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Research paper



Evaluation of Pile Technique to Improve Weak Subgrade Soil Under Traffic Loading

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Abstract

The quick imperative for transportation development has driven thruway specialists to find safe approaches to construct the foundation of roadway on delicate subgrade layers. Nonetheless, Delicate immersed fine-grained subgrade soils are remarkable by extraordinary volume change and little shear quality. Numerous issues identified with building roadway dikes over delicate subgrade layer i.e.; dikes flimsiness, high settlements and tedious required for union of the establishment soil. The impact of utilizing Heaped dike to upgrade the execution of asphalt frameworks including increment the roadway benefit life. The investigational work included paired models: crude materials model and heaps show were considered. A research center model tests are completed to created the black-top asphalt layers and configuration cycling load framework likewise to the standard single pivot wheel stack, that were organized amid a plan and amassing of metal Box show. Three-dimensional (3-D) limited component models has been altered in this work for adaptable asphalt setup utilizing ABAQUS programming ver.6.14.4 to break down and reenact the reaction of the asphalt layers of all models with the cycles connected load and soil relocation. The aftereffects of this work demonstrate that the lasting dislodging at the surface of black-top solid (air conditioning) layer utilizing the heap strategy display as contrasted and the crude material model shows diminishes by (14.62%). The consequences of ABAQUS program have a decent concurrence with the trial results.

Keywords: *Cycling loading, flexible pavement, piles, weak subgrade.*

1. Introduction

The subgrade layer characterizes as one of the important fundamentals in the pavement design. The subgrade layer responses impact the whole pavement behavior. Weak subgrade layers are difficulty task to the engineers always 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. Soft subgrade layers are notable with small value of strength and great volume change. A large percentage of the deflection in a pavement layers' surface is a direct result of the support provided by the foundation soil. Overall, the main purpose of subgrade layers is to afford supported to pavement structures. Subgrade layers may deform as result of repeated traffic loads that leads to distress in the overlying pavement structure layers. However, the distress in flexible pavements usually creates the form of rutting and cracking that reduces the service life (Mohammed, 2015).

2. Study Objective

The principle goals of the present examination can be condensed, as pursues:

•Investigating, assessing tentatively (by Research facility demonstrate) the impact of utilizing a Heap system to enhance the execution of delicate subgrade soils underneath adaptable asphalt structure under cyclic stacking.

•Using a three-dimensional (3-D) enhancement limited component (FE) program based numerical examination has been done utilizing ABAQUS programming ver.6.14.4 to reenact and investigate the relations between the cyclic movement stacking and distortion of the proposed models for asphalt framework which incorporates: crude material model and heap upheld dikes demonstrate. In this examination, run reenacting a dynamic load, demonstrated as a weight stack applying at a similar area of the asphalt.

The most well-known use of burdens in a limited component investigation is by applying weight load to a round contact zone with a uniform tire weight. The heap connected to the ABAQUS programming is (2.75 KN) which is circulated uniform style over the contact are with asphalt surface. The subsequent uniform contact weight is (550 MPa) which is spoken to the weight of tire.

3. Laboratory Work

3.1. Materials Used

3.1.1. Soil used

The used soil is taken 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. The tests are

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carried out to find out the chemical and physical properties of the used soil, as pointed in Table1.

3.1.2. Subbase

The used subbase is taken from Al-Nibaee quarry, north of Baghdad. The subbase is ordinarily used as a first choose material for embankment layer in flexible pavement construction. The used subbase can be classified as (GW) according to the Unified Soil Classification System (USCS). Table 2 presents the subbase soil parameters.

Table 1: Basic Soil Properties

Property	Value	Standard
(*LL*) %	41	ASTM D 4318
(PL) %	18	ASTM D 4318
(*PI*) %	23	
Specific gravity (G_s)	2.7	ASTM D 854
Maximum dry unit weight (*KN/m³*)	18.34	ASTM D 1557
Optimum moisture content (%)	12.5	
Total disolved 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

Table 2: Subbase soil Parameters.

