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Analytical evaluation of the rutting response under the static loading in flexible pavement

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Abstract. In this research, a special model for assessing the impact of static load on flexible pavement behavior is studied, through the use of crawling screening parameters. Relying on previous experiments, the FEM simulation was done using the Abaqus program, which is accurately predicted the behavior of the static load. The results showed that this pregnancy greatly affects the sidewalk response, and thus leads to the accumulation of stress and emotion and their development in asphalt concrete, in the end, it leads to the formation of permanent distortion. The FEM analysis shows an increase in the depth of distortion of the static load result, which means the importance of taking its impact into consideration when designing the sidewalk and maintenance strategies. The research underscores the value of enhanced rutting prediction models to improve pavement performance and support the development of more durable and sustainable road infrastructure.

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1. Introduction

Asphalt concrete (AC) road is one of the kinds of roads used, and although it is commonly used due to its many advantages, it is prone to a number of types of breakdowns such as cracks of all kinds, fatigue, rutting, and others, which is undesirable because of the problems it causes to the road and its users. This type of failure occurs as a result of stresses exceeding the capacity of the roadway, lack of materials, design error of the asphalt mix, traffic loads of its dynamic and static types [1, 2]. One of the most harmful loads on the pavements is static load [3, 4], which occurs in places where vehicles stop, such as at checkpoints, at intersections, and in places on roads with high traffic volume (congestion), almost complete cessation of traffic [5], weather. This failure is considered a danger to the pavement because it poses a danger to road users and causes permanent deformation of the pavement, reducing the performance of the pavement [6, 7]. This failure is limited to one layer, that is, AC, or several layers, that is, all layers of the pavement. However, as a result of the impact of this deformation on the transport infrastructure and its sustainability, rutting must be predicted before construction to ensure that roads are preserved from deterioration. This is done either through laboratory tests or by using simulation programs to represent the real conditions of the pavement using more accurate programs than laboratory tests, in this way a technique is use [8].

Finite element, a powerful numerical method used in fields such as pavement geometry, and Abaqus program uses this technique to perform vim simulations in the context of this prediction. It enables the development of various models and also predicts the impact of vehicle loads, environmental conditions, and various pavement materials. The program, used by many researchers, creates complex models of finite elements by dividing the model into a number of finites. The program can conduct a detailed analysis of stress, overstrain, traffic loads, etc. [9]. The Abaqus program can predict the rutting before the pavement is built over time at the impact of static load. By simulating static load, which provides an insight into the pressure distribution on the pavement as well as its impact during the maintenance period, heavy equipment is often placed on pavements with constant loads, thereby assessing the structural response to alternating current and the problems that occur. In general, static load simulation provides a remedy for cases of slow-moving static conditions, which provides a comprehensive approach to the pavement under various conditions. Finally, by simulating vim with Abacus program, the degree of resistance of the pavement to deformation is assessed, materials are selected, and construction practices are improved. This predictive ability enhances the decision-making process in the design of sidewalks, contributing to the improvement of flexible and sustainable transport infrastructure. This research paper aims to simulate the grooving behavior of an AC layer before construction using the Abacus program and under the influence of static load.

2. Methodology

The methodology of this research involves predicting the permanent deformation of the AC layer through the use of the finite element model (FEM), which is carried out by simulating a wheel track test and depending on previous research [10, 11]. All the necessary parameters were taken from the modulus of elasticity and creep test parameters, as well as load distribution and other factors, for the purpose of simulating this in an exam in the Abaqus program. Also, measure the distribution of stress and strain in the slab under the influence of traffic loads, especially static loads. The purpose of stress and strain forecasting is to measure the range of resistance of alternating current to applied loads and its durability, which makes it more powerful and reliable.

2.1. Program of Testing

There are many laboratory tests that are performed for asphalt or asphalt mixtures in order to ensure its structural integrity when built. When simulating a wheel track examination in this research using the Abaqus program, it requires entering some of the necessary parameters to identify the materials as well as those related to the examination. This is made based on past lab tests such as uniaxial compressive cyclic (creep), indirect tensile stiffness modulus (ITSM), and wheel tracking [12].

2.2. Uniaxial Compressive Cyclic (Creep) Test

The creep test of asphalt, also called as the uniaxial compressive cyclic test, is a laboratory procedure used to estimate the viscoelastic behavior and deformation features of AC pavement materials below repeated loading. Through the creep test, an asphalt specimen is prepared according to standard procedures and placed in a machine of testing [13]. The specimen is then subjected to a fixed compressive load, typically applied at a specified rate, and maintained for an extended time. As the load is applied, the asphalt mix specimen undergoes deformation, which is monitored and measured with time. The distress behavior is typically measured as axial strain, representing the various in length of the sample relative to its original length. This test is evaluating asphalt's viscoplastic response under sustained loading, know its deformation behavior with time and the model given by Equation 1, also developed in the Abaqus program.

