World Journal of Basic and Advanced Sciences Research
Vol. 1, No. 1, November 2014, pp. 1 -7
Available online at http://wjbasr.com

Research article

CONSTANT STRESS MODEL PREDICTION OF PAVEMENT FAILURE INFLUENCED BY FATIGUE CRACK ON THIN AND THICK LAYER

Eluozo, S N.

Subaka Nigeria Limited Port Harcourt Rivers State of Nigeria
Director and principal consultant Civil and Environmental Engineering, Research and Development
E-mail: soloeluozo2013@hotmail.com
E-mail: solomoneluozo2000@yahoo.com

Abstract

Constant stress that subject pavement failure through fatigue cracking has been observed, several deformation problems has been noted by researchers in various nations around the globe. In developing nations there are several causes of this pavement deformation which hinder it from reaching its designed life span. The study focuses on deformations on thin and thick layer through fatigue crack in deltaic formation. Due to none adherence to design procedures, lots of fatigue crack in thin and thick layers has been observed in the study area. Several researchers have improved on the prevention of deformation in various studies carried out. It has been confirmed that most of these results have created tremendous improvement on pavement deformation, but definite result for some deltaic deposition has not been thoroughly developed. Based on these factors, development of these model to predict the rate of pavement failure in thin and thick layer become an imperative study to carry out, the expressed model generated were developed through parameters that influences the deformation of pavement from fatigue crack. The derived solution expressed these models to predict this type of pavement deformation in thin and thick layer, experts will find the model a useful tool to monitor or predict deformation of pavement in thin and thick layer.

Keywords: Constant stress, pavement failure fatigue crack and thin and thick layer

---

1. Introduction

Fatigue (also known as alligator) cracking caused by fatigue damage, is the major structural distress that occurs in asphalt pavements by means of granular and weakly stabilized bases. Alligator cracking initial first stage comes into view as parallel longitudinal cracks in the wheelpaths, and improve into a network of interconnecting fracture similar to chicken wire or the skin of an alligator. Alligator cracking may improve further; particularly in area where the support is weakest, limited to a small area under localized condition develop failures and potholes. Factors which persuade the expansion of alligator cracking are the numeral and magnitude of functional loads, the structural design of the pavement (layer materials and thicknesses), the superiority and consistency of foundation support, the steadiness from asphalt cement, the asphalt content, the air voids and aggregate quality of the asphalt concrete mix, and the weather of the site (i.e., the seasonal assortment and allocation of temperatures) substantial laboratory study has expressed several fatigue life of asphalt concrete mixes conducted in different ways. However, attempting to deduce from such investigation tests showing how asphalt concrete mix properties manipulate asphalt pavement fatigue life need consideration of the method of Laboratory testing (steady stress or stable strain) and the failure criterion are applied. Steady stress investigation suggests that any asphalt cement property (e.g., lower infiltration, advanced viscosity) or mix properties which enhance mix rigidity will increase fatigue life. Constant-strain investigation suggests the opposite: that less fragile mixes (e.g., higher infiltration, lesser viscosities) display longer fatigue lives. The established recommendations are that low-stiffness (little viscosity) asphalt cements ought to be used for thin asphalt concrete layers (i.e., less than 5 inches), and that the fatigue life of such mixes should be evaluated using constant-strain testing, while highstiffness (high viscosity) asphalt cements should be used for asphalt concrete layers 5 inches and thicker, and the fatigue life of such mixes should be evaluated using constant-stress testing. In practice, however, it is not common to modify the mixture stiffness for different asphalt concrete layer thicknesses [1].

