Evaluation of Reinforced Pile Technique for Structural Improvements of Flexible Pavements over Weak Subgrade under Cyclic Loading

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ABSTRACT

The increasing need for transportation development has led highway engineers to find safe ways to construct the infrastructure of the roadway on soft foundation soils. Many problems associated with constructing roadway embankments over soft subgrade soil i.e.; embankments instability, large settlements and the period of long time required for consolidation of the foundation soil. Such soils cover most of the middle and southern parts of Iraq. The effect of using Piled embankment with geogrid reinforcement to enhance the performance of pavement systems including increase the pavement service life. To simulate the above-mentioned situation, the experimental work included two models: raw materials model and piles-geogrid model were considered. 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 numerical study has been carried out 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 all models. Based on the results and the limitation of this study it is concluded that using the reinforced pile technique model is found to be more effective to resist permanent displacement and vertical stress under cyclic load if compared with the raw material model. The results of ABAQUS program seem to be close to results of laboratory tests.

Keywords: *Reinforce Piles, Weak subgrade, Flexible Pavement, Cycling Loading.*

1. Introduction

Weak subgrade soils have always been a challenge to the geotechnical engineers in case of the construction of such an embankment over weak foundations soil, especially for the evacuation of; slope stability, bearing capacity, lateral pressures, differential settlement, and movements.

In pavement structural layers' design, the responses are the strains, stresses, and displacement, are highly dependent on the support provided by the foundation soil. A large percentage of the deflection in a pavement layers' surface is a direct result of the support provided by the foundation soil. In general, the primary function of foundation soils is to provide support to pavement structures. Under repeated traffic loads, foundation soils may deform and contribute to distress in the overlying pavement structure layers. In flexible pavements, this distress normally takes the form of rutting and cracking that affecting the pavement performance and service life (Mohammed, 2015).

In case of the construction of railway track or roadway on soft subgrade soil, the soil has to be improved. Several techniques have been developed and applied for improvement the soft soil to and improving the performances of the roadway structure. They include geosynthetic reinforcement (GR), piles supported embankment and geosynthetic reinforced pile supported embankments (GRPS) (Widodo, 2013).

2. Study Objective

The main objectives of the present study can be summarized, as follows:

- Design and assembling a laboratory model which simulate the pavement layers under cyclic loading.
- Investigating and evaluating experimentally the effect of using geogrid reinforcement and small pile samples as an approach to improve the performance of pavement system.
- Using a three-dimensional (3-D) developmental finite element (FE) 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 geosynthetic reinforced pile supported embankments model.

3. Experimental Work

3.1. Materials Properties

3.1.1. Soil

The soil used in this study was brought from sports city site, north of Baghdad city, the soil was taken at a depth of about (2-4m) below the ground surface to prepare the soft subgrade soil in the model. Standard tests are performed to determine the physical and chemical properties of the soil, details are given in Table1.

Table 1. Physical and Chemical Properties of Soil.

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/m³)	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

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 subbase is classified as (GW) according to the Unified Soil Classification System (USCS). Modified compaction test for the subbase is performed to determine the maximum dry unit weight is (21.58 KN/m³), the optimum moisture content is (6.9%); the tests are performed according to (BS 1377:1975, Test 13). The California bearing ratio of subbase is (50) the tests is performed according to (ASTM D 1883). Table 2. shows the chemical properties of subbase.

Table 2. Chemical properties of Subbase.

Index Property	Index Value	Test Method
SO3 Content%	0.36	BS 1377 test No. 9
TDS (Total Dissolved Salt) %	2.66	Earth manual of U.S.
Gypsum Content%	0.78	AASHTO T 112
Organic Matter%	0.05	Test No. 8 of BS 1377

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. HOT MIX Asphalt

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 3.

Table 3. 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	------

Aggregate

The crushed aggregates used in this study is brought from Al-Nibaee quarry. The physical properties of the aggregate (coarse and fine) are shown in Table 4.

Table 4. 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	……

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 5.

Table 5. Physical and Chemical Properties of Portland Cement.

