Evaluation of Geogrid-Reinforced Flexible Pavement System Based on Soft Subgrade Soils Under Cyclic Loading

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Abstract

Geogrids have been successfully used to improve soft subgrade and reinforce weak base course by providing lateral confinement. However, Soft saturated fine-grained subgrade soils are distinguished by their high compressibility and low undrained shear strength. Moreover, when the stress is applied on the soft foundation soil resulting from repeated traffic load causing the soil particles to press together and the volume of the soil will decrease resulting in settlements. While applying stress on saturated soft foundation soil due to the increase of the water stress is squeezed out of the soft subsoil causing settlements. In this regard, geogrid reinforcement is the soil improvement technique which proposed to be used in this study to provide a solution for this problem. Using these techniques has been contributing to enhancing the pavement performance systems including the increase of the pavement service life. To simulate the above-mentioned situation, the experimental work included two models: raw materials model and geogrid model. A laboratory model tests are carried out to simulate the asphalt pavement layers and design cycling load system equivalent to the standard single axle load, which were prepared throughout a design and assembling of steel Container model. In this study, development of three-dimensional finite element models for flexible pavement system based on the numerical study has been carried out throughout the application of elastic model using ABAQUS software ver.6.14.4 to simulate and analyze the relationship between the number of applied load cycles and permanent displacement for the pavement layers of two model. The test results that recorded at 1600 cycle load, showed that the permanent displacement at the surface of pavement for improved models and compared with the raw material model has seen decreases by (7.75%). Also, by using the reinforced model is found to be more effective to resist vertical strain under cyclic load at the surface of subgrade soil if compared with the raw material model. Moreover. The results of ABAQUS program are very close to results of laboratory tests.

Keywords: Geo-Grid Reinforcement, Soft Subgrade, ABAQUS.

1. Introduction

Highway pavement constructed on soft subgrade soil is prematurely subjected to excessive rutting, permanent deformation, and cracking. However, to distribute the vertical load that induced by a moving wheel load in a roadway to the ground, soft subgrade soils are subjected to repeated loads due to heavy traffic will cause an increase of the stress in the soft subsoil. Due to the increase of stress creep and consolidation occur in the subsoil (Jie Gu, 2011). Soft saturated fine-grained soils are distinguished by their low undrained shear strength (Cu <40kPa) and high compressibility. Such soils cover most of the southern part of Iraq. Random data collected from several site investigations reports demonstrated values of undrained shear strength less than (30kPa) in Basrah governorate and less than (40kPa) in Missan and Nasirya governorates (Rahil, 2007). Such soils are classified as poor for road construction. Where the importance of this study applies to the road network in Iraq especially most of the southern area with weak soil, several techniques have been developed and applied to enhancement the pavement performance. Geogrids materials have been successfully used for subgrade soils improvement and base reinforcement for unpaved and paved roads in the past several decades, in a pavement system, the most effective location the inclusion of geogrids layer at the interface between a pavement granular course and subgrade can significantly improve the performance of the pavement on a soft subgrade soils.

2. Objectives of Study

The main objectives of the present study are to investigating, evaluating experimentally the effect of using a geogrid layer to improve the performance of soft subgrade soils beneath flexible pavement structure under cyclic loading. Also, developing a three-dimensional developmental finite element model based numerical study has been carried out using ABAQUS software ver.6.14.4 to simulate and analyze the relations between the cyclic loading and deformation of the proposed models for pavement system which includes: raw material model and geogrid model.

3. Experimental Work

3.1. Materials Property

3.1.1. Soil

The soil used to prepare the soft subgrade layer in the model is brought from a depth of (4m) from sports city site, north of Baghdad city. Standard tests are performed to determine the physical and chemical properties of the soil, details are given in Table 1. The grain size distribution is performed according to (ASTM D 422), as shown in Figure 1.

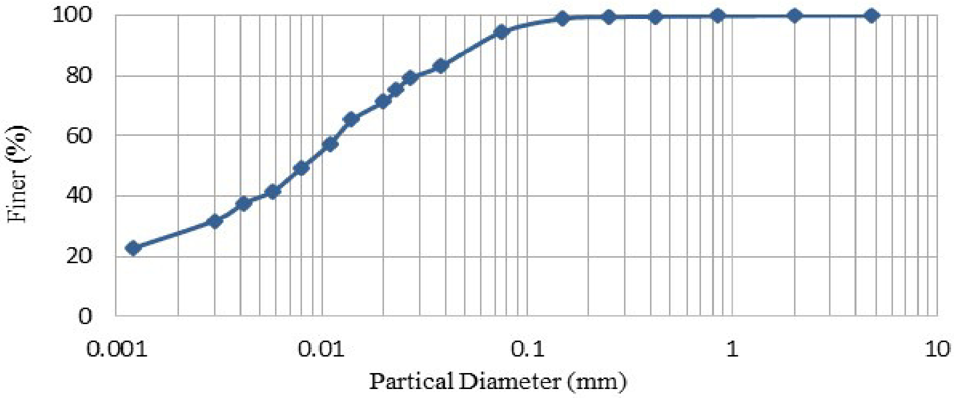

Figure 1. Grain Size Distribution of Soil

Table 1. Physical and Chemical Properties of Soil Used.

Property		Value	Standard
Liquid limit (LL) %		41	ASTM D 4318
Plastic limit (PL) %		18	ASTM D 4318
Plasticity index (PI) %		23	
Specific gravity (Gs)		2.7	ASTM D 854
Maximum dry unit weight (KN/m^3)	Modified Proctor test	18.34	ASTM D 1557
Optimum moisture content (%)		12.5	
Total dissolved salts (TDS) %		1.3	BS 1377 test No.10
SO_3 content %		0.6	BS 1377 test No.9
Organic matter (O.M.) %		0.45	ASTM D 2974-00
Calcium oxide (CaO) %		0.38	BS 1377 test No.8
pH %		8.9	BS 1377 test No.11

3.1.2. Subbase (Embankment Fill Material)

The subbase is brought from Al_Nibaee quarry, north of Baghdad. The subbase is ordinarily used as a fill material for embankment layer in flexible pavement construction. The grain size distribution of subbase is performed according to (ASTM D422), as shown in Figure 2. The subbase is classified as (GW) according to the Unified Soil Classification System (USCS) and classified as a class (B) according to the standard specifications for the State Corporation for Roads and Bridges (SCRB, 2003).

