Analysis of Asphalt Geogrid Reinforced Pavement Rutting by Finite Element Method

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Abstract

Pavement is a complex structure consisting of several layers of different materials that influence its stressful behavior. Permanent deformation can occur in pavement layers of insufficient hardness at high temperatures. Significant rutting normally only occurs during hot weather, especially when the flexible pavement surface temperature is 60 °C or higher. 2D model analysis using ABAQUS software can predict the rutting behavior. The modeling procedure assumes that all materials performance is a linear elastic. Surface, base, subbase and subgrade layers consist of models. Models in every pavement model, subgrade layers are supposed to have endless depth. This paper presents an element-finite model (FE) for the behavior analysis of the dynamic loading unreinforced and geogrid reinforced paving. Increased loading of the model and critical pavement responses for unreinforced or geogrid-reinforced flexible paving, such as vertical stress and vertical surface deflection, were determined. The results indicated a difference in the displacement results when adding the geogrid layer. The results also showed a significant improvement in the behavior of the pavement system. A parametric study was carried out on a type of Truck (3-S1) and the applied pressure was 36 tons with different thicknesses of the asphalt layer once 150 mm and again 25 cm at different temperatures of 20, 40 and 60 °C. It was found that the higher the temperatures, the higher the displacement as well.

Keywords: Pavement performance, geogrid, ABAQUS program, FE model, wheel load, temperature, displacement.

1. Introduction

Flexible pavement advantages, including low construction cost and large-scale construction availability Materials; This is why pavement type is the most common in the world. Usually, flexible pavement consists of several layers, for example; the substratum surface, base and ground and the soil (base). The combination of several flexible pavement layers is the key to increasing its load resistance. Flexible pavement is at risk of deformation under loads. Traffic loads affect the surface layer directly and are passed through the particle friction to the bottom layers. The effect on the surface to the foundation ground is caused by traffic loads. The temperatures differ more significantly, as they affect the hardness of the asphalt mixture and non-adherent layers, affecting the elastic deformation of the pavements. An increase in temperature increases the adverse effects of stress, tension and surface oscillation. Changing temperatures also causes other distress, thermal rutting and damages (El-Maaty, 2017). Some studies
stated that inserting geogrid layers in an unbound aggregate base-subgrade interface could enhance pavement performance. The complexity of the pavement layered system and moving load application can result in complications with geogrid’s reinforcement purpose.

The geogrid-reinforcement layer is usually placed between the sub-base and subgrade interface or between the base course and sub-base. Because the technique was extensively applied, several experimental and analytical studies were carried out, in which improvements associated with the reinforcing of routes were evaluated and potentially quantified. Geogrid strengthening started in the 1970s in road applications. The geogrid reinforcement technique has, since then, been used more and more and several studies have been carried out to study its conduct on roads (Howard and Warren, 2009). Through finite element (FE) simulation, analysis of how pavement with and without geogrid reinforcement is performed under static and dynamic conditions loading, the researchers used a two-dimensional FE model. They found that horizontal fatigue or stress was more significantly reduced when the geographical reinforcement feet in the base concrete facade. while, placing geo-reinforcement at the interface between the ‘asphalt layer’ and the base layer significantly reduced vertical stress (Perkins et al., 1999).

Barksdale et al., (1989) study results indicated that placing geogrid at the interface of base and subgrade layers decreased vertical strain in comparison with unreinforced pavement investigated the structural performance of unreinforced and geogrid reinforced pavement subjected to laboratory cycling loading testing. Al-Qadi et al., (1994) stated that effective application of geogrid ensures sudden failure and collapse during construction and prevents potential structural defects. Consequently, understanding the real impact of geogrid within flexible pavements is unclear.

Perkins (2001) studied the two dimensional axisymmetric finite element simulation model to investigate the impact of using high modulus geogrid reinforcement for pavement layers on pavement performance under static and dynamic loading conditions. Fattah et al., (2017) conducted a number of model tests on a pavement system, to show that pavements reinforced using geogrid would have a significantly higher load bearing capability than unreinforced subbase layers sitting on expansive subgrade soil. Each test was carried out using cyclic loading under dry weather conditions and involved geogrid reinforcement at the point where the subgrade and subbase layers intersect, as well as using it in the center of the subbase layer. The values returned from the failure load supported the theory as the loads were much greater in the reinforced model in comparison to the unreinforced counterpart, with the reinforced model showing a reduction in displacement of approximately 4.7-7.7%. The third model used showed a small reduction of just 4-6.1%. The objective of the present study is to develop a finite element model for an existing flexible pavement that is capable of predicting the stress and strain responses of elastic pavements. Geogrid layer is inserted between the asphalt layer and base layer to investigate its role in enhancement of rutting behavior of the asphalt pavement.