Physical Properties	
Passing sieve No. 200%	98
Apparent Specific Gravity	3.1
Specific Surface Area (M^2/kg)	3.55
Chemical Compound	
Silica, SiO_2	21.52
Lime, CaO	62.5
Sulfuric Anhydride, SO_3	1.6
Alumina, Al_2O_3	5.63
Magnesia, MgO	3.76
Ferric Oxide, Fe_2O_3	3.32
Loss on Ignition	1.30

3.1.5. Geogrid Reinforcement

The geogrid reinforcement used in this study to improved and reinforced pavement layer is Pars Mesh Polymer (PMP), which is manufactured by the Pars Mesh Polymer company -Tehran, Iran. Plate 1. Shows geogrid used in this study, and Table 6. Summarizes the physical and mechanical properties of geogrid.

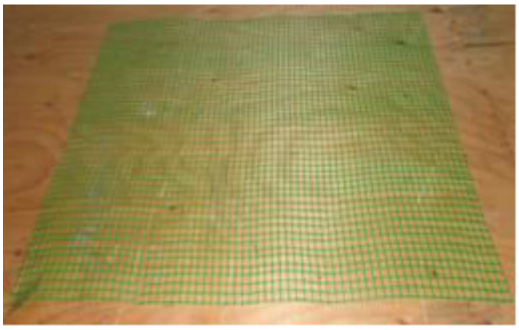

Plate 1. Geogrid.

Table 6. Physical and Mechanical Properties of Geogrid Layer.

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

3.1.6. Piles Used in Tests

The piles used in the model tests are made of hollow square cross-section Aluminum bar brought from local markets. The Aluminum bar has a thickness of (2 mm), an outer side crosses the sectional width of (20 mm), the embedded length of piles is 200 mm. The length to diameter ratio (L/D) is 10. Piles used in all tests are closed at the ends using an Aluminum plate with suitable dimensions. Modeling piles used in this study are [4x4] pile groups with the distance between piles of 6D (where D is the width of pile cross-section). Pile configurations used in this study are shown in Figure 1. Table 7. summarizes the mechanical properties of the tested pile. Plate 2. shows the piles used.

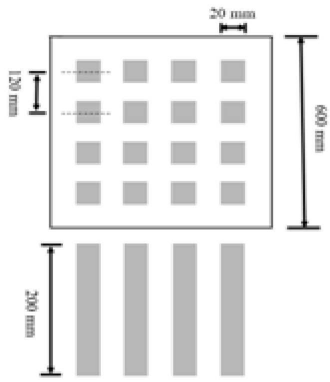

Figure 1. Pile Configurations.

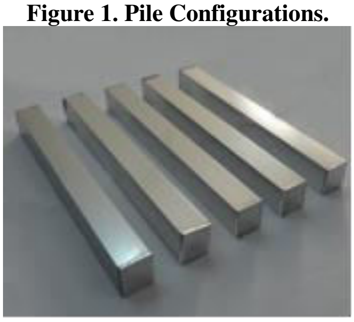

Plate 2. Piles Used in this Study.

Table 7. Mechanical Properties of the Tested Pile.

Mechanical properties	Unit	Data
Elastic modulus	GPa	69.1
Maximum elastic stress	MPa	81.73
Stress at failure	MPa	339.03
Maximum test elongation	%	4.21

3.2. 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 2. 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).

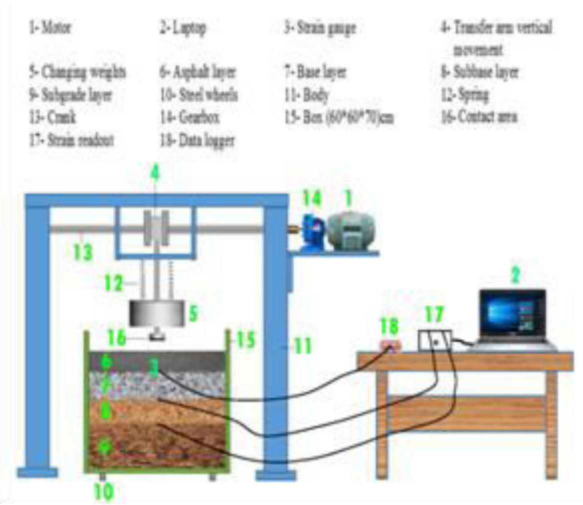

Figure 2. Experimental Test, Steel Box, Loading System Setup.

