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Moisture Content Numerical Simulation on Structural Damage of Hot Mix Asphaltic Pavement

O S Abejide and M M H Mostafa
Sustainable Urban Roads and Transportation (SURT) Research Group,
Department of Civil Engineering, Central University of Technology, Private Bag X20539, Bloemfontein, 9300, Free State, South Africa.

E-mail: bskrtell@gmail.com; mmostafa@cut.ac.za;

Abstract. Considering the merits of road transportation in the economy and communication activities of the modern societies, it is imperative to design a safe, stable, efficient and cost effective road that will lead to increased economic development and growth of the South African nation. Although, the overarching effect of failed roads has in many ways led to increased travel time, loss of life and property; leading to reduced driver control on failed road sections (riding quality). Thus, time rate delamination of flexible pavement is a major focus of this study. Since structural collapse in a flexible pavement structure is caused by the evolution of different types of damage mechanisms; fatigue cracking, advanced crushing, temperature variation, and delamination. The effect of moisture content on HMA was analysed. The analysis from the multi-layered elastic model indicates that increase in moisture content in the underlying layer of HMA pavement results to increase in the strain of the individual layers and culminates to a decrease in the structural carrying capacity of the pavement with respect to number of load cycles that can be carried on the HMA pavement. This study shows a clear relationship between the moisture/saturation coefficient and the Elastic Modulus of the underlying geometric material layer properties of the pavement during the service life of the pavement.

1. Introduction

Excessive moisture in the underlying granular base layer can result to lose of its structural capacity by reducing the area over which the traffic load will be distributed. The increased moisture level has a significant effect on pavement structure which decreases resilient modulus and increases permanent deformation [1]. Excessive moisture and fine particles can be transported by hydrostatic pressure to the surface layers, thus reducing the strength of the overlying HMA by increasing strain under service conditions. Understanding the environmental effects on HMA pavements allows better prediction of pavement performance and behavior under different environmental conditions [2]. Regardless of the strength of the HMA surface course, the stability and durability of a pavement depends on the strength of its subbase and subgrade [3]. A strong surface layer will undoubtedly fail prematurely if constructed over a weak foundation as the strength of a pavement may fluctuate with changes in moisture content of its sub layers [4]. It is well known that the performance of a pavement construction is adversely affected by the presence of moisture within underlying layers [1]. Design and construction of the pavement is generally carried out with the intention of keeping the layers unsaturated.

2. Stress and strain models

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The response of a pavement structure to traffic loading is mechanistically modeled by computing stresses and strains within its layers. However, excessive stresses may cause pavement fatigue cracking and/or surface rutting. This will further result in both structural and functional failure, thus causing a safety hazard to motorists. These failure distresses are minimised among others by use of stochastic pavement designs. Pavement stress-strain analysis is an ideal tool for analytical modeling of pavement behavior and thus, constitutes an integral part of pavement design and performance evaluation.

2.1 Two-dimensional stress state

The analysis is based on a mechanistic design approach [5], [6], and a linear elastic two-layer pavement system [7]. The common analytical method to model pavement-traffic load response is stress-strain analysis.

2.2 Three-dimensional stress state

The development of FEM and its analysis presents description of three FE models in line with the set objectives with regards to moisture ingress. This model was used to validate the efficiency of using 3D FEM over a multilayered elastic design model in the design of pavement structure and examine the structural response of a stabilized base layer in terms of the stresses and strains at the surface of the subgrade and the tensile strain at the bottom of the Asphalt surface layer. Overall, all the models were developed using Abaqus® [8].

2.3 Traffic loading

In view of the current traffic regime, this study's emphasis was focused on high traffic loading which is considered as a major factor responsible for most pavement damage world-wide [9]. However, a design input value of 80,000N and a pressure distribution of 650Mpa is adopted in the design. The tire track is assumed to act along a radius of 195mm2; assuming a category “A” road with maximum traffic count at peak periods over a wet condition environment.

3. Methodology

3.1 Fatigue cracks and rutting

Fatigue cracking in asphalt layers is considered a major structural distress and is predominantly caused by traffic loading. In addition, ingress of rainwater through the cracks can lead to serious structural failure of the underlying layers particularly the unbound granular materials, subgrade and base course. [10] there exist two primary models used and would be considered in this study[11]. The strain values gotten from the FEM will be inserted into the equation for fatigue cracking and rutting [11] and the regression graph of safety will be plotted based on a statistical approach.

3.2. The NCHRP model

[11] introduced in the Mechanistic-Empirical Pavement Design Guide [12] estimates the resilient modulus using a generalized constitutive model for Level 1 analysis for the nonlinear stress-dependent modeling of both the unbound aggregates and fine-grained soils. Tests done by [13] also showed that the deviator stress is between 14 and 20 kPa (2 and 3 psi) and developed an expression for variation of resilient modulus obtained from laboratory tests on soil from the Ohio SHRP test section which will be adopted in this study to determine the resilient modulus of the UGB material when saturated.