2. Definition of problem

The asphalt pavement system in the Abaqus (6.14) program consists of several asphalt layers, which are from asphalt, base layer, sub-base layer, and sub-grade layer. The dimensions of the asphalt pavement are from the length (X) and the model width is (Y). The pavement layers consist of surface and binder layer with thickness of 150 and 250 mm, respectively. The thickness of the base layer is (300 mm), the thickness of the sub-base layer is (500 mm), and the thickness of the natural subgrade is 2 m as shown in Figure 1.
Figure (1). Schematic illustration of asphalt pavement different layers.

A network is created to use a step time consisting of CPE8R to create a network (8 node biquadratic plane strain quadrilateral, reduced integration) with 3 degrees of freedom per node as illustrated in Figure 2.

Figure (2). Finite element model mesh.

From the bottom of the layer, the bottom border axis was determined, which means \( u_1=0, u_2=0 \), but from the sides, the x-axis was fixed, which means that \( u_1=0 \) was defined as shown in Figure 3.

2.1 Simulation of numbers

The main reasons for asphalt paving failure are the rutting which is defined by the continuous densification by traffic load as longitudinal depressions in wheel tracks. The ABAQUS program, which has the following material properties, investigates the effect of traffic loads on routing values for flexible asphalt paves. Temperature and load analysis was carried out on the asphalt pavement. Under the influence of the loads imposed on it by vehicles, also a finite element analysis of the response of the pavement was carried out. The asphalt mix consists of a viscoelastic material that responds to the response of the pavement through different temperatures and applied loads and was chosen as a predictor of the optimal elastic-plastic conduct of the broken material in the Mohr-Coulomb model (M-C). Table 1 shows the material properties of the pavement layers.
Figure (3). Finite element boundary conditions.

Table (1): Input of flexible pavement layers martial properties.

| Layer      | Thickness (cm) * | E (MPa) * | Poisson’s ratio* | Friction angle f (°) ** | Dilation angle ** |
|------------|------------------|-----------|------------------|-------------------------|-------------------|
| Asphalt 1  | 25               | 2689      | 0.35             | -                       | -                 |
| Asphalt 2  | 15               |           |                  | -                       | -                 |
| Local Base | 30               | 1655      | 0.35             | 38                      | 8                 |
| Subgrade   | 200              | 35        | 0.4              | -                       | -                 |

* Ministry of Construction, Housing Municipalities and Public Work.
** From Hassan et al. (2018).

3. Thermal Properties of the Asphalt Concrete Pavement

The thermal properties and environmental conditions to which the paving has been exposed directly affected the temperature distribution of the pavement (Yavuzturk et al., 2005). The ability to predict asphalt floor temperature accurately is helpful in re-calculating parameters for materials. The change in pavement temperature in relation to air temperature was delayed as a result of heat exchange (Huang et al., 2008). The thermal characteristics of asphalted materials are presented in Table 2.

Table (2): Thermal properties of flexible pavement layers.

| Layer       | Thermal conductivity k (W/(m.K)) * | Density (kg/m³)* | Specific heat e (kJ/Kg/°C)* | Radiation** | Emissivity ** | Stefan constant (W/m².k)*** | Film coefficient (W/m².°C)*** |
|-------------|------------------------------------|------------------|------------------------------|-------------|--------------|-----------------------------|-------------------------------|
| Asphalt     | 1.3                                | 2210             | 800                          | 0.9         | 0.81         | 5.67x10^-8                  | 15.6                          |
| Local Base  | 1                                  | 2000             | 800                          | -           | -            | -                           | -                             |
| Local Subgrade | 1.85                         | 1900             | 750                          | -           | -            | -                           | -                             |

* From Qin et al., (2019). ** From Wang et al., (2018). *** From Yang and Liu, (2007).
**Plastics examination**

The Mohr-Coulomb theorem applies to a finite element model called the plastic Mohr-coulomb model, which can be used with any stress/shift element and will allow strengthening and/or softening of the material's potential as a stress level model. A linear fault envelope is considered in the Mohr-Coulomb model to determine the critical combination of normal stress and shear stress. In other words, the shear stress and regular stress cause the friction angle representing the failure of the plane (Labuz and Zang, 2012).