Fatigue cracking in flexible asphalt road is caused by the recurring stresses and strains due to traffic loading. Cracking occurs when the useful horizontal tensile strain reoccurrence exceeds the fatigue life capability of the asphalt coat. Once the asphalt has attained a specific level of cracking it is said to have attained its fatigue life. The fatigue lives of asphalt are influenced by a multiplicity of factors, together with: the underlying rigidity of the pavement composition; traffic loading spectrum; environmental factors; construction variables; and material characteristics [2, 7]. Furthermore, the firmness of asphalt is an invention of the bitumen type and content; quantity of air voids inside the mix; hotness and frequency of loading; and the category of aggregate and its gradation inside the mix.

Loading setting is another aspect distressing the examination of fatigue life of asphalt. Particularly, there are numerous dissimilar investigating procedures used to measure the fatigue life of asphalt that aim to duplicate the asphalt road response in field situation. These diverse investigation setups comprise: bending testing (three and four point loading schemes), indirect tensile testing, and direct tensile testing. Flexural fatigue testing is the preferred Australian procedure as it is said to replicate the definite behaviour of an asphalt layer under wheel loading more closely than any another procedures [7]. Among these are variety of loading setups, there are also two types of restricted loading modes: restricted strain and controlled tension. Restricted strain (disarticulation) investigation is defined by maintaining a steady deformation for the period of cyclic loading throughout the test. In the strain controlled test, the load diminishes for the period it is tested to keep a stable deformation. Cracks commence at the bottom of the asphalt specimen and proliferate through cyclic loading. As the numeral of cycles raise, the flexural modulus of the sample beam diminishes. In the restricted strain testing there is no apparent failure, therefore, collapse is often defined when the flexure modulus reduces to a 50 percent of its inventive value [5]. In another development, restricted stress (force) is attained by sustaining a constant stress loading all through the test. In this issue or situation, the deformation raises at the period the test are base as a result of cracking; hence, failure is defined when the specimen crack. In the contest, restricted disarticulation investigation or examination is said to be more appropriate for comparatively thin asphalt pavements (less than 100 mm thick), however, restricted stress testing is more applicable for thick pavements; usually, models developed based on restricted strain testing that provides longer fatigue lives compared to those based on restricted stress. However, additionally it is said that for pavements with a greater flexibility, that is, lower stiffness; controlled strain testing that has more superior fatigue performance with comparable initial strain amplitudes [2]. [2] Express discrepancies between the field and the laboratory due to differences in the loading setups (axle loads and traffic arrangement position); setting up practical loading times and rest periods between traffic loading; the environmental temperature throughout the pavement service life; and the intensity of compaction of the asphalt. Due to these differences, a calibration factor usually called shift factor is useful to a laboratory fatigue model to give a superior approximation of the fatigue life in the field. The reliability factor is not a shift factor that takes into description in-service field situation. The Shell fatigue forecast model was generated by Shell researchers in [11] from ‘a wide sort of mix types containing conventional binders’ [7]. Furthermore, [2] affirmed ‘this fatigue relationship was based on laboratory-restricted strain sinusoidal loading fatigue testing on several (13) typical asphalt mixes used in a variety of countries [4, 6].’For heavy loads, pavements require to be supported structurally. In doing so, asphalt road engineers follow the AUSTROADS asphalt road Design: A Guide to the Structural Design of Pavements [3] hereinafter presented it as the AUSTROADS, and the New Zealand enhancement to the [8, 9]. The guiding principles determines the suitable thickness of asphalt road layers in accordance with particular traffic loads, volumes, and fast; manufacture materials; meteorological climatic setting; and failure criteria for the expected design period of the road. For a flexible pavement system, the asphalt road design process is based on a multi-layered structural investigation comprising: asphalt, unbound granular material, cemented materials, and the subgrade. These structural layers are designed to avoid two modes of collapse, the fatigue of bound materials and the everlasting deformation of the subgrade.

