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Pavement Material Characteristics and its Influence on Stress and Strain Pavement Layer

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Abstract: There is a growing interest for the use of mechanistic procedures and analytical methods in the design and evaluation of pavement structure rather than empirical design procedures. The mechanistic procedures rely on