3.3. Preparation of Model Test

Natural subgrade soil is mixed with a quantity of water until they reached the homogenous mixture. 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 to remove entrapped air. This process is continuing until the required thickness of (300 mm) is reached for the soil in the steel container. Then, the installation of piles through the foundation soil in the model which was layered in the steel box was carried out by creating a borehole of length and diameter less than that of the pile.

A borehole of the length of (180 mm) and diameter of (16 mm) was drilled using a screw auger manufactured for this purpose. Then, the geosynthetic reinforcement is placed over the piles is typically used at the interface between the top of the piles and the embankment. Then, the construction of the subbase layer is beginning following four days from the preparation of the subgrade soil. A predetermined weight of subbase material is mixed with water by hands at a moisture content of (6.9%), this weight is adequate to create a subbase layer of thickness (150 mm). Then, Preparation of Base layer of thickness (150 mm) consists of durable crushed limestone, filler and weighting aggregate according to (SCRB, 2003) for base course. After the preparation of the base layer, the asphalt slab is placed on the surface of the base layer and the wood collar is put around the pavement to avoid movement of flexible pavement in the model, 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 (EN12697 - Part 33: 2003), the asphaltic slab mix is compacted in the heated mold using the Roller Compactor machine. Figure 3. shows the cross-section view of the piles-geogrid model.

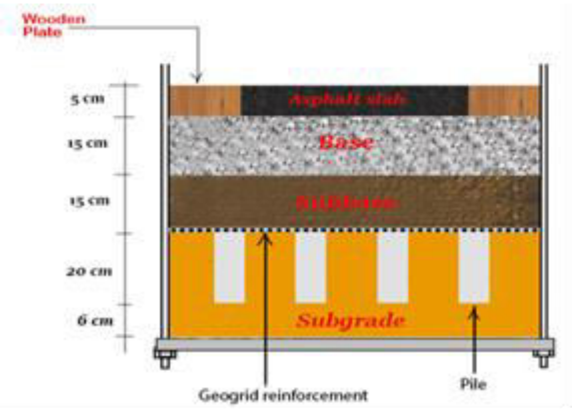

Figure 3. Cross-Section View Piles-Geogrid Model.

3.4. Results of Experimental Work

3.4.1. Displacement of the pavement surface Test Results

The data obtained from the experimental work is permanent displacement for each layer in the model. Figure 4. shows the relation between permanent displacement and number of applied load cycles for the asphalt concrete (AC) layer. It can be noted that the results show 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 surface pavement layers of the improved model and compared with the raw material model results are seen a decrease by (17.21%).

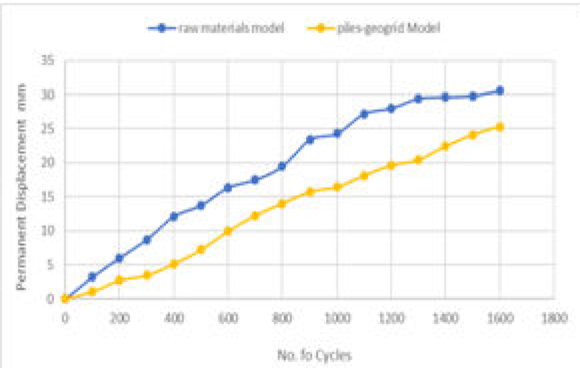

Figure 4. Permanent Displacement versus Number of Load Cycles for Asphalt Concrete (AC) Layer for two models.

3.4.2. Vertical Stress of the Subgrade Surface Test Results

Figure 5. illustrates the relationship between the vertical stress and number of applied load cycles of the Subgrade layer for the model. Based on Figure 5., the vertical stress at load cycle number 1600 for the improved model and compared with the raw material model has seen decreases by (20.55%) for the piles-geogrid model. It is observed that the vertical stress increases with the increase of cycles load applied number. Generally, the maximum value of vertical stress can be noticed in the raw material model, while the minimum value of vertical stress can be shown in the piles-geogrid model.