Property content	Index Value	Test Method
Maximum dry unit weight (Modified), KN/m³	21.58	BS 1377:1975, Test 13
Optimum moisture content (Modified), %	6.9	BS 1377:1975, Test 13
California bearing ratio	50	ASTM D 1883
SO3 %	0.36	BS 1377 test No. 9
TDS (Total Dissolved Salt) %	2.66	Earth manual of U.S.
Gypsum %	0.78	AASHTO T 112
Organic Matter%	0.05	Test No. 8 of BS 1377

3.1.3. Base

Base layer contains strong crushed limestone, filler and weighting aggregate based on (SCRB, 2003). The maximum dry unit weight is 2.12 (gm/cm³).

3.1.4. HOT MIX Asphalt

Asphalt Cement

The binder used in this work is asphalt cement with penetration grade (40-50) that is provided by the Daurah Refinery, southwest of Baghdad. The physical and chemical properties of the asphalt cement as show in Table 3.

Table 3: The Asphalt Cement Physical Properties.

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 used crushed aggregate is taken from Al-Nibaee area. Table 4 presents the physical properties of the used aggregate.

Mineral Filler

The ordinary Portland cement used in this work as filler. Table 5 shows the physical properties and chemical composition of the ordinary Portland cement.

3.1.5. Piles Used

A hollow square bar cross-section from Aluminum locally fabricated was used as pile in the experimental work. The bar of Aluminum has the following dimensions: 2 mm in thickness, 20 mm width, and 200 mm the embedded length of piles. The ratio of length to dia. of pile (L/D) is 10. The ends of all used are closed. Modeling piles used in this study are [4x4] pile groups with the distance between piles of 6D, where D is the width of pile (Fadhil, 2015) .Pile configurations used in this study are shown in Figure 1. Table 6 summarizes the mechanical properties of tested pile. Plate 1 show the piles used.

Table 4: Physical Properties and gradation of the used Aggregates (from Nibaee area)*.

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

Sieve size	Sieve opening(mm)	Percentage Passing by Weight of total Aggregate: Base Course: Specification Limit (S.C.R.B)	Percentage Passing by Weight of total Aggregate: Base Course: Selected gradation of Aggregate
100	1 1/2"	37.5	100
90	1"	25.0	80-100
65	1/2"	12.5	50-80
45	No.4	4.75	30-60
20	No.40	0.425	10-30
10	No.200	0.075	5-15

*The tests were conducted by NCCLR.

Table 5: Portland Cement Physical and chemical Properties.

Properties (Physical)	Value
Passing sieve # 200, %	98
Apparent specific Gravity	3.1
Specific Surface Area (M^2/kg)	3.55
Compound (Chemical)	
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



Plate. 1: Pile Used in this Study.

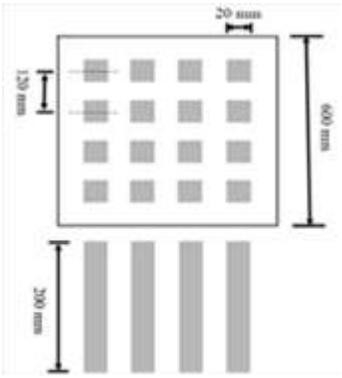


Fig. 1: Pile Configurations

Table 6: The Used Pile's Mechanical Properties.

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. Preparation of Slab Asphalt Pavement

To simulate of a flexible pavement layer, asphaltic slabs are prepared for each model. The dimensions of the slab with length of (300 mm), width (300 mm) and height of (50 mm) as proposed by (EN 12697-33, 2003). To obtain 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 2. The preparation of slab asphalt was conducted at Petroleum Research and Development Center in Iraq (PRDC).

3.3. Laboratory Model Test

To examine the best technique to develop the bearing resistant of pavement layers above weak ground (subgrade) layer; a new developed device is designed and constructed to attain this objective as in Figure 3. 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).



Fig. 2: Preparation of Slab Asphalt Concrete in PRDC.