To analyze the fatigue spoil of structural pavements, AUSTROADS have adopted the Shell fatigue transfer function (FTF), also known as the Shell fatigue performance criterion. The Shell FTF was generated by examining asphalt mixes from abroad, not the study area asphalt (Shell International Petroleum Company Ltd. [11]. Consequently, the Shell FTF does not characterise the behaviour of local materials in New Zealand In addition, the Shell FTF was developed from a number of laboratory conditions. Fatigue tests were carried out using a sinusoidal loading shape in both two-point or three-point bending modes, with test temperatures ranging from -10–50°C, and a test frequency from 10–50 Hz [12]. A have sine loading pulse, however, is generally acknowledged to represent the in-service conditions.

2. Theoretical background

Load-associated fatigue cracking has been confirmed to be one of the major agonies occurring in flexible pavement systems. The deed of repetitive traffic loads induces tensile and shear stresses in all chemically stabilized layers, definitely these ultimately generate to a loss in the structural reliability of the stabilized coating. Recurring load or fatigue cracks initiate at points where the critical tensile strains and stresses take place. The position of the critical strain/stress is dependent upon numerous factors. The most significant is the rigidity of the layer and the load configuration. In addition, it ought to be realized that the utmost tensile strain developed are contained by the pavement system, it might not be the most critical or destructive value. This is because the crucial strain is a role of the stiffness of the mix. Since the rigidity of an asphalt mix in a coated pavement system varies with depth, these transformations will ultimately effect the position of the critical strain that causes fatigue damage. Once the damage initiates at the crucial position, continuous action of traffic eventually develop these cracks to proliferate throughout the entire bound layer. Proliferation of the cracks all over the entire layer thickness will ultimately allow water to leach into the lower unbound layers, weakening the pavement structure and reducing the overall performance. The consequences will be increased of unevenness of the pavement system, causing a decline in pavement serviceability. This phenomenon of crack commencement and then proliferation through the entire layer occurs not only in the surface layer, however all the stabilized layers are underneath. In underlying layer cracking, such as cement stabilized sub base, also reduces the overall structural capability of the coating (and pavement) may induce reflective cracking in the upper layers. It has been confirmed that this type of fatigue is not as well defined from a mechanistic point of view as the more standard "bottom-up" fatigue. However, it is a reasonable engineering assumption, with the current state of knowledge, that this distress may be due to critical tensile and/or shear stresses developed at the pavement surface and, perhaps, caused by extremely large contact pressures at the tire edge-pavement interface; coupled with highly aged (stiff) thin surface layer that have become oxidized. In this initial mechanistic attempt to model top-down cracking in the Design Guide; the failure mechanism for this distress is hypothesized to be a result of tensile surface strains leading to fatigue cracking at the pavement surface. The fatigue life of an asphalt concrete mixture is influenced by many factors. Numerous major mix properties such as asphalt type, asphalt content and air-void content are well known to influence fatigue. Other factors such as temperature, frequency, and rest periods of the applied load also are known to influence fatigue life. Other material properties may also affect the fatigue life. It is obvious that mix properties need to be carefully balanced to optimize fatigue cracking of any mixtures (NCHRP, 2004). Series of interconnected crack caused by fatigue failure of the HMA surface (or stabilized base) under repeated traffic loading in thin pavement, cracking initiates at the bottom of the HMA layer where the tensile stress is the highest they propagate to the surface as one or more longitudinal cracks. This is commonly referred to as bottom-up or classical fatigue cracking in thick pavement, the crack most likely initiate from the top in area of high localized tensile stresses resulting from tire pavement interaction and asphalt bind aging (top-down cracking). After repeated loading, the longitudinal crack connect forming many-side sharp angled piece that develop into pattern resembling the back of alligator or crocodile.