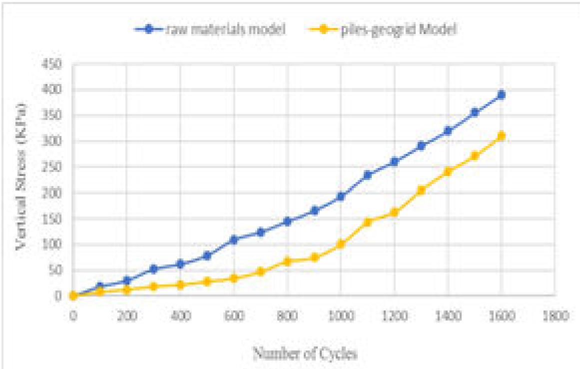

Figure 5. Vertical Stress versus Number of Load Cycles for Subgrade Layer for two models.

4. Finite Element Modeling

4.1. Pavement Layers Modeling based on ABAQUS Program

4.1.1. Model Geometry

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 6. The thickness of the asphalt concrete (AC) layer is 50mm, base layer (150mm), subbase layer (150mm) and subgrade (300mm).

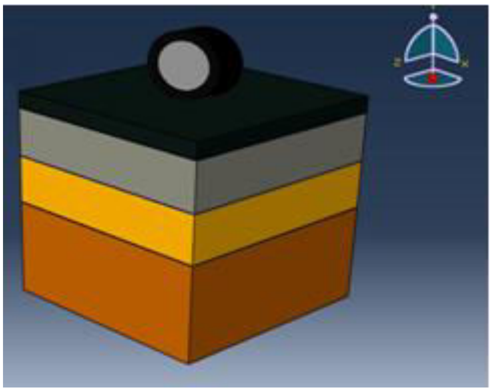

Figure 6. 3D Finite Element Model.

4.1.2. Material Characteristics

The most significant side of Finite Element Analyses is the simulation of material characteristics. The model used in the study conducted by **(Zaghloul and White, 1993)** The asphalt concrete (AC) layer is modeled as a linear viscoelastic material, while the other three layers (base, subbase, and subgrade) are modeled as elasto-plastic (Moho - Coulomb) materials, respectively. The material properties of pavement layers used in this analysis are summarized in Table 8.

Table 8. Material Properties.

Layer	Density (Kg/m³)	Young's Modulus (MPa)	Poisson's Ratio (**ν**)*	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 the finite element model parts for 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 (Massod, 2013). Figure 7. shows meshing of the total numerical model.

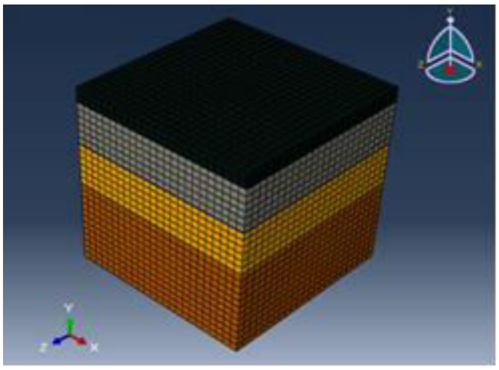

Figure 7. 3D Finite Element Mesh Model.

4.1.4. Loading and Boundary Condition

ABAQUS/Standard provides simulating a dynamic load, the pressure load is applied at the same location of the pavement surface in the model, as shown in Figure 8. The load applied to the ABAQUS software is (2.75 KN) which is distributed uniform style over the contact area with pavement surface. The resulting uniform contact pressure is (550 MPa) which is represented by the pressure of the tire.