2.3. Indirect Tensile Stiffness Modulus Test

Indirect Tensile Stiffness Modulus Test is one of the tests used to measure the viscoplastic behavior of asphalt, i.e., the creep test parameters that depend on the material and the deformation characteristics of the mixture as a result of repeated loads on the model. This examination is carried out by preparing samples according to the standard specifications for the examination. The sample is then subjected to a constant, compressive load inside the testing device at a specific rate, which results in deformation of the sample and is measured over time. The axial strain is measured through it, which is the ratio of the change in length to the original length. This way, the performance of the material over time is known, and it also gives an equation that contains the creep test parameters, as in Equation 1, and it was also developed in the Abaqus program.

2.4. Wheel Tracking Test

Wheel tracking testing is a standard laboratory procedure used to evaluate the rutting resistance of asphalt pavement materials under simulated traffic loading conditions [14]. A wheel tracking apparatus is used for testing the asphalt samples that are prepared according to standard procedures. The dimensions of this apparatus differ depending on its manufacturer, but in our case, they were equal to 50 mm in thickness, and 400 mm × 305 mm [15]. The device contains a wheel that moves back and forth across the sample surface, applying a constant load following a predetermined path pattern. Usually, such a test is performed to imitate the effects of traffic loads, among which may also be the static loads on pavement grooves.

It is a regular practice to perform groove depth measurements during the test in order to assess how much deformation or rutting occurs on the sample of asphalt. The data obtained from wheel track tests is then processed in order to estimate the resistance of the asphalt mixture to permanent deformation, which is an important criterion for assessing the operational characteristics of pavements under simulated traffic loads.

2.5. Finite Element Modeling

The FEM is generally used in engineering to analyses complex structures, including asphalt layers. In this context, the FEM helps to model and simulate the behavior of asphalt below several conditions, considering parameters like load, temperature, and material properties. It permits engineers to predict how the AC layer will respond to different stresses, assisting in the design and optimization of road structures. There are many techniques used to anticipate rutting of flexible pavements. One of these techniques is the finite element method, which has been used successfully to analyses the performance of flexible pavements. This technique has become more important and has been adopted by many researchers, and it is one of the best techniques used to analyze the permanent deformation behavior of the road under different conditions. Thus, in this research, on this technique for the solid structural analysis of the AC layer using the C3D8R element, which is eight-node bricks elements with reduce integration [16–19] to simulate the AC casting section for the entire simulation, as in Fig. 1, which gives the finite element mesh. The goal is to analyze the model accurately by dividing it into smaller units and analyzing it through an appropriate mesh test that gives the appropriate results. However, the FEM has dimensions of 50 mm, thickness of the pavement layer, and other transverse dimensions 305 × 400 mm, but a quarter of the model was modeled. To reduce the cost and time of analysis, symmetry boundary conditions were used along the symmetry plane [20]. Apply a 3D model of the pavement layer, which is more accurate than 2D. As for the boundary conditions, in reality or the real conditions of the sidewalk, it is allowed to move freely in the vertical direction only and is restricted in the horizontal direction. As for the model, the surface part is free to move, the lower part is restricted in all directions, and the rest of the edges are prevented from moving in the horizontal direction. Regarding the loads imposed on the model in the Abaqus program, the load is 0.7 MPa of pressure load, which is distributed uniformly over the contact area with dimensions 230 × 50 mm to simulate the static load of the model as shown in Fig. 2. Where ther is also shown the load distribution and boundary conditions.

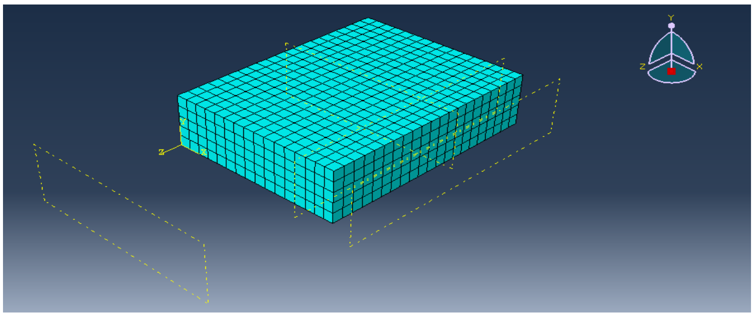

Figure 1. Finite element mesh of pavement model.

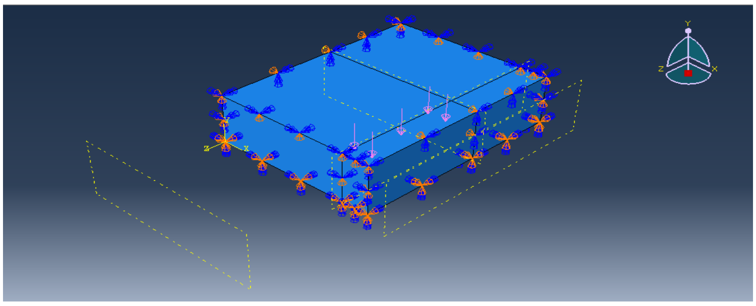

Figure 2. Boundary conditions and load distribution using Abaqus program for pavement model.