**Geogrid reinforcement in pavement layers**

As an addition to the used asphalt layers, Geogrid was applied and placed between the asphalt and the layer of the base. The geogrid layer had a thickness of 6 mm. Geogrid species reduce the rutting stress and create a tensioning membrane effect if they are used in the bituminous concrete layer, geogrids are advantageous. Geogrid base reinforcement of roadways' ability to measure and evaluate improvements as a result of its wide applicability has spurred an abundance of empirical and analytical research. The behavior of geogrid material was modeled using a linear elastic model. Incorporating geogrid into the subsurface can improve the pavement performance, but how much depends on the strength of the subgrade, the geogrid's properties, where it is located in the pavement, and the depth of the foundation (Al-Qadi and Wang, 2009). The material properties are listed in Table (3) as shown in Figure (4).

![Figure (4) SS2 geogrid reinforcement used in tests.](image)

**Table (3) Physical properties of the SS2 geogrid (Tensar International, 2001).**

| The physical properties | Data |
|-------------------------|------|
| **Polymer**             | PP   |
| **Color**               | Black|
| **Polymer type (Rib shape)** | SS2Rectangular |
| **Dimensional Properties** | **Unit** | **Data** |
| Roll width              | M    | 4    |
| Roll length             | M    | 50   |
| Unit weight             | kN/m$^3$ | 2.9  |
| **Aperture size**       | Mm   | **28*40** |
| WLR                     | Mm   | 3    |
| WTR                     | Mm   | 3    |
4. Moving load simulation

The deformation behavior of the pavement layer was calculated under the influence of traffic loads caused by a Truck (3-S1), a point was imposed from the top of the pavement structure and a stress of 36 ton was applied at a temperature of 20, 40 and 60 °C which is subjected to a repeated stress of 36 ton. A point was taken on the surface of the asphalt layer, the vehicle speed is 110 km / h and the difference between one vehicle and another 30 seconds. A simulated passenger car is shown in Figure (5). The geogrid layer, which is a deformation material, was added between the asphalt layer and the base layer. The thickness of the geogrid layer was 6 mm. Figure (6) represents the shape of the geogrid layer.

| tTR thickness of transvers ribs | Mm | 0.9 |
|---------------------------------|----|-----|
| tLR thickness of longitudinal ribs | Mm | 1.2 |

**Figure (5)** Truck Type (3S-1) (36 ton) (Iraqi Highway Design Manual, 1982).

**Figure (6)** Repeated load function 3 with time for truck type 3S-1.

4.1 Results of Analysis

The displacement was examined for different thicknesses (150 mm) and (250 mm). The displacement was also checked when laying the geogrid layer and without the geogrid, and the pavement was under the influence of repeated load, and the loading time in the analysis was 3600 seconds. The layer behavior was linear and three different temperatures were applied namely 20, 40 and 60°C. When the thickness of the asphalt layer is increased from 150 mm to 250 mm, this increase reduces the transfer of the load to the asphalt layers. Figures (7a), b and c show the distribution of the repeated load for wheel load of (36 ton) within 3600 seconds. When the temperature of the asphalt layers is changed from 20 to 40 and 60 degrees Celsius, it was shown that the resulting displacement increased under
the influence of repeated load.

Figure (7). Pavement layer model displacement under repeated loads (Truck 3–S1) at different temperatures at time 3600 s, for asphalt layer thickness 150 mm.
Figures (8) a, b and c present displacement distribution in the asphalt layers with a thickness of 25 cm under the influence of repeated load and different temperatures.
Pavement layer model displacement under repeated loads (Truck 3-S1) at different temperatures at time 3600 s, for asphalt layer thickness 250 mm.

A comparison between the maximum displacement in the pavement layers of two thicknesses under the effect of repeated loading and different temperatures is shown in Figure 9.

![Figure 9](image1.png)

**Figure (9)** Difference between displacement and different temperatures at different thickness of the asphalt layer.

When adding the geogrid layer, the displacement will decrease because this layer as a reinforcing material will reduce the rutting that occurs in the road. The displacement was calculated with a difference in the thickness of the asphalt layer and also with a difference in temperature according to the environmental conditions. Figures (10a), b and c display the displacement distribution in the asphalt layers with a thickness of 150 mm under the influence of repeated load and different temperatures with the laying of the geogrid layer.

