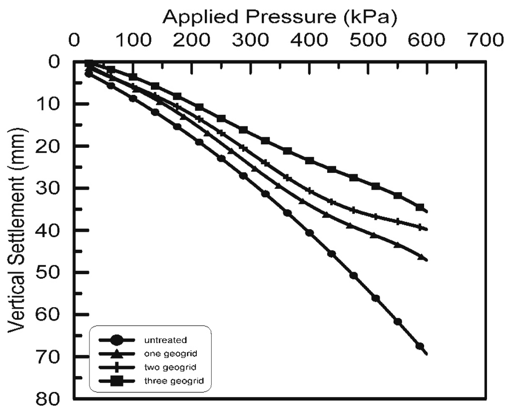


Fig. 4. Load–settlement relationship for reinforced pavement (geogrid elastic axial stiffness = 1000 kN/m

In dry conditions, the effect of using geogrid layer has low significance on vertical settlement when using two and three-geogrid layers as shown in Figure 5. Also, the settlement values of

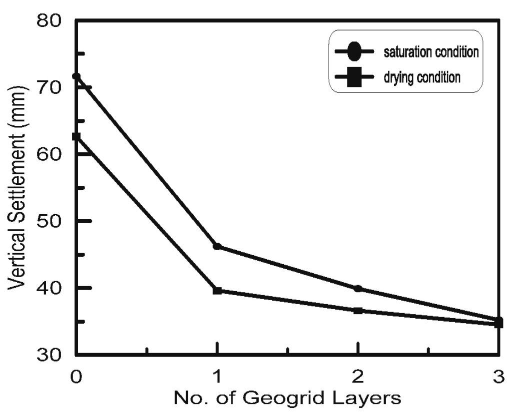
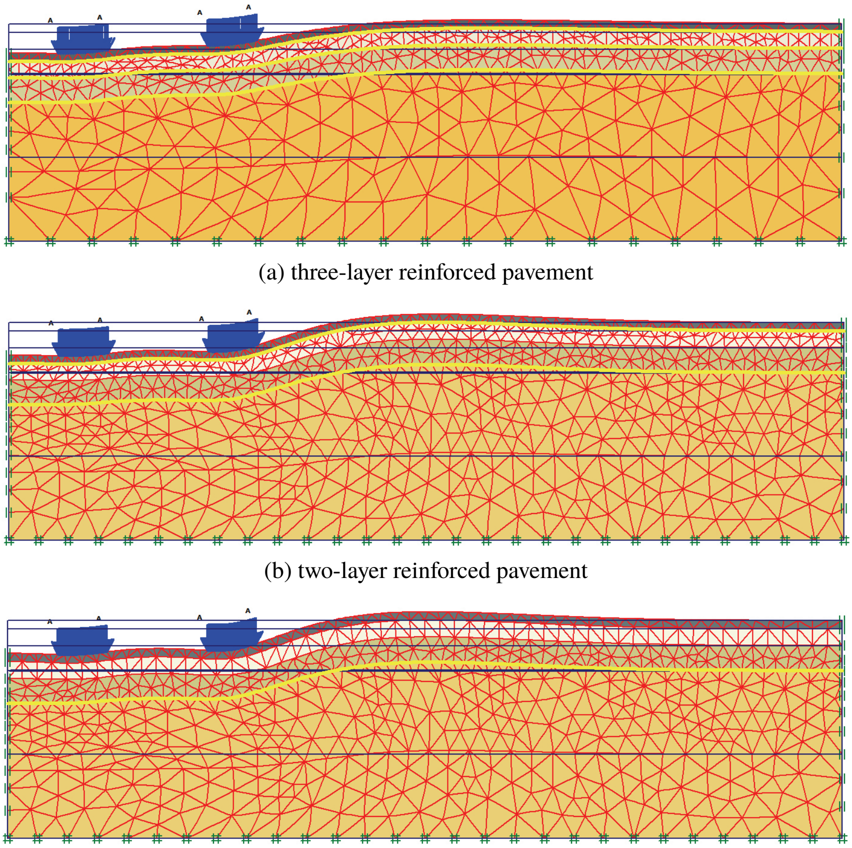


Fig. 5. Effect of geogrid layers No. on vertical surface settlement

the subgrade soil reinforced with three geogrid layers under dry and saturation conditions are approximately close; this may be due to the strength of the dry subgrade layer. Figure 6 shows the deformed mesh under applied axel pressure for different geogrid layer positions.