3. Governing Equation

$$\frac{\partial Nf}{\partial t} = \frac{\varepsilon_t}{\varepsilon}\frac{\partial N^2 f}{\partial t^2} - \frac{V_b}{V_a}\frac{\partial Nf}{\partial X} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

Where

Nf = Number of repetition of fatigue cracking

ε_t = Tensile strain at the critical location

E	=	Stiffness of the material
V_b	=	Effective content in volume (%) and
V_a	=	Air void (%)
T	=	Period of pavement design
X	=	length of pavement crack

Let $Nf\ (z,t) = Z_{(z)}\ t_{(t)}$ be the solution

$$ZT^1 = \frac{\varepsilon_t}{\varepsilon} ZT^1 - \frac{V_b}{V_a} Z^1 T \qquad \ldots\ldots\ldots\ldots \qquad (2)$$

Dividing equation by ZT

$$\frac{T^1}{T} = \frac{\varepsilon_t}{\varepsilon}\frac{T^1}{T} - \frac{V_b}{V_a}\frac{Z^1}{Z} \qquad \ldots\ldots\ldots\ldots \qquad (3)$$

From equation (2) we have:

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

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

$$\frac{\varepsilon_t}{\varepsilon}\frac{T^1}{T} - \frac{V_b}{V_a}\frac{Z^1}{Z} = -\lambda^2 \qquad \ldots\ldots\ldots\ldots \qquad (6)$$

$$\frac{\varepsilon_t}{\varepsilon}\frac{T^1}{T} - \frac{V_b}{V_a}\frac{Z^1}{Z} + \lambda^2 = 0 \qquad \ldots\ldots\ldots\ldots \qquad (7)$$

$$T^1 - \frac{1}{\frac{\varepsilon_t}{\varepsilon}} Z^1 - \frac{\frac{V_b}{V_a}}{\varepsilon} + \lambda_Z = 0 \qquad \ldots\ldots\ldots\ldots \qquad (8)$$

$$T^1 - Z^1 - BZT = 0 \qquad \ldots\ldots\ldots\ldots \qquad (9)$$

Where $\beta = \frac{V_b}{V_a}\frac{1}{\frac{\varepsilon_t}{\varepsilon}} + \lambda^2$ $\qquad \ldots\ldots\ldots\ldots \qquad (10)$

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

$$= M\ell^Z \;\; Z^1 = M^2 \ell^{M_Z} \qquad \ldots\ldots\ldots\ldots \qquad (11)$$

$$ZM^2 \ell^{M_Z} - M\ell^{M_Z} - \beta\ell^{M_Z} = 0 \qquad \ldots\ldots\ldots\ldots \qquad (12)$$

$$\left(ZM^2 - M - \beta\right)\ell^{M_Z} = 0 \qquad \ldots\ldots\ldots\ldots \qquad (12)$$

But $\ell^{M_Z} \neq$ ……………………………. (13)

$$ZM^2 - M - \beta = 0 \qquad (14)$$

Applying quadratic expression, we have

$$M_{1,2} = \frac{-1 \pm \sqrt{1+4\beta Z}}{2Z} \qquad (16)$$

$$M_1 = \frac{-1 + \sqrt{1+4\beta Z}}{2Z} \qquad (17)$$

$$M_2 = \frac{-1 - \sqrt{1+4\beta Z}}{2Z} \qquad (18)$$

Therefore $Z_{(x)} = C_1 \ell^{M_1 Z} + C_2 \ell^{M_2 Z}$ ……………………………. (19)

$$= C_1 \, Cos M_2 Z + C_2 \, Sin M_2 Z \qquad (20)$$

Solving from equation (3) gives

Hence the $T_{(t)} = \ell^{-\lambda^2 t}$ solution of the equation can be expressed as:

Nf = *C1* and C_2

$$Nf(Z,t) = \left(C_1 \, Cos M_1 Z + C_2 \, Sin M_2 Z\right)\ell^{\lambda^2 t}$$

The developed model at this stage express the rate of constant stress on pavement failure pressured by fatigue crack on thin layer; the developed model equation considered other consequences of pavement deformation that resulted to fatigue crack in roads. Several factors in deltaic environment generated to this type of pavement deformation, the rate tensile strain on asphalt layer are paramount in roads from developing nations where designed principles are hardly adhered to in construction of any type of pavements. Fatigue cracking in an asphalt concrete layer occurs as a result of repeated tensile strain in the asphalt layer. Since an asphalt overlay of a concrete slab, even if unbonded, should never experience significant tension under flexural loading, true fatigue cracking should never occur in a stable asphalt overlay of a sound concrete slab. If longitudinal or alligator-type cracking does appear in an asphalt-overlaid concrete pavement, it indicates one of the following unusual conditions: an unstable asphalt concrete mix coupled with loss of bond between the asphalt and concrete layers, or complete degradation of the concrete, e.g., extensive and severe “D” cracking. In this latter case, the breakdown of the concrete is more likely to be concentrated in localized areas near joints and cracks, and produce potholes and localized failures where the wheelpaths cross these areas.

4. Conclusion

Fatigue crack on thin layer has been expressed through the developed model. Lots of unusual practices in design and construction of roads in deltaic environment and other parts of the country developed deformation of pavement, depending on the type of pavement proposed in any side of deltaic environment. The expressed model considered numerous conditions that developed fatigue crack in roads which were able to monitor the rate of fatigue in thin layer. Furthermore, fatigue cracking in flexible pavements is caused by the repetitive stresses and strains due to traffic loading. Cracking occurs when the applied horizontal tensile strain repetitions exceeds the fatigue life capacity of the asphalt layer. Once the asphalt has reached a defined level of cracking, it is said to have reached its fatigue life. The fatigue life of asphalt is influenced by a variety of factors, including: the underlying stiffness of pavement structure, traffic loading spectrum, environmental factors, construction variables and material characteristics. probable cause, failure of base, subbase or subgrade support, failure of drainage or spring that consequences generate in less stiff base Stripping on the bottom of HMA layer (the stripped fraction contribute slight to pavement strength so the efficient HMA thickness decline raise in loading (e.g. more heavier trucks than anticipated designs, inadequate structural designs.

References

[1] NCHRP. (2004). Guide for Mechanistic-Empirical Design of new and rehabilitated pavement Structures National Cooperative Highway Research Program Transportation Research Board National Research Council.

[2] Baburamani, P. (1999). *Asphalt Fatigue Life Prediction Models–A Literature Review.* ARRB Transport Research Ltd, Vermont South, Victoria. Research Report ARR 334.

[3] Pavement Design: A Guide to the Structural Design of Road Pavements. Austroads Publication No. AP-GP17/04. Austroads, Sydney.

[4] New Zealand Supplement to the Document, *Pavement Design – A Guide to the Structural Design of Road Pavements (Austroads, 2004)* Transit New Zealand, 2007

[5] Saleh, M. (2003). *Course Reader: ENTR603: Advanced Pavement Design.* University of Canterbury, New Zealand.

[6] Anthony, S., Mofreh, S, and Howard, J. (2010). Investigation into the validation of the shell fatigue transfer function technical paper IPENZ Transportation Group Conference Christchurch.

[7] AUSTROADS. (2004). Technical Basis of Austroads Pavement Design Guide. Sydney

[8] AUSTROADS. (2008a). Guide to Pavement Technology Part 2: Pavement Structural Design. Sydney, NSW: Austroads Incorporated.

[9] AUSTROADS. (2008b). Technical Basis of Austroads Guide to Pavement Technology Part 2: Pavement Structural Design AP-T98/08. Sydney.

[10] Shell International Petroleum Company Ltd. (1978). *Shell pavement design manual - : asphalt pavements and overlays for road traffic*. London, UK.

[11]Van Dijk, W., & Visser, W. (1977). The energy approach to fatigue for pavement design. *Proceedings Association of Asphalt Paving Technologists, 46*, 1-40.

[12] Van Dijk., W. (1975). Practical Fatigue Characterization of Bituminous Mixes. *Proceedings Association of Asphalt Paving Technologists, 44*, 38-74.