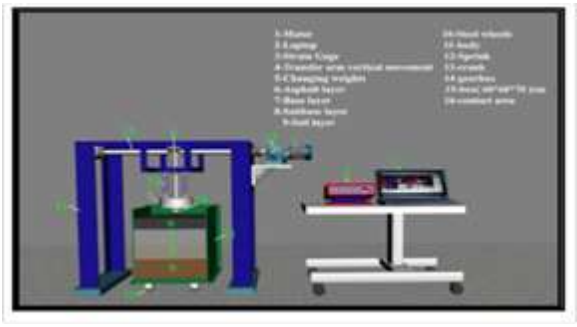


Fig. 3: Experimental Test, Steel Box, Loading System Setup.

3.4 Model setup

The subgrade material is blended with measure of water until the point that they came to the homogenous blend detail. At that point the dirt put in five layers inside a steel holder of (600 * 600 * 700) mm, each layer was packed delicately by manual steel mallet to evacuate ensnared air. This procedure is proceeding until the required soil stature of (300 mm) is accomplished in the crate. At that point, the establishment of heaps through the establishment soil in the test setup which was layered in the crate was performed by creation a gap of length and distance across littler than that of the heap.

A gap of the length of (180 mm) and measurement of (16 mm) was exhausted utilizing a screw twist drill made for that objective. From that point onward, the production of the subbase layer is starting after 4 days after the making of the subgrade layer. A mass of soil material is blended with water by hands at a water substance of (6.9%), this blend material is satisfactory to set up the subbase layer of stature (150 mm). At that point, Readiness of Base layer of thickness (150 mm) comprises of strong pounded limestone, filler and weighting total for base course as per (SCRB, 2003). When the arrangement of the base layer is done, the blacktop chunk is sited on the surface of the base layer and wood neckline is put around the asphalt to keep away from development of adaptable asphalt in model, to mimic of an adaptable asphalt layer, asphaltic pieces are set up for each model. The elements of the chunk are: length of (300 mm), width of (300 mm) and thickness of (50 mm). Figure 4 demonstrates the cross-segment perspective of heaps geogrid display.

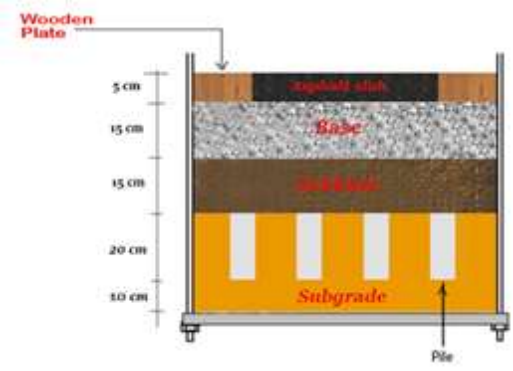


Fig. 4: Cross-Section View Piles-Geogrid Model.

3.5. Results of Laboratory Tests

The results gotten from the Laboratory tests are displacement for every layer in the model. Figure 5 shows the behavior of displacement vs. number of applied load cycles for the asphalt concrete (AC) layer. It can be noted that, the outcome data presents that the displacement increases when the number of load cycles increases. Furthermore, the displacement at load cycle number 1600 for surface pavement layers of improved model and compared with the raw material model results is shown decrease with (14.62%).

4. Modeling of Finite Element

4.1. Modelling the Pavement Layers used 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 5. The thickness of the asphalt concrete (AC) layer is 50mm, base layer (150mm), subbase layer (150mm) and subgrade (300mm).

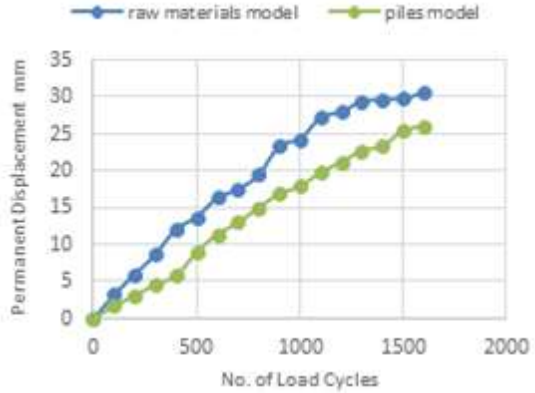


Fig. 5: Permanent Displacement versus Number of Load Cycles for Asphalt Concrete (AC) Layer for two models.