2.6. Material Properties

The behavior of the viscoplastic and elastic material of hot mix asphalt (HMA) was used, that is, based on creep testing for the purpose of using creep coefficients to predict realistic rutting, in addition to the material's modulus of elasticity and Poisson's ratio of 0.35. The creep test equation was used, Equation 1 and Table 1 show the material properties of the pavement:

$$\varepsilon_{vp} = A\sigma \cdot n \cdot t, \tag{1}$$

where A, n, and t are the creep power law parameters that relate to the material properties as: ε_{vp} – viscoplastic strain, A – power law multiplier, n – equation stress order, t – time order.

Table 1. Elastic and viscoplastic properties of HMA(16).

A	N	M	E (MPa)
8.19×10^{-4}	1.758	–0.0123	835

3. Result and Discussion

The FEM finite element approach was used to analyze the AC layer using a 3D model with appropriate material properties and loading conditions described in the previous sections. A model was implemented to analyze the pavement. In this research, the permanent deformation, stress, and strain of the AC were evaluated. For the purpose of understanding the behavior of this layer when exposed to static loads. Fig. 3. shows the effect of the static load on the model, as it leads to the formation of rutting on the pavement over time, and thus leads to premature damage to the pavement. Figs. 4 and 5 show the vertical strain and stress of the road. Vertical strain refers to the amount of change (elongation) in the layer as a result of the load. This indicates that it has an important effect because it leads to damage to the pavement. As for stress, it also represents the internal changes that occur in the pavement as a result. Traffic loads or temperatures, and based on the results of Figs. 4 and 5, it was found that static traffic loads also affect the pavement, i.e., cause damage to the pavement. Therefore, all of this indicates that static traffic loads cause damage to the road in terms of stress, strain, and rutting, and this results in premature maintenance or rebuilding of the sidewalk. Therefore, the effects of these loads must be taken into consideration, and this agrees with what was stated by [20].

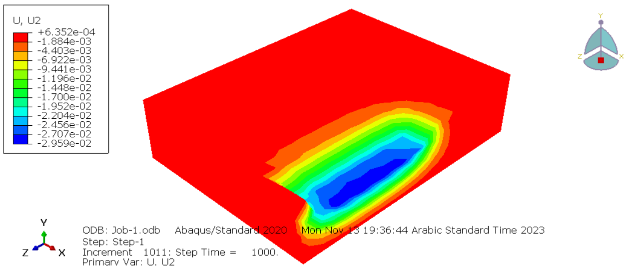

Figure 3. Rutting deformation of AC under the effect of static load.

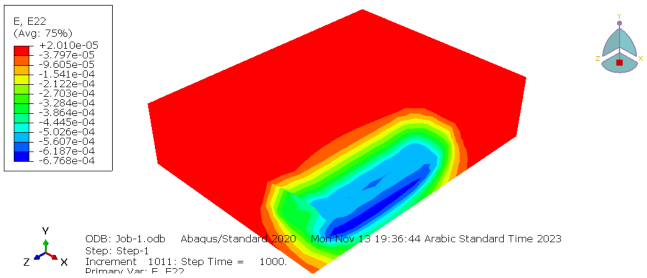

Figure 4. Vertical strain distribution of AC under the effect of static load.

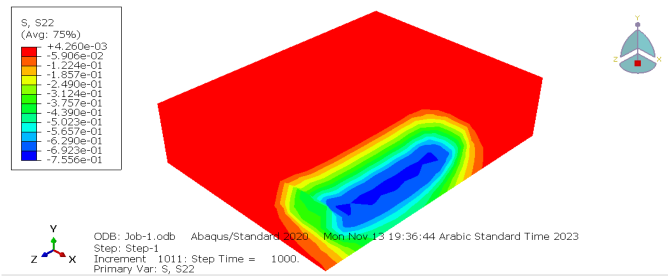

Figure 5. Vertical stress distribution of AC under the effect of static load.

4. Conclusions

This research presents a viscoplastic model of AC using a hot asphalt mixture that is subjected to a constant load. This model was developed to simulate the AC layer at this load. It is required for the purpose of knowing the effect of static load on the pavement in terms of depth of deformation, stress, and strain, which gave important results, through which we can know the effect of this load on the asphalt.

1. The generalized model can be used effectively to determine the effect of static load on asphalt and by using creep test parameters for asphalt.
2. The developed model can predict rutting accurately, based on the results.
3. The static load has an effect on the pavement, where it leads to the formation of stress, strain. Permanent deformation results in premature failure of the pavement.
4. FEM results indicate a somewhat high rutting depth as a result of the static load that matches with results of previous studies.

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