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Research article

PREDICTIVE MODEL TO DETERMINE RESILIENT MODULUS ON BITUMINOUS MIXTURES IN LOAD REPETITION ON PAVEMENT FAILURE

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Abstract

Resilient modulus is a method of determining a directory that explains nonlinear stress-strain behavior of soils under cyclic loading. Resilient modulus is merely the proportion of the dynamic deviatoric stress to the healthier strain under a specified aversive pulse loading. Mechanistic design measures for pavements and overlays need resilient modulus bitumen and unbound pavement layers to determine layer thickness and the overall system response to traffic loads To established this predictive model, mathematical model was develop, to exhibits an approach that can precisely predict the resilient modulus on bituminous mixture, the approach will also reflect the influence on load repletion causing pavement failure, the model were derived form an established governing equation generated from the parameters in the system. the model were developed in phases base on some conditions considered in the system, this finally produce an expressed model that can predict the resilient modulus on bituminous mixtures that reflect load repletion in pavement failure.

Keywords: predictive model resilient modulus, bituminous mixtures and pavement failure

1. Introduction

To develop design a long lasting pavement, it is very imperative to approximate the actual field situation in design phase of asphalt concrete pavements. For example, better structural performance depends on a good projection of future traffic and accurate representation of field conditions, i.e., temperature. Traffic loads are represented by cyclic loads in the performance testing of asphalt mixtures, and the resilient modulus is used to explain the stress-strain performance of asphalt concrete under cyclic traffic loading. It is the most significant material parameter in the design procedure of asphalt concrete pavements characterizing the complete structural performance of pavement structure. Hence, the accurate estimation of resilient modulus directly affects the layer thickness, service life and the overall cost of the pavement construction (Canser 2010)

The AASHTO Pavement Design Guide (1993), in addition to other revisions, incorporated the resilient modulus (MR) concept to characterize pavement materials subjected to moving traffic loads. MR values may be estimated directly from laboratory testing, indirectly through correlation with other laboratory/field tests, or back calculated from deflection measurements. The testing procedure for the determination of MR consists of the application of a repeated deviator stress (ζd), under a constant cell pressure and then measuring the resilient axial strain. Under repeated load tests, it is observed that as the number of load cycles increases, the secant modulus increases. After a number of load cycles, the modulus becomes nearly constant, and the response can be presumed to be elastic. This steady value of modulus is defined as the resilient modulus (Rahim , 2005, Canser 2010). As the number of load applications increases, the plastic strains due to load repetition decreases (Huang, 1993). It can be observed from the figure that the permanent deformation rate approaches to zero with the increasing number of load repetitions (Çöleri E., 2007). Stiffness modulus of bituminous mixes can either be measured in the laboratory or predicted from properties of mix components, namely, aggregate and bitumen. There are a number of well known empirical models that were developed by various researchers and relate resilient modulus to bituminous mix properties (Suhaibani et al., 1997). The resilient modulus can be performed on laboratory prepared specimens or field cores. For consistency in design, results obtained from laboratory prepared specimens should match with results obtained from field cores (Katicha , 2003). Resilient modulus measured in the indirect tensile mode (ASTM D 4123-82) has been selected by most engineers as a method to measure the resilient modulus of asphalt mixes (Brown et al., 1989) Witczak and Fonseca (1995) propose an empirical model to predict the complex modulus of an asphalt mixture.

Theoretical background

Resilient modulus is a possession for bound and unbound pavement materials characterizing the elastic behavior of materials under lively repeated loading. Resilient modulus is an important design parameter for pavement structures because it represents the structural strength of pavement layers through which the thickness design is based on.

Modulus of material some time may be complex, the material is subjected to sunsidal loading at varied frequency, most times when there is hypothesis on the linear viscous elastic material valid, it response to sunsidal loading, most times there is an emphasized that the type of test is not a dynamic test due to normal applied frequency.. the stiffness of the mix prevent to consider the stress and strain of mix, theses prevent to consider the stress and strain fields, complex modulus is a complex amplitude of sundial stress pulsation applied in material, the complex amplitude of sundial strain result to steady due to the viscous elastic character of the material strain lag behind the stress.