3.3. Multi layered elastic theorem

The methodology adopted for this study makes use of a Multi-Layered Elastic Theory of pavement design and Analysis. The material properties and parameters of the pavement are as shown in Table 1. Consequently, the analysis was followed by a Finite Element analysis mesh optimization in Abaqus to determine the horizontal tensile strain at the bottom of the Asphalt pavement and also the vertical compressive strain at the top of the subgrade considering an Axis-symmetric modeling.

4. Results and discussion

Radial strain at the bottom of Asphalt layer and vertical strain at the top of Subgrade have been used to control fatigue and rutting of flexible pavements respectively using a multi-layered elastic design principle by mePADS Several fatigue and rutting models were developed to relate the asphalt modulus and the measured strains to the number of load repetitions to pavement failure. The result of the analysis as generated from the input values in (table 1) is shown in (table 2).

Table 1. Material properties of pavement layers

Layer	Material Code (Colto 2008)	Thickness (mm)	Elastic Modulus (Mpa)	Poisson's Ratio
Asphalt	AC	30	4000	0.40
Base C4	C2	200	2560	0.35
Unbound Granular Base	G4	350	Varied	0.35
Subgrade	G5	5000	200	0.35

From [11], the data in (table 2) was further analysed into to the Number of fatigue cracks to failure as well as the Number of Rutting to failure. A clear difference can be seen between the Normal strain at 20% Saturation Coefficient and 70% Saturation Coefficient; at this point, it is expected that the pavement has exceeded its yield point where it fails and deforms completely. The Figures 1-A and 1-B clearly reveal the behavior response of the soil with increasing saturation coefficient.

Table 2. Strain and resilient modulus for different percentage saturation coefficient levels

Saturation Coefficient (S %)	Elasticity Modulus (Mpa)	Horizontal Tensile Strain Et(10^{-6}) Bottom AC *MLED*	Vertical Compressive Strain *Top Subgrade* *MLED*	Horizontal Tensile Strain Et(10^{-6}) Bottom AC (Abaqus)	Vertical Compressive Strain Top Subgrade (Abaqus)
20	441	67.8	253	93.2	238.8
30	369.9	72.2	257	99.2	244
40	325.5	75.2	260	103.5	246.2
50	281.4	79.3	261	108.4	247.9
60	237.4	83.7	260	114.2	248.2
70	187	89.8	257	122.3	245.6
80	130	99.2	245	134.6	235.5

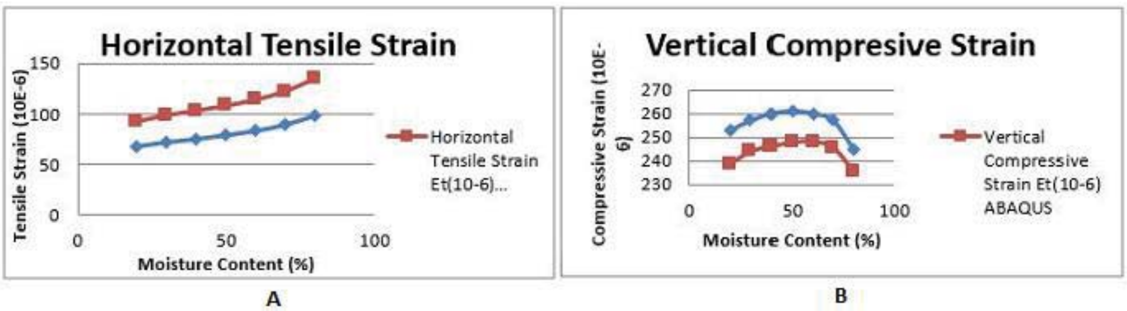

Figure 1. A - Horizontal Tensile Strain at Bottom of Asphalt, **B -** Vertical Compressive Strain at Top of Subgrade

5. Conclusion

A Multi-Layered Elastic design was used to determine the horizontal tensile strain at the bottom of the Asphalt and the vertical compressive strain at the top of the subgrade. The analysis from the multi-layered elastic model indicates that increase in moisture content in the underlying layer of HMA pavement results to increase in the strain of the individual layers and culminates to a decrease in the structural carrying capacity of the pavement with respect to number of load cycles that can be carried on the HMA pavement. The results obtained from the Finite Element Method indicates that; considering an Axis symmetric model, the percentage difference of the deformation response with an optimized meshing for Vertical Compressive Strain has an average percentage difference of 5.4% with the strain values obtained from the Multi-Layered Elastic Method, and the Horizontal Strain has an average percent difference of 31% compared with the results generated from the Multi-Layered Elastic Method. This study shows a clear relationship between the moisture/saturation coefficient and the Elastic Modulus of the underlying geometric material layer properties of the pavement during the service life of the pavement.

Furthermore, this study serves as a preface to an ideal and highly sophisticated field testing and monitoring model to be analysed with moisture instrumentation devices for an optimized and reliable analysis of moisture content effect in the flexible pavement which will be carried out on both old and newly constructed flexible pavement in South Africa.

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