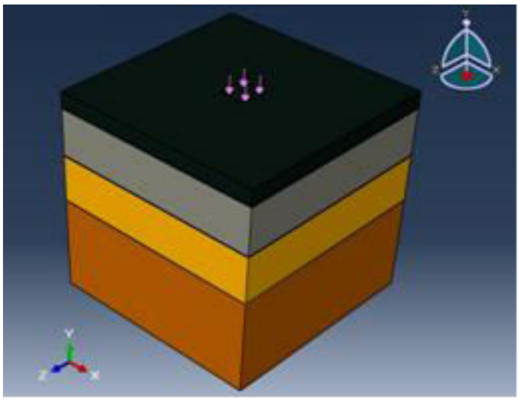

Figure 8. Loading Applied in ABAQUS Program.

The boundary conditions for Finite Element model have a highly affects in foreseeing the response of the numerical model, the bottom surface of the subgrade soil layer and sides of model layers is assumed to be fixed. Figure 9. illustrates the Finite Element model boundaries condition.

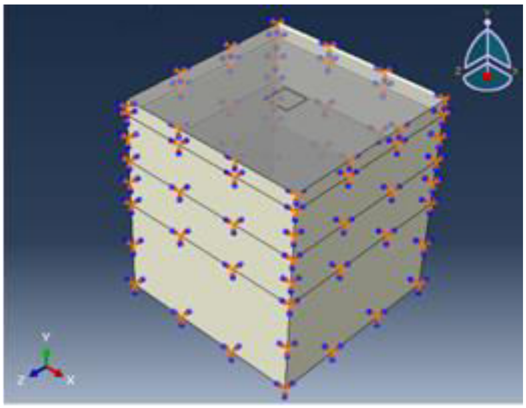

Figure 9. Boundary Conditions for Sides and Bottom for Models.

4.1.5. 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 10 shows formulation of contact states model.

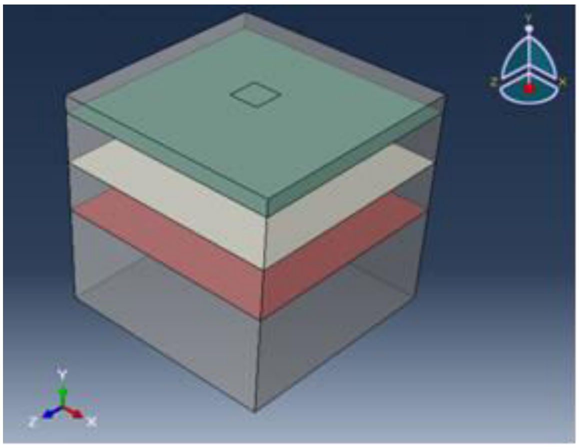

Figure 10. Formulation of Contact Used in the Model.

4.1.6. Model Geometry for Piles-Geogrid

The pavement structure for piles-geogrid model consists of the same layers for raw materials model (asphalt concrete (AC), base, subbase, and subgrade) except the subgrade soil layer which consists of piles installed through the foundation soil, geosynthetic reinforcement is placed over the piles is typically used at the interface between the top of the piles and the subbase layer, as shown in Figures 11.

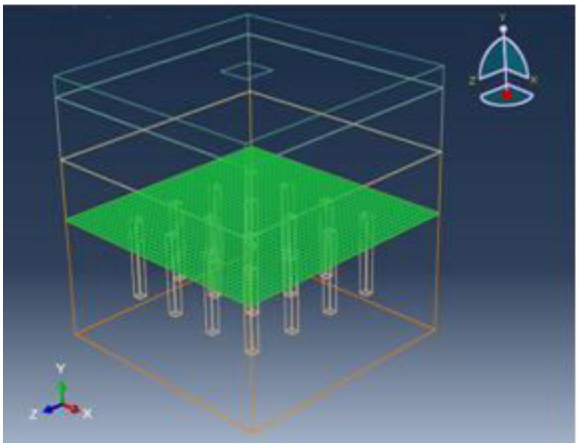

Figure 11. Translucent Model of Piles-Geogrid.

4.2 ABAQUS Program's Output

The 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. The ABAQUS program results for displacement U beneath the center of the load at load cycle number 1000, as shown in Figure 12. and Figure 13.