![Figure 10a](image2.png)

**a. 20°C Temperature.**
b. 40°C Temperature.

c. 60°C Temperature.

Figure (10) Distribution of vertical displacement in pavement layers when the asphalt layer thickness 150 mm under repeated single load and different temperature with geogrid layer.

a. 20°C Temperature.
b. 40°C Temperature.

c. 60°C Temperature.

**Figure (11)** Distribution of vertical displacement in pavement layers when the asphalt layer thickness 250 mm under repeated single load and different temperature with geogrid layer.

A comparison between the maximum displacement in the pavement layers of two thicknesses under the effect of repeated loading and different temperatures is shown in Figure 12.

By distributing the load over a wider area, geogrid reinforcement improved the load distribution and reduced the rut depth at the asphalt course's surface (Wasage et al., 2004).
Figure (12) Difference between displacement and different temperatures at different thickness of asphalt layer with geogrid.

4.2 Maximum displacement without geogrid and with geogrid
Table (3) presents the results of the difference in displacement when laying a geogrid layer and without the geogrid. When adding the geogrid, the displacement decreases, and this concludes that this material is a reinforcing material for the asphalt layer and through it, the displacement is reduced and the rutting occurs on the road.

Table (4) Result maximum displacement.

| Temperature °C | Thickness of surface layer (mm) | Maximum displacement without geogrid (mm) | Maximum displacement with geogrid (mm) |
|----------------|---------------------------------|------------------------------------------|---------------------------------------|
| 20             | 150                             | 0.006144                                 | 0.00624                               |
| 40             | 150                             | 0.006197                                 | 0.00626                               |
| 60             | 150                             | 0.00625                                 | 0.00627                               |
| 20             | 250                             | 0.002701                                 | 0.00612                               |
| 40             | 250                             | 0.002712                                 | 0.00615                               |
| 60             | 250                             | 0.002743                                 | 0.00618                               |

Figure (13) presents the displacement with temperature when laying the geogrid layer and without the geogrid for a single repeated load (Truck 3-S1) with the thickness of the asphalt layer 150 mm and 250 mm.
a. thickness 150 mm.

b. thickness 250 mm.

**Figure (13)** Variation of the maximum vertical displacement with temperature under the effect of repeated load with geogrid layer.

Jebur et al. (2021) found that when laying the geogrid between the base course and subgrade, a lower decrease in the stress and vertical displacement could be obtained with the increase in frequency and loads.

From the results of the specific elements for the different cases, taking into account the different thicknesses of the asphalt layer and different temperatures, and also when adding the geogrid layer, equations were made by carrying out statistical analysis using SPSS program through the variables that were entered, and the variables of the results were obtained taking into account the applied pressure of 36 tons, and the speed of the car was 110 km / h, and the thickness of the asphalt layer was once 150 mm and the other 250 mm, with the different temperatures used which are 20, 40 and 60 °C. Equation (1) was derived for pavement layers without geogrid while Equation (2) for geogrid reinforced layers.

\[
\log \varepsilon = 11.5023 + 5.327 \log N + 4.24 \log T - 32.405 \log h \quad ... (1)
\]

where:

\( \varepsilon \) is the vertical strain,

\( N \) is the number of cycles,
\( T \) is the temperature (°C), and
\( h \) is the thickness.

\[
\log \varepsilon = 40.581 + 1.202 \log N - 32.6 \log h + 1.913 \log T \quad \ldots \ (2)
\]

5. Conclusions

The combined effect of traffic loading conditions has been studied through the application of the ABAQUS program for the limited elements, including the behavior of high temperatures on the fragmentation damage that occurs in the flexible pavement. Conclusions can be drawn as follows:

- Increasing the thickness of the flexible pavement causes rupture of the same value (failure value), which leads to a reduction in the displacement of the asphalt layers.
- The ABAQUS program has provided success in simulating the pavement structure model, from which it is concluded that the ABAQUS program can be used in road analysis.

Using the linear-elastic model for asphalt layer linear-elastic perfectly-plastic Mohr-Coulomb model for subgrade to predict stresses and strains in the pavement structures can lead to acceptable results. When using the geogrid layer, it reduces the displacement when the load is placed on the asphalt pavement, so the geogrid is a reinforcing material used to reduce the rutting in the road. When the temperature increases, the displacement also increases.

An experimental model is suggested to study the effect of different types of loading and temperatures on the rutting development in asphalt pavements.

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