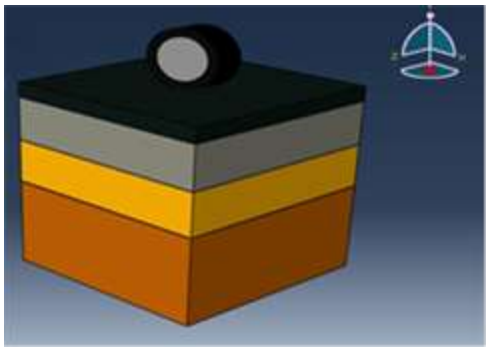


Fig. 6: 3D Finite Element Model.

4.1.2. Material Characteristic

The more significant side of Finite Element method is the model of material features. 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 (Mohr-Coulomb) materials, respectively. The parameters: shear modulus (G) equal to (0.744), bulk modulus (K) equal to (0.978), and time dependent equal to (13.3) seconds, are inputs into the viscoelastic materials model. The material properties for pavement layers used in software program analysis are summarized in Table 7.

4.1.3. Element Type and Mesh Size

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 overall number of element is 14976. All pavement layers in numerical model are represented with the same form to maintain the continuousness of nodes between sequential layers (Massod, 2013). Figure 7 presents meshing of whole numerical model.

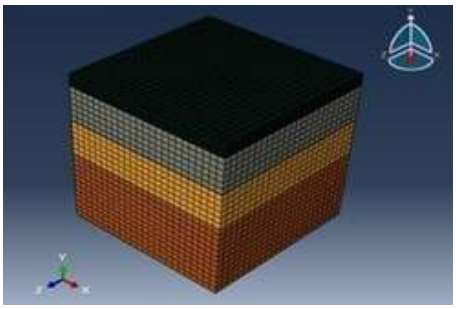


Fig. 7: 3D Meshing of Finite Element Model.

4.1.4. Loading and Boundary Condition

ABAQUS/Standard provides pretending a dynamic load, the pressure load is applied at the similar position of the pavement surface in the model, as shown in Figure 7. The load applied to the ABAQUS software is (2.75 KN) which is distributed uniform style over the contact are with pavement surface. The out coming pressure in contact area position is (550 MPa) that is represented to the stress of axil wheel.

The boundary conditions for Finite Element model have a highly affects in foreseeing the reaction of the numerical analysis, the boundary condition for the bottom of the lower layer (subgrade) and all the vertical edges of model layers is applied as a fixed. Figure 8. illustrates Finite Element model boundaries condition.

Table 7: Material Properties.

Layer	Density (Kg/m^3)	Young's Modulus (MPa)*	Poisson's Ratio (ν)**
Asphalt concrete (AC) layer	2350	2068	0.35
Base layer	2120	186	0.35
Subbase layer	2200	110	0.35
Subgrade layer	1020	10	0.45

* Assumed value. **Poisson ratio (Huang, 2004).

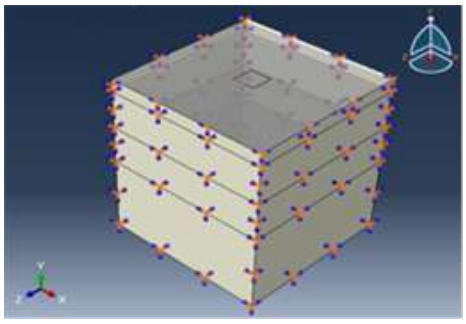


Fig. 8: Loading Applied in ABAQUS Program.

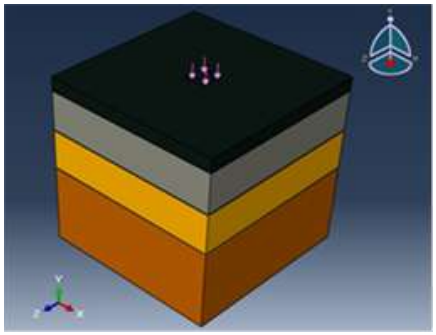


Fig. 9: The applied Boundary Conditions for Edges and Bottom for Models.