In most cases it has confirmed that bituminous mixtures, mechanical properties determined including sinusoidal Loading tests, this can be modelled applying the complex modulus method this definitely described the stiffness modulus including the phase angle. For several years past, research activities have centered on the derivation of extrapolative models for the mechanical properties, these are based on the composition and components characteristics of the bituminous mixtures. The establishment of experimental method to monitor pavement behaviour has been improved by modeling it by applying the finite element method. This are concept considers to monitor pavement behaviour the model developed in this research is to predict the stiffness modulus of bituminous materials. Comparisons of the measured and calculated strains were confirmed to establish a good agreement of the results as reveal. More so it indicates an appropriately adjusted model.

Most laboratories testing have also pointed out some established influence in temperature, porosity, rise-time and load factors in the indirect tensile stiffness modulus of bituminous materials. Results presented from in those studies are the means series of indirect tensile stiffness modulus obtained in each test performed in repeatability conditions. In conclusion it could be drawn that the stiffness modulus is not dependent on applied indirect tensile stress for all test temperatures. Instead, the stiffness modulus depends on rise-time, mainly in the case of high temperatures. Life of flexible pavements is determined by Fatigue cracking, this represents major distress that affects the service of the pavement. This from rheological properties of the HMA mixes, after the passing of a vehicle, the asphalt concrete layer tends to return to its original condition. But, due to the cycling nature of the loading, the asphalt concrete exhibits the fatigue cracking. Cracking usually starts from the bottom of the asphalt layer, where the material is in tension when wheel loads are applied at the pavement surface, and propagates up to the surface. Once they reach the surface, the cracks represent avenues for water to enter the pavement and cause the deterioration of the foundation. Layers. The cracks may also lead to the formation of potholes, which greatly reduces the ride ability of the pavement, the comfort and safety of road users. Therefore, understanding the phenomenon of fatigue cracking and measuring the fatigue properties of asphalt concrete is essential for the design of flexible pavements (Monismith et al., 1985 Richard 2004).

2. Governing Equation

$$\frac{\partial Nf}{\partial t} = K_1 C \left(\frac{1}{\varepsilon}\right)\frac{\partial Nf}{\partial Z} + \left(\frac{1}{\varepsilon}\right)\frac{\partial Nf}{\partial Z} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

The express governing equation is to streamline the rate of resilient modulus of the materials. Any mechanistic design procedure for asphalt pavements includes models for the rut depth evolution, as well as for the initiation and development of fatigue cracking. Fatigue cracking models use as input parameters the fatigue properties and stiffness of the asphalt concrete. These models are effective only when the appropriate fatigue parameters are selected in the design .the governing equation considered the influential parameter that developed fatigue cracking including the expression of resilient modulus. However, even fatigue cracking is not a major distress type for asphalt pavements in the State, appropriate input parameters in the fatigue model will be required to ensure an efficient structural design. The parameters in this study will definitely developed the model by ensuring that the parameters that expressed the cause of the fatigue cracking and determinant of resilient modulus through the governing equation.

Let $Nf_{(z,t)} = Z_{(z)}\ T_{(t)}$ be the solution

$$ZT^1 = K_1C\frac{1}{\varepsilon}Z^1T + \frac{1}{\varepsilon}Z^1T \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

Dividing by ZT

$$\frac{T^1}{T} = K_1C\frac{1}{\varepsilon}\frac{Z^1}{Z} + \frac{1}{\varepsilon}\frac{Z^1}{Z} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3)$$

From (2)

$$\frac{T^1}{T} = -\lambda^2 \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (4)$$

$$T + \lambda^2T = 0 \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (5)$$

$$K_1C\frac{1}{\varepsilon}\frac{Z^1}{Z} + \frac{1}{\varepsilon}\frac{Z^1}{Z} = -\lambda^2 \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (6)$$

$$K_1C\frac{1}{\varepsilon}\frac{Z^1}{Z} + \frac{1}{\varepsilon}\frac{Z^1}{Z} + \lambda^2 = 0 \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (7)$$

$$Z^1 - \frac{1}{\varepsilon}Z^1 - \frac{1}{K_1C\frac{1}{\varepsilon}} + \lambda^2 = 0 \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (8)$$

$$Z^1 - Z^1 - \beta Z = 0 \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (9)$$