(a) three-layer reinforced pavement

(b) two-layer reinforced pavement

(c) one-layer reinforced pavement

Fig. 6. Vertical surface settlement profile using different numbers of geogrid layers

6.3. Effect of geogrid stiffens

Execution of pavement structure is affected by the elastic axial stiffness of geogrid which represents one of the significant geogrid reinforcement properties. The effect of tensile modulus on the pavement performance included three types of geogrid with stiffness ranged between 100 and 420 kN/m. Figure 7 shows the vertical settlement of unreinforced and reinforced pavement models with different elastic modulus values. It can be noticed that pavement with geogrid reinforcement of higher tensile modulus has a higher reduction in settlement by about (51%, 44%, 43%) for three, two, and one layer respectively under saturation conditions compared with unreinforced model.

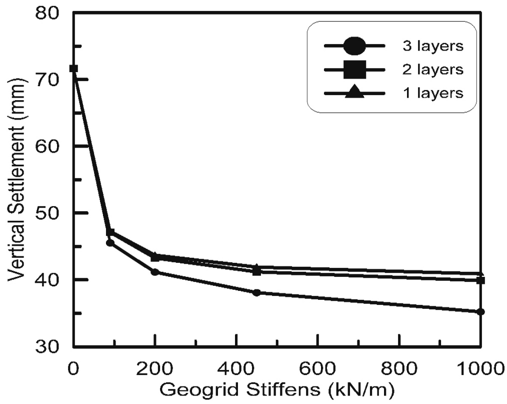


Fig. 7. Effect of the geogrid stiffens on the vertical surface settlement in saturation condition

Also, as the tensile modulus increase, the effect on vertical settlement has low significance especially in one and two layers. Figure 8 shows the vertical settlement of unreinforced and reinforced pavement with different elastic modulus values under dry conditions. It can be observed that the effect of high geogrid stiffness is more significant while its effect became little at lower value of stiffness especially for two and three layers.

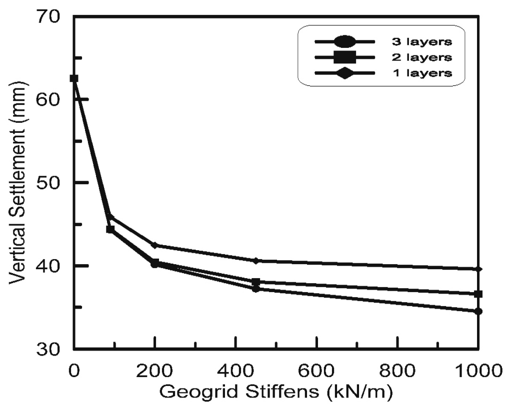


Fig. 8. Effect of the geogrid stiffens on the vertical surface settlement in dry condition

7. Conclusions

A series of FE models have been analyzed to evaluate the effect of using geogrid layers in different positions and stiffnesses on swelling subgrade soil. The following conclusions are drawn from this study:

1. Significant reduction in the vertical settlement about (51%, 44%, and 43%) as using 3, 2 and 1 geogrid layers of 1000 kN/m stiffens under saturation condition and 600 kPa traffic pressure. The rate of reduction in vertical settlement about (45%, 41%, and 37%)

as using 3, 2 and 1 geogrid layers of 1000 kN/m stiffens under dry condition and 600 kPa traffic pressure.
2. Using 3 geogrid layers has a more significant effect on the vertical settlement under dry and saturation conditions. The reduction in settlement is about 75% and 100%, respectively.
3. Increasing the stiffens of geogrid from (90 to 1000 kN/m) increase the rate of reduction in settlement about (36% to 51%) under saturation condition and 600 kPa traffic pressure.
4. Using 2 geogrid layers one at the base of the asphalt and subbase layers with stiffens (200 to 1000 kN/m) under saturation condition reduced the vertical settlement at a rate close to that for 3 geogrid layers.
5. In the dry condition, using 1 geogrid layer at the base of the subbase layer with stiffens (200 to 450 kN/m) diminished the vertical settlement at a rate close to 2 layers.
6. The best location for adding geogrid within the pavement structure is near to applied tire pressure within the asphalt layers for each condition.

8. Data availability

The authors affirm that the information supporting the discoveries of this investigation is accessible inside the article or its strengthening materials.

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