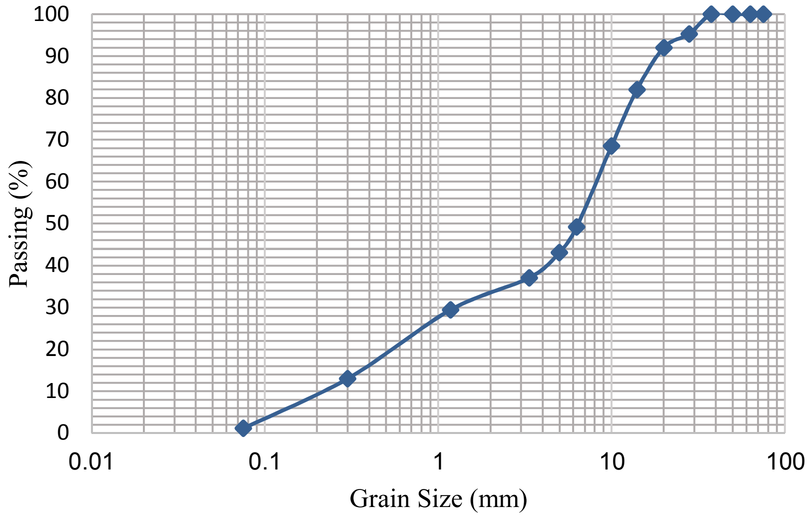

Figure 2. Grain Size Distribution of Subbase.

3.1.3. Base

Base layer consists of durable crushed limestone, filler and weighting aggregate according to State Corporation for Roads & Bridges in Iraq (SCRB, 2003).

3.1.4. Asphalt Cement

The binder used in this study is asphalt cement (40-50) penetration grade is obtained from the Daurah Refinery, southwest of Baghdad. The physical and chemical properties of the asphalt cement, which are presented in Table 2.

Table 2. The Physical Properties of Asphalt Cement.

Tests	ASTM Designation	Units	Test Result	SCRB Specification
Penetration at 25˚C, 100g, 5sec	D 5	(1/1mm)	43	(40-50)
Ductility at 25˚C, 5 cm/min	D 113	(cm)	110	(>100)
Flash Point (cleave land open cup)	D 92	(C˚)	260	(>232)
Softening point (ring and ball)	D 36	(C˚)	51	------

3.1.5. Aggregate

Natural fine and crushed coarse aggregates used in this research are brought from Al-Nibaee quarry in Taji, north of Baghdad. The physical properties and chemical properties of the of the aggregate (coarse and fine) are shown in Table 3. and Table 4. The gradations that were selected in this study follows the mid gradation according to (SCRB, 2003) for hot-mix bituminous paving mixtures of aggregate nominal size (12.5 mm) (wearing layer gradation). Table 5. and Figure 3. show the gradation for wearing layer.

Table 3. Physical Properties of Nibaee Aggregates.

Property	Coarse Aggregate	Fine Aggregate
Bulk Specific Gravity (ASTM C127 and C128).	2.610	2.631
Apparent Specific Gravity (ASTM C127 and C128).	2.641	2.680
Percent Water Absorption (ASTM C127 and C128).	0.423	0.542
Percent Wear (Los Angeles Abrasion) (ASTM C131)	20.10	……

Table 4. Chemical Composition of Al-Nibaee Aggregate.

Chemical Compound	% Content
Silica, SiO2	82.52
Lime, CaO	5.37
Magnesia, MgO	0.78
Sulfuric Anhydride, SO3	2.7
Alumina, Al2O3	0.48
Ferric Oxide, Fe2O3	0.69
Loss on Ignition	6.55
TSS (total soluble salts) %	1.85
Mineral Composition	
Quartz	80.3
Calcite	10.92

Table 5. Aggregate Gradation for Wearing Course.

Sieve size	Sieve opening (mm)	Percentage passing by Weight of total Aggregate	
		(SCRB) Specification Limits	Mid-point Gradation
3/4"	19	100	100
1/2"	12.5	90 - 100	95
3/8"	9.5	76 - 90	83
No. 4	4.75	44 - 74	59
No. 8	2.36	28 - 58	43
No. 50	0.3	5 - 21	13
No. 200	0.075	4 - 10	7

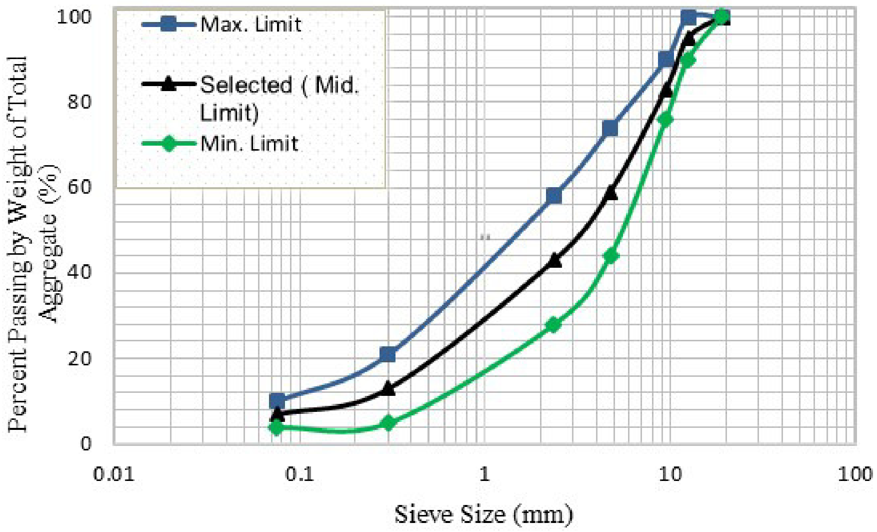

Figure 3. Specification Limits and Selected Mid-Point Gradation.

3.1.6. Mineral Filler

One type of mineral filler used in this study is ordinary Portland cement. it is thoroughly dry and free from lumps or aggregations of fine particles. The physical properties and chemical composition are shown in Table 6.

Table 6. Physical and Chemical Properties of Portland Cement.