Where $\beta = \frac{1}{K_1C\frac{1}{\varepsilon}} + \lambda^2$ $\qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (10)$

Equation (2) to (10) were subject to parameters were discretize in the system this to ensure variables Are separated in accordance with the established variables which develop relationship between each other, variables in this phase express there various functions that reflect the influence of determining the resilient of this materials, this streamlined are in the characteristics of the variables which determinant the resilient modulus of the materials under the influence load repetition. "Fatigue Cracking" is the progressive cracking of the asphalt surfacing or stabilized base layers due to cumulative repeated traffic loading. This occurs as a result of tensile tresses and strains from the bottom zone and propagates upward to the top. On the pavement surface, it finally manifests as alligator cracks along the wheel tracks. 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 granular and unbound materials including the subgrade. The cracks are measured in square meters of the surface area.

For thorough design that will develop a long lasting pavement, it is imperative to approximation the real field situation in design phase of asphalt and concrete pavements. More so, better structural performance depends on a good protrusion of future traffic and accurate symbol of field conditions, i.e., temperature. Traffic loads are protrusive by cyclic loads in the performance testing of asphalt mixtures, and the resilient modulus used to explain the stress-strain behavior of asphalt concrete under cyclic traffic loading. These remain most significant material parameter in the design process of asphalt concrete pavements characterizing the entire structural performance of pavement structure. Hence, the accurate opinion of resilient modulus in a straight line that affects the layer thickness, service life and the overall cost of the pavement construction

Suppose $Z = \ell^{M_z}$ in (9)

$$ZM^2 - M\ell^{M_z} + \beta\ell^{M_z} = 0 \tag{11}$$

$$XM^2\ell^{M_z} + M\ell^{M_z} - \beta\ell^{M_z} = 0 \tag{12}$$

$$\left(ZM^2 - M - \beta\right)\ell^{M_z} = 0 \tag{13}$$

But $\ell^{M_z} \neq 0$

$$ZM^2 - M + \beta = 0 \tag{14}$$

Applying quadratic expression, we have

$$M_{1,2} = \frac{-1 \pm \sqrt{1+4\beta z}}{2z} \tag{15}$$

$$M_1 = \frac{-1 + \sqrt{1+4\beta z}}{2z} \tag{16}$$

$$M_2 = \frac{-1 - \sqrt{1+4\beta z}}{2z} \tag{17}$$

Therefore, $$Z_{(Z)} = C_1\ell^{M_{1Z}} + C_2\ell^{M_{2Z}} \tag{18}$$

$$= C_1 CosM_{1Z} + C_2 SinM_{2Z} \tag{19}$$

Solving from equation (3) gives

$$\boxed{T_{(t)} = \ell^{\frac{-\lambda^2}{P}t}} \tag{20}$$

Traffic loading refers not only to the magnitude of the loads – the weight that is being applied to the pavement section – but also the nature or arrangement of the applied loads, and the frequency of the loading, that is, how many times that weight is applied, or the axle load accumulation It is obvious that a deviation between the estimated and the actual modulus may easily cause inaccurate design solutions. Evaluations of various empirical methods by several researchers assessed are based on these research results, including method leading to the closest estimate to the measured modulus values are presented accordingly. The testing process for the determination of MR consists of the application of a recurring deviator stress (ζd), under a steady cell pressure and then measuring the resilient axial strain. Under recurring load tests, it is noticed that as the numeral of load cycles increases, the secant modulus increases. After a number of load cycles, the modulus becomes nearly steady, and the reply can be presumed to be elastic. This steady value of modulus is defined as the resilient modulus (Rahim A.M., 2005). The express model in (20) streamline the rate of mix stiffness modulus of materials , this condition are reflected from the rate of accumulative load repetition, this expression determine the stiffness modulus of the material with respect to time tensile stress and strain of the material of fatigue on pavement failure. Subject to this relation, pavement developed fatigue at a very short time before the designed period. Hence the solution of the equation can be expressed as