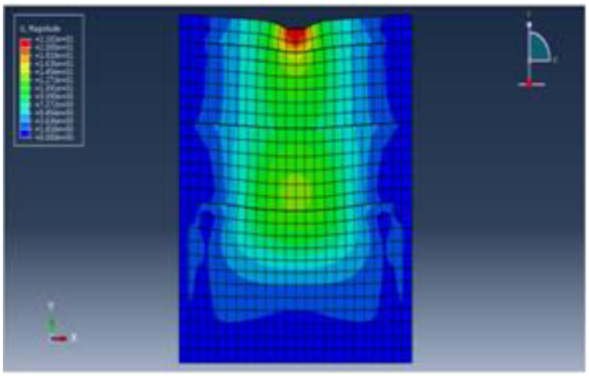

Figure 12. ABAQUS Output of Vertical Displacement for Raw Materials Model.

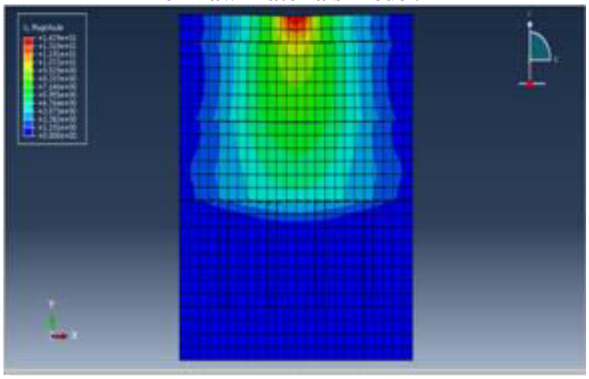

Figure 13. ABAQUS Output of Vertical Displacement for Piles-Geogrid Model.

Figures 14. and 15. show the comparison between permeant displacement that obtained from experimental work and ABAQUS results at a different number of applied load cycles.

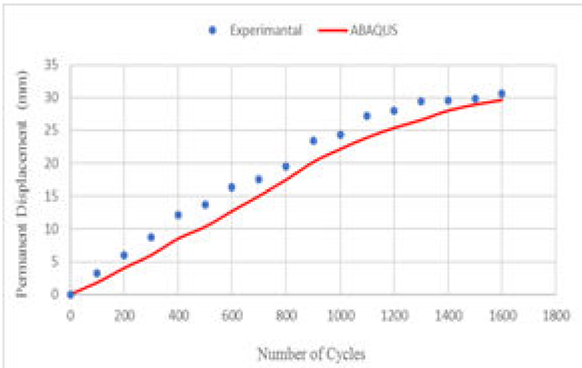

Figure 14. Comparison between Experimental Results and ABAQUS Results for AC layer for Raw Materials Model.

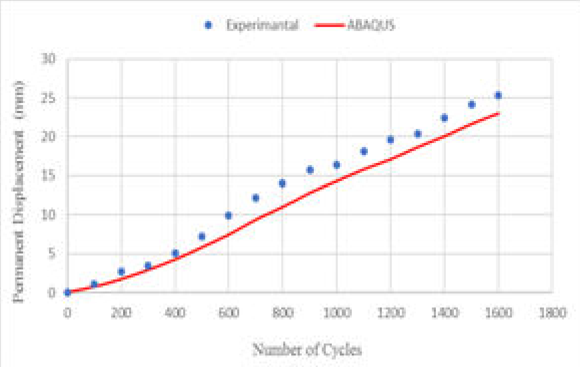

Figure 15. Comparison between Experimental Results and ABAQUS Results for AC layer for Piles-Geogrid Model.

Figures 16. and 17. show the comparison between Vertical Stress that obtained from experimental work and ABAQUS results at a different number of applied load cycles.

5. Conclusions

- In general, pavement material subjected to cyclic load over soft ground supported by piles and geosynthetic reinforcement (GR), is more suitable and can be considered as a practical alternative to improve a soft subgrade soil against permanent displacement and stresses as compared with another simulated pavement model. It is found an increase in the ability of the foundation soil to support the cyclic loading that transmitted from the pavement structure.
- The simulation of numerical pavement models using the FEM program ABAQUS shows that the program outputs present that the results obtained seem to be too close to the experimental results.

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