Passing sieve No. 200%	98
Apparent Specific Gravity	3.1
Specific Surface Area (M^2/kg*)*	3.55
Silica, SiO2	21.52
Lime, CaO	62.5
Sulfuric Anhydride, SO3	1.6
Alumina, Al2O3	5.63
Magnesia, MgO	3.76
Ferric Oxide, Fe2O3	3.32
Loss on Ignition	1.30

3.1.7. Geogrid Reinforcement

The geogrid material used in this study is Pars Mesh Polymer (PMP) Type SQ12, manufactured by the Iranian company Pars Mesh Polymer. Table 7. Summarizes the physical and mechanical properties of geogrid used.

Table 7. Physical and Mechanical Properties of Geogrid Reinforcement.

Physical Properties		
Property	Data	
Mesh type	Square	
Color	Green	
Polymer type	HDPE	
Packaging	Rolls	
Dimensional Properties		
Property	Unit	Data
Aperture size	mm	12x12
Mass Per unit area	g/m2	318
Roll Width	m	1.2
Roll Length	m	30
Technical Properties		
Property	Unit	Data
Elastic modulus	MPa	25
Tensile strength at ultimate	MPa	0.25
Percentage elongation at maximum load	%	1

3.2. Preparation of Slab Asphalt Pavement

To simulate of a flexible pavement layer, asphaltic slabs are prepared for each model. The dimensions of the slab (300 mm) in length, (300 mm) in width and (50 mm) in height as proposed by (EN 12697-33, 2003). To obtain an asphalt slab, approximately (10575 gm) of asphalt mixture is prepared for wearing layer. Also, the asphaltic slab mix is compacted in the heated mold using the Roller Compactor machine, as shown in Figure 4.

Figure 4. Preparation of Slab Asphalt Concrete.

3.3. Experimental Setup

To study and investigate the optimal way to improve the strength of pavement layers over weak subgrade; an experimental setup is designed and assembled to achieve this goal as shown in Figure 5. This loading system used in this study is manufactured by (Mohammed, 2015). The contact area of loading in the model is circular with a diameter (8 cm) and consists of two parts (steel and rubber). The thickness of steel part (1 cm) and thickness of rubber part (1.5 cm) which is to be in contact with asphaltic pavement layer surface are (1.5 cm) to simulate rubber tire contact. A total load of (2.75 KN) is applied which produces a contact stress of (550 kPa).

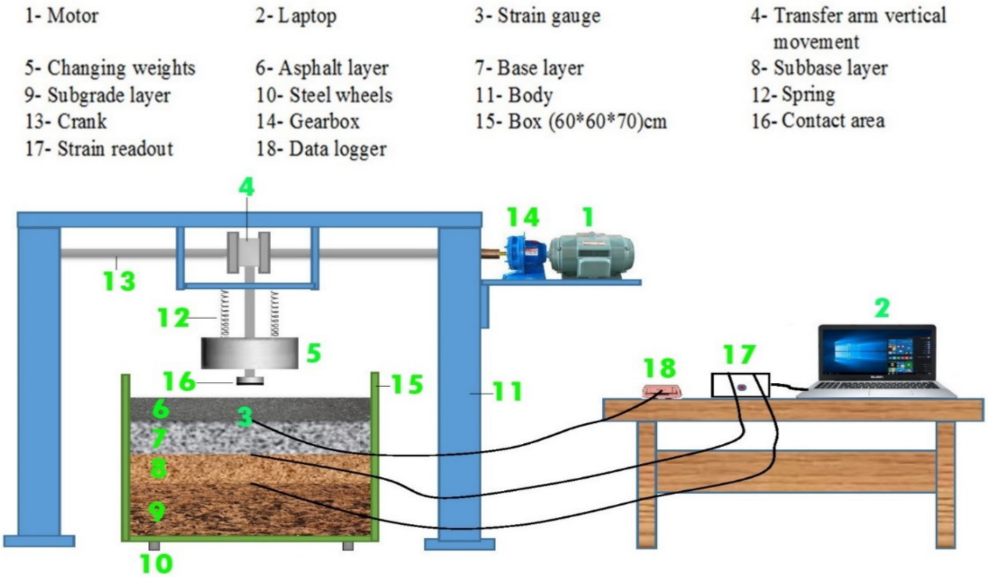

Figure 5. Experimental Test, Steel Box, Loading System Setup.

3.4. Laboratory Model Setup

3.4.1. Raw Material Model

The bed of soil is mixed with a quantity of water until reached the homogenous status just before starting to apply repeated traffic loading to test multilayers model's system. Then, the soil placed in five layers inside a steel container of (600 * 600 * 700) mm, each layer was tamped gently by manual steel hammer. This process is continuing until the required thickness (300 mm) of soil is reached in the steel container. Then, the subbase layer is placed on of the subgrade soil and compacted manually by steel hammer till the desired subbase layer thickness (150 mm) is achieved. After that, Preparation of Base layer of thickness (150 mm) consists of durable crushed limestone, filler and weighting aggregate according to (SCRB, 2003) specification for the base course. After the preparation of the base layer, the slab specimen of asphalt is placed on the surface of the base layer, the slab specimen of asphalt is placed on the base layer and the wood collar is put around the pavement to avoid movement of asphalt slab in the model. Figure 6. shows the cross-section view of raw materials model.

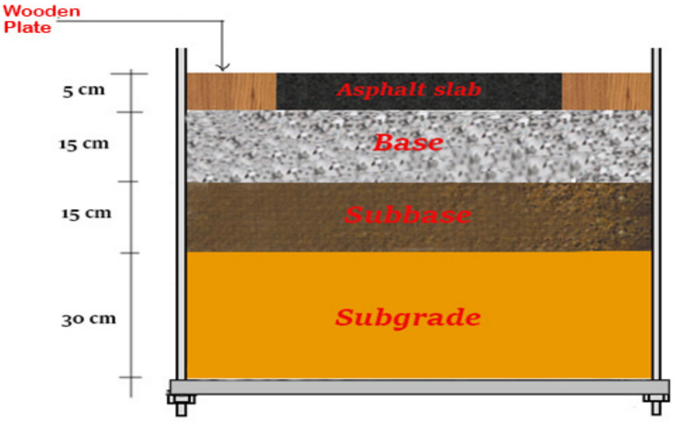

Figure 6. Cross-Section View of Raw Materials Model.