Hence the solution of the equation can be expressed as

$$Nf = C_1 \; and \; C_2$$

$$\boxed{Nf_{(Zt,t)} = \left(C_1 \, CosM_{1Z} + C_2 \, Sin\, M_{2Z}\right)\ell^{-\lambda^2 t}} \qquad \text{………………………..} \quad (21)$$

The expression in (21) is the final developed mode predict the resilient modulus of material that reflect the fatigue of pavement through the applied materials., this condition has confirmed to generate the influence of stress and strain from load repetition, the issue of load repletion subject the pavement to stress. With the ever growing truck tyre loading and inflation pressures, a improved knowledge of pavement stress-strain behaviour is an improvement in the expansion of more constitutive design of some models focused on pavement-traffic load response and distress minimization. Wide use of thin asphalt surfacing (≤50mm) in most developing nation they are considered economical, this mean that extra studies should be systematically carried out to forecast the stress and strain influence on resilient modulus of material from load repletion. More so there is needed to understanding the traffic load response of these layers (Canser 2010). These parameters were subsequently correlated to the pavement service life in terms of the number of load repetitions to initiation of fatigue cracking (relative fatigue life). The stress-strain distributions and the three-dimensional stress state in relation to the asphalt surfacing layer thickness are also presented. This is under the influence of accumulative load repetition constantly subjecting the pavement to stress.

4. Conclusion

The resilient modulus is the elastic modulus used in the layered elastic theory for pavement design. Thus. an experience has proof that from permanent deformations in every application of load cycle. However, if the load is little compared to the strength of the material and after a comparatively great numeral of repetitions (100 to 200 load repetitions), the deformation after the load application is almost totally recovered. The deformation is proportional to the applied load and since it is nearly entirely recovered it can be considered as elastic. In surveillance of the current traffic rule, study's has presently emphasis focused on high traffic loading which is considered as a major factor responsible for most pavement damage world-wide. In nation like South Africa traffic statistics revealed that 35% of the 90 000 weighed heavy trucks were overloaded (De Beer et al, 1999). In most developing nation like Zambian weighbridge stations (Kafue) it was confirm on physically visit in 1998, 6 of the 25 weighed trucks between 08.00hrs to 16.00hrs were on average 12.5% overloaded above the 80kN legal axle-load limit. Thus, on average, one in every five trucks on the Nigerian roads could be overloaded. Following “fourth power law", 12.5% overload results in about 60% more pavement damage compared to an 80kN legal axle load. Therefore it is imperative understand the level of seriousness and it advantage on the current standard design loads, if modern pavements are to sustain these extreme high loads. Traffic laws and regulations also need to be effectively enforced to minimize pavement damage. Nigeria is not left behind, constant repetitions of load from different truck accumulate stress and strains consequently develop fatigue on pavement, thus, the tensile strength is one of the critical parameters to always taken into consideration for performance evaluation. The evaluation of the fatigue life of a mixture is based on the flexural stiffness measurements. Tensile strain at the bottom of the asphalt concrete layer in a pavement is an important parameter in the measurement of fatigue life of a mixture. The bottom of asphalt concrete layer has the greatest tensile stress and strain. Cracks are initiated at the bottom of this layer and later propagate due to the repeated stressing in tension of asphalt concrete pavements caused by bending beneath the wheel loads. Ultimately, the crack appears on the surface in the wheel paths which we characterize as fatigue cracking. Moreso most material characteristic strength are substandard in design material, in fact most roads are not designed developing pavement failure thus life span of the pavement cannot be determined. Subject to this ugly scourge, high rate of pavement failure are of high increase in Nigeria roads. The developed model will definitely predict resilient modulus of bitumen mixture on load repletion in the study area.

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