4.2 Output of Finite Element Program(ABAQUS)

The ABAQUS version (6.14-4) Finite Element Program is used to analysis the vertical movement values that are considered as a response of applied load cycles. The ABAQUS program results for displacement U under the center of the load at load cycle number 1000, as shown in Figure 10. and Figure 11.

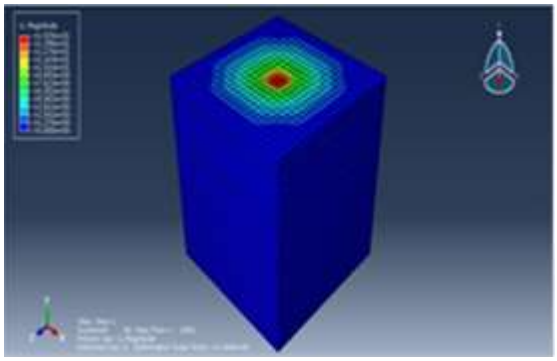


Fig. 10: ABAQUS Output of Vertical Displacement for Raw Materials Model.

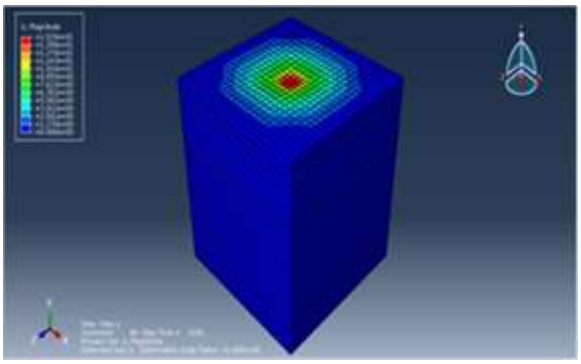


Fig. 11: ABAQUS Output of Vertical Displacement for Piles-Geogrid Model.

Figures 12, Figure 13 present the results of the permanent displacement that outcome from Laboratory model (experimental) and ABAQUS outcomes at a diverse number of applied load cycles. The slight differences between the experimental results and the finite element modeling may be related to the assumed value of input data of material properties. However, the suitable adopted mechanical modeling in finite element program may cause such slight changes in results

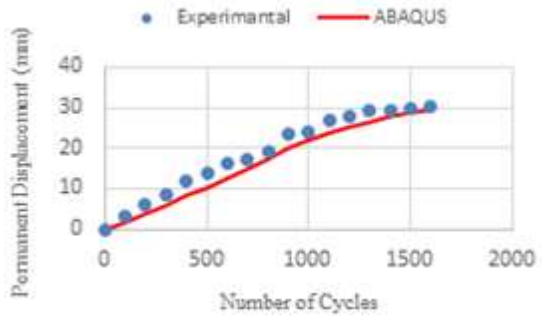


Fig. 12: Experimental Outcomes and ABAQUS Outcomes for AC layer for Raw Materials Model

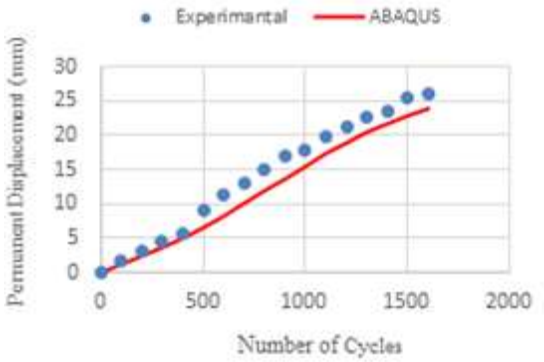


Fig. 13: Experimental Outcomes and ABAQUS Outcomes for AC layer for Piles Model

5. Conclusions

- In general, pavement material subjected to cyclic load over soft ground supported by piles technique is more suitable and can be considered as a practical method to develop a soft ground soil resists to soil displacement as associated with another representative pavement model. It is found an increasing 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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