3.4.2. Reinforced Model

After the preparation of the weak soil's bed inside the steel container of (600 * 600 * 700) mm, the HDPE geogrids reinforcement layer is placed flat above the layer of subgrade soil with care to avoid any wrinkles in case of the geogrid reinforced model and then folded at 90° at the steel box sides, as shown in Figure 7., to obtain the necessary slight pre-tensioning and Anchorage, as well as to avoid shifting of the geogrid layer out of position (Al-Utbi, 2011). After complete the process, the construction of the subbase and base layer begins. Then, the asphalt slab is placed on the base layer. Figure 8. shows the cross-section view of the geogrid model.

Figure 7. Place HDPE Geogrid layer above Subgrade Layer.

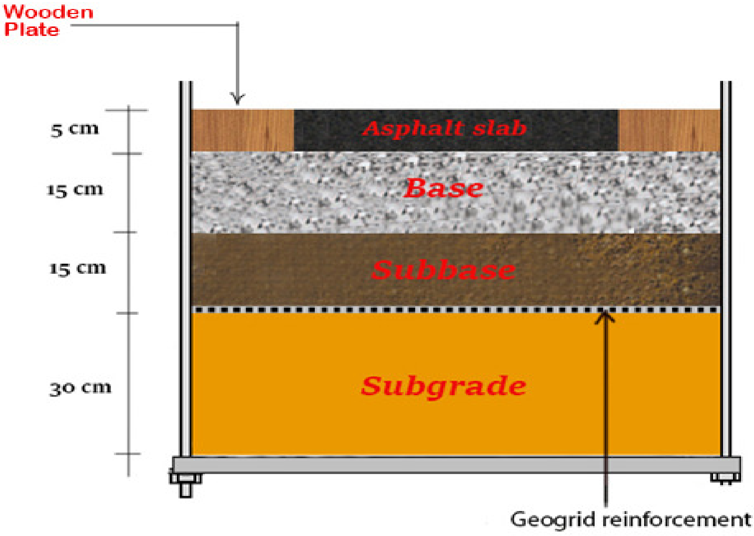

Figure 8. Cross-Section View of Geogrid model.

3.5. Results of Experimental Work

3.5.1. Displacement of the pavement surface Test Results

The data obtained from the experimental work is permanent displacement for each layer in the model, figure 9. shows the relation between permanent displacement and the number of applied load cycles for the asphalt concrete (AC) layer. It can be noted that, based on the presented results, the trend that the permanent displacement accumulated with the increase in the number of load cycles. Furthermore, the permanent displacement at load cycle number (1600) for the surface pavement layers and compared with the raw material model results is can be seen a decrease by (7.75%).

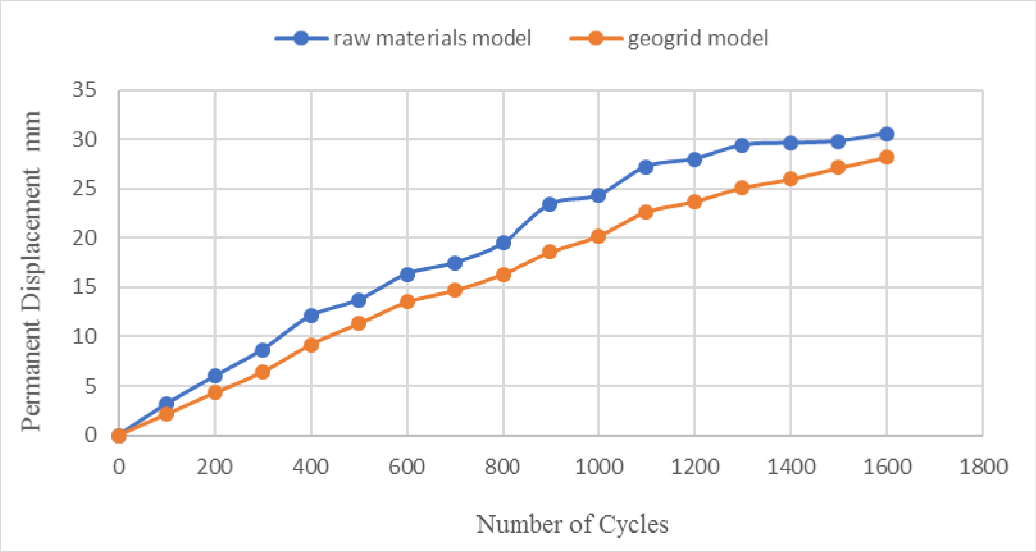

Figure 9. Permanent Displacement versus Number of Load Cycles for Asphalt Concrete (AC) Layer for two models.

3.5.2. Vertical Stain of the Subgrade Surface Test Results

Figure 10. shows the relation between the vertical strain and number of applied load cycles of the subgrade layer for the models. It is observed that the vertical strain increases with the increase of a number of applied load cycles. Generally, the maximum value of vertical strain can be noticed in the raw material model, while the minimum value of vertical strain can be shown in the geogrid model.

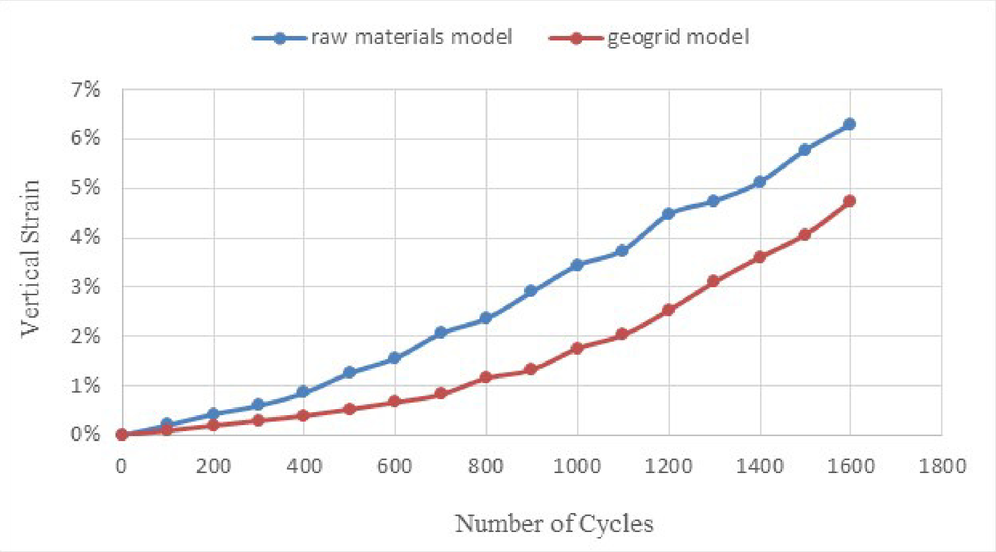

Figure 10. Vertical Stain versus Number of Load Cycles for Subgrade Layer for two models.

4. Finite Element Modeling

4.1. Pavement Layers Modeling based on ABAQUS Program

4.1.1. Model Geometry

Assuming the model dimensions of (600mm) length, (600mm) width, and (700mm) depth is selected that consists of four layers of pavement structure; asphalt concrete (AC), base, subbase, and subgrade. The pavement layers are modeled as 3D model, the pavement structure is simulated, as shown in Figure (5.2). The thickness of the asphalt concrete (AC) layer is (50mm), base layer (150mm), subbase layer (150mm) and subgrade (300mm).

4.1.1.1 Model Geometry for Raw Materials

The pavement structure for raw materials model consists of asphalt concrete (AC) (wearing course layer), base, subbase, and subgrade as shown in Figure 11.

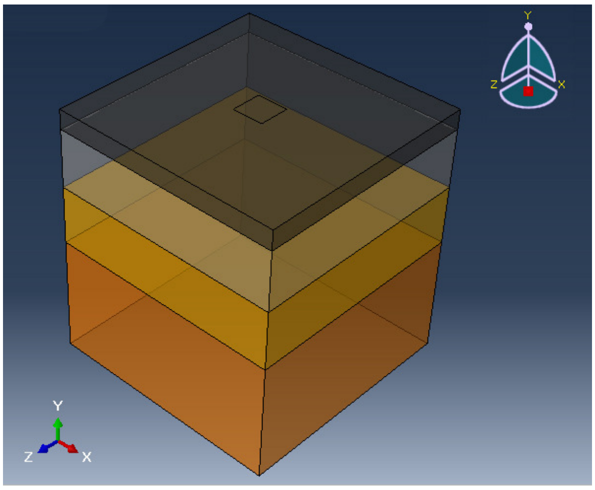

Figure 11. Translucent Model of Raw Materials.

4.1.1.2 Model Geometry for Geogrid

The pavement structure for the geogrid model consists of the same layers for raw materials model (asphalt concrete (AC), base, subbase, and subgrade) except the addition of geogrid layer at the upper surface of the subgrade soil layer, as shown in Figures 12. and Figure 13.

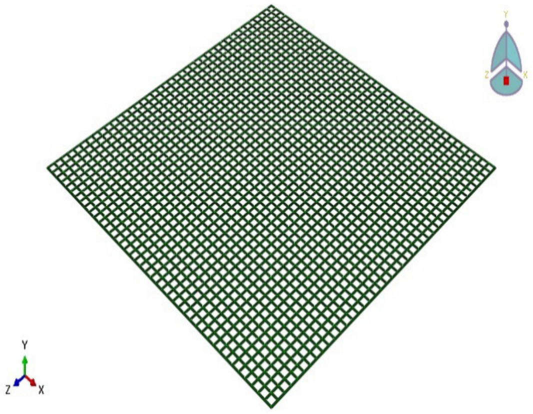

Figure 12. Geogrid Geometry.

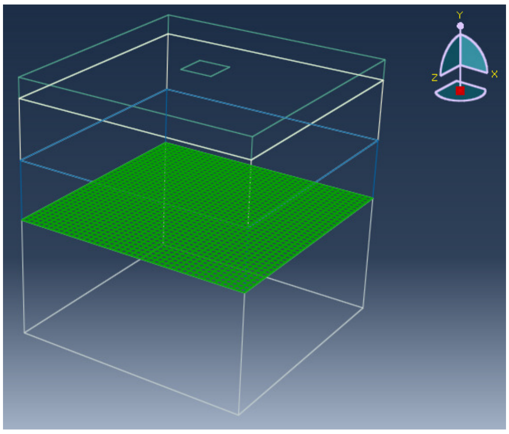

Figure 13. Translucent Model of Geogrid.

4.1.2. Material Characteristics

The most significant side of Finite Element Analyses is the simulation of material characteristics. The proposed model is used in the study conducted by (Mohammed, 2015). Flexible pavement layers were considered for elastic and linear responses in amount with applying load. The material properties of pavement layers used in this analysis are summarized in Table 8.

Table 8. Material Properties

Layer	Density (Kg/m^3)	Young's Modulus (MPa)	Poisson's Ratio ($\mathbf{\nu}$)	Friction Angle (°)	Cohesion (KPa)
Asphalt concrete (AC) layer	2350	2068	0.35	-	-
Base layer	2120	186	0.35	47	4.7
Subbase layer	2200	110	0.35	40	20
Subgrade layer	1020	10	0.45	24	100

4.1.3. Element Type and Mesh Size

Model meshing has been considering in a way to reach the best and the most accurate results. All parts of the finite element model for the pavement structure is meshed using an (8 nodes) continuum three-dimensional linear bricks (C3D8R) with reduced numerical integration elements available in (ABAQUS/CAE) version (6.14-4). The total number of an element is 14976 and the mesh convergence study is executed to find this optimum number of the element. All pavement layers in numerical model are simulated with the same form to maintain the continuousness of nodes between sequential layers (Masood, 2013). Figure 14. shows meshing of the total numerical model.

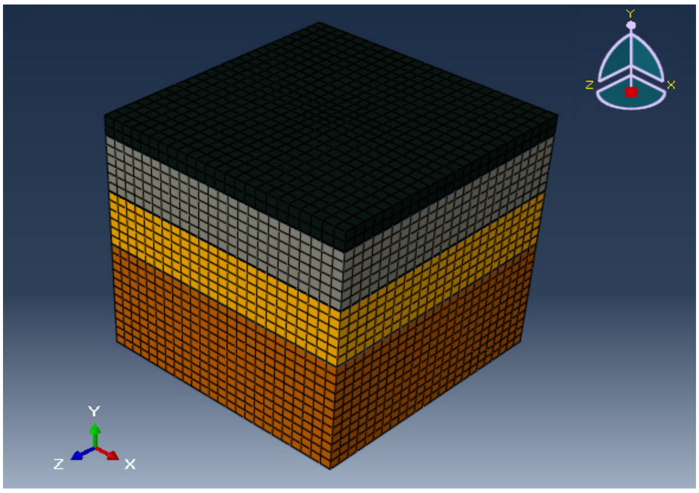

Figure 14. 3D Finite Element Mesh Model.

4.1.4. Interaction Modeling Techniques

The flexible pavement design involves understanding the behavior of the interaction between various materials (namely, the asphalt concrete (AC), base course, subbase, subgrade, piles, geosynthetic reinforcement layers). The interface between two 'surfaces' is referred to as a 'contact'. Generation of contact interaction between the layers of the model using ABAQUS software version (6.14-4) needs to define surfaces of interaction for each layer. ABAQUS/Standard provides several contact formulations. Each formulation is based on the assignment of "master" and "slave" roles to the interaction of contact surfaces between layers in the model. Figure 15. shows formulation of contact states model.

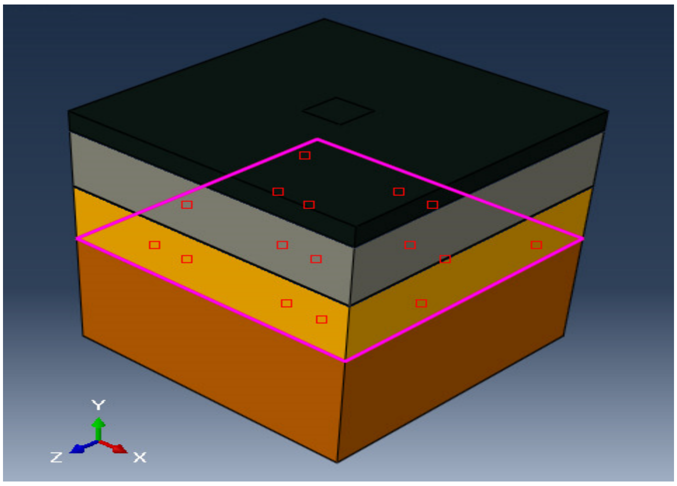

Figure 15. Formulation of Contact Used in the Model.

4.1.5. Loading and Boundary Condition

ABAQUS/Standard provides simulating a dynamic load and the pressure load is applied at the same location of the pavement surface in the model, as shown in Figure 16. The applied load used within the application of ABAQUS software is (2.75 KN) which is distributed in a uniform style over the contact of the pavement surface. The resulting uniform contact pressure is (550 MPa) which is represented by the pressure of the tire.

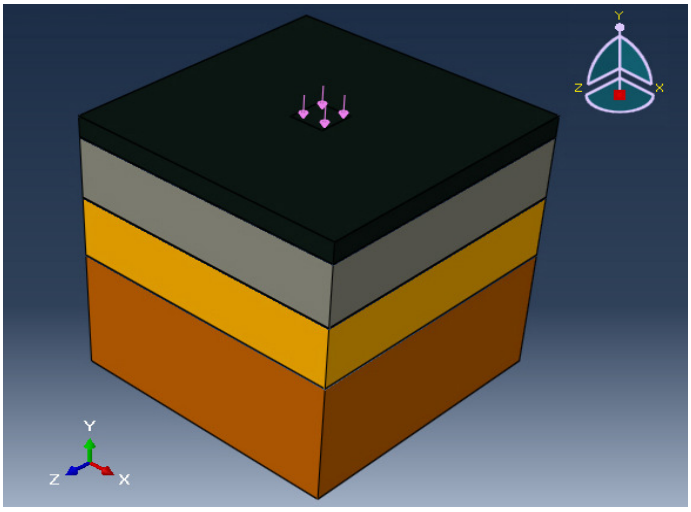

Figure 16. Loading Applied in ABAQUS Program.

The boundary conditions for Finite Element model have a highly affects in foreseeing the response of the numerical model and the bottom surface of the subgrade soil layer and sides of model layers is assumed to be fixed. Figure 17. illustrates the Finite Element model boundaries condition.

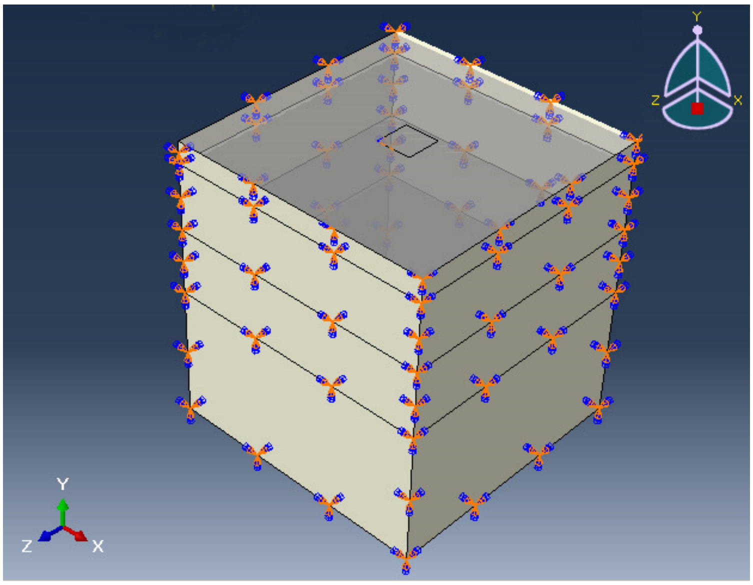

Figure 17. Boundary Conditions for Sides and Bottom for the Models.

4.2. ABAQUS Program's Output

ABAQUS version (6.14-4) Finite Element Program is applied to determine the vertical displacement values that are considered as a response to applied load cycles. ABAQUS program results for displacement U beneath the center of the load at load cycle number 1000, can be shown in Figure 18.

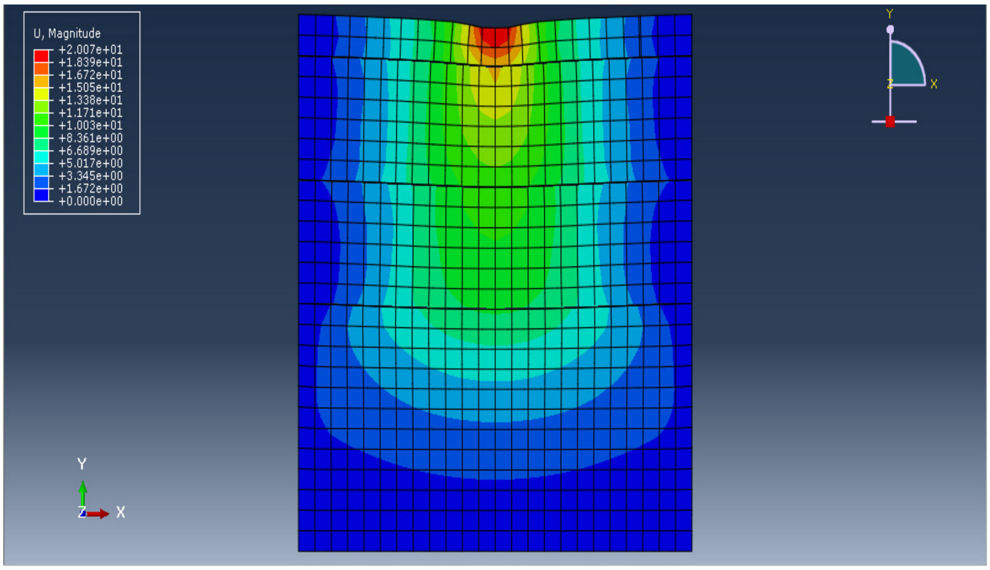

Figure 18. ABAQUS Output of Vertical Displacement for the Model with Elastic Raw Materials.

ABAQUS program results for the elastic geogrid model can be seen in Figure 19.

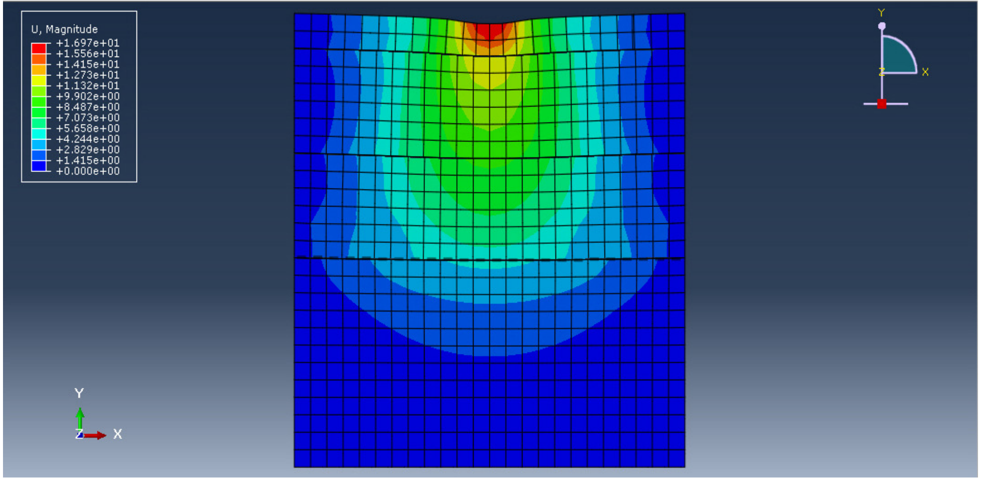

Figure 19. ABAQUS Output of Vertical Displacement for the Model with Elastic Geogrid Model.

Figures 20. and 21. show the comparison between permeant displacement that obtained from experimental work and ABAQUS results at a different number of applied load cycles.

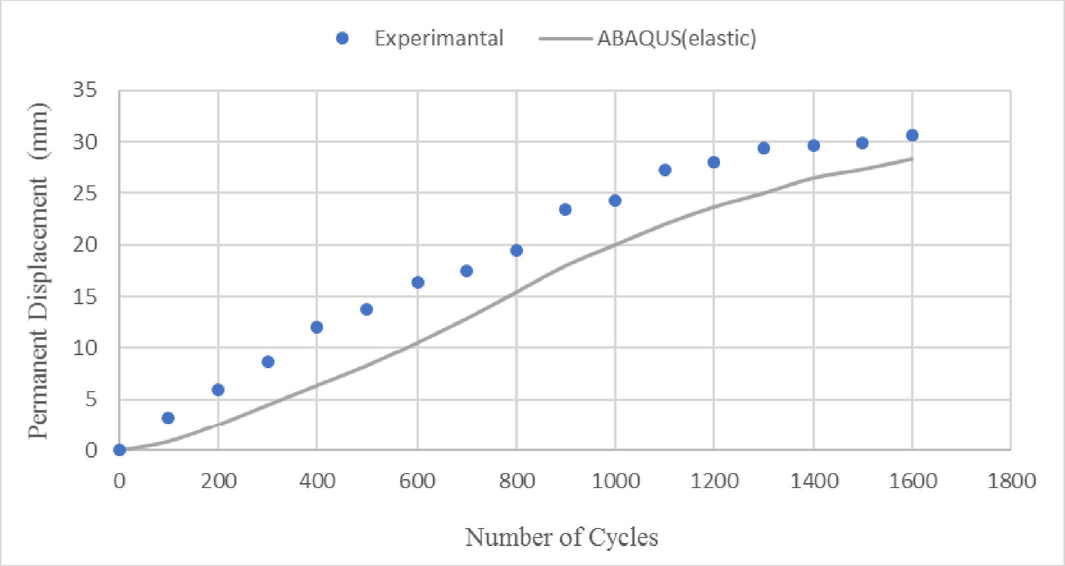

Figure 20. Comparison between Experimental Results and ABAQUS Elastic Results for AC layer for Raw Materials Model.

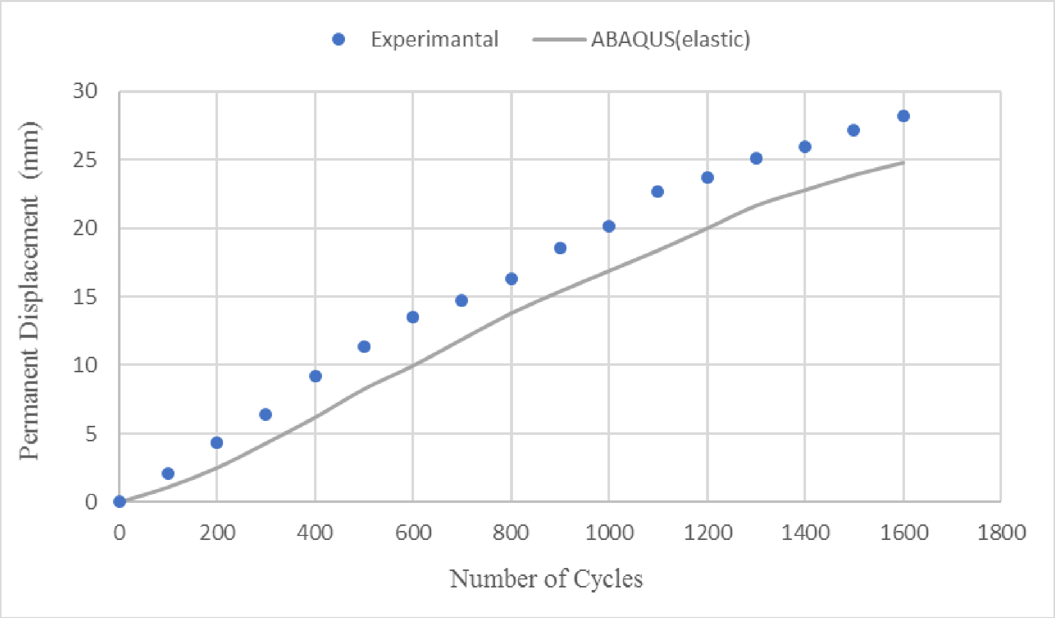

Figure 21. Comparison between Experimental Results and ABAQUS Elastic Results for AC layer for Geogrid Model.

Figures 22. and 23. show the comparison between a vertical strain that obtained from experimental work and ABAQUS results at a different number of applied load cycles.

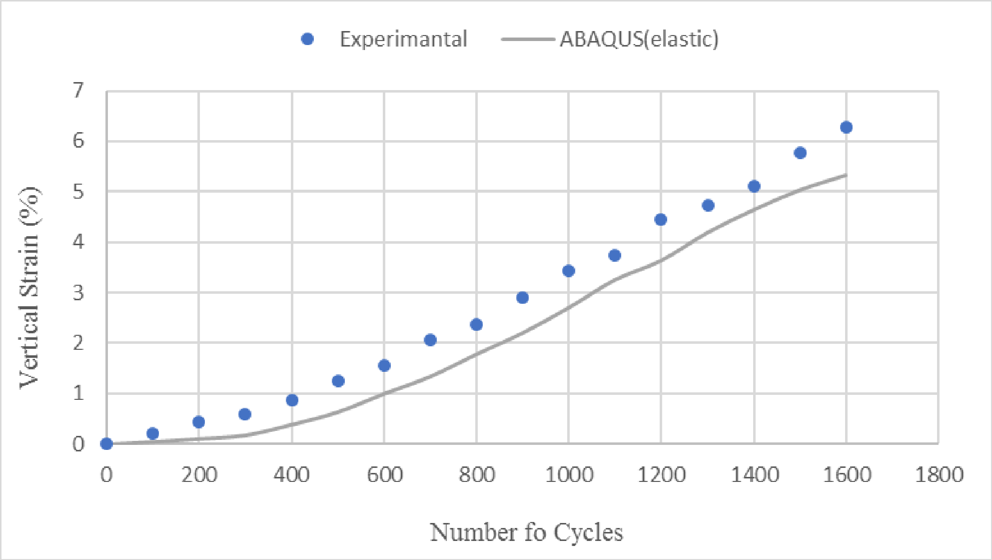

Figure 22. Comparison between Experimental Results and ABAQUS Elastic Results for Subgrade layer for Raw Materials Model.

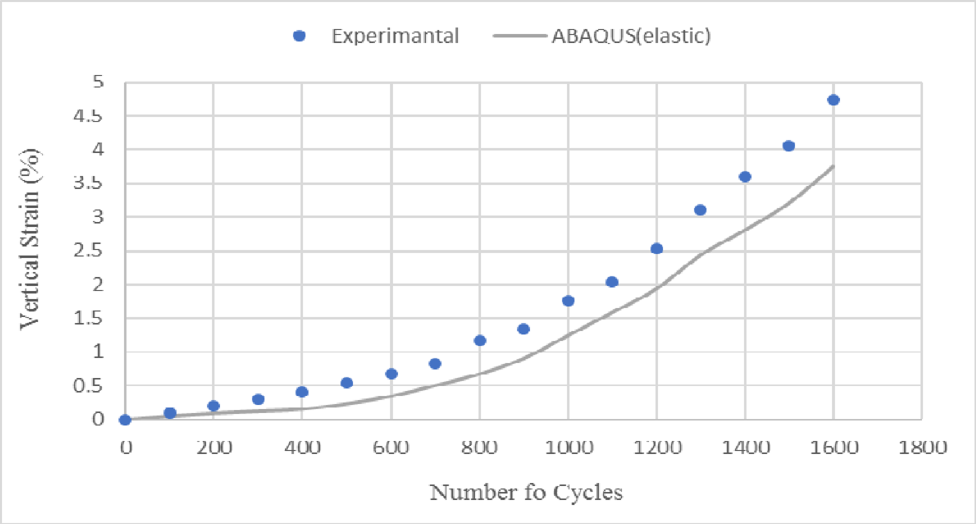

Figure 23. Comparison between Experimental Results and ABAQUS Elastic Results for Subgrade layer for Geogrid Model.

5. Conclusions

1. Using geogrid reinforcement shows an improvement in testing results of the pavement performance in resisting permanent displacement and stresses of the pavement layers as compared with the raw material model.
2. Vertical strain magnitude that recorded at surfaces of asphalt concert (AC) layer is more than others pavement layers (base, subbase, and subgrade). In general, the results showed that vertical strain value was lowered whenever be closer to the subgrade soil layer.
3. The simulation of numerical pavement models was successful using the FEM program ABAQUS. Thus, ABAQUS program is recommended to be used in analysis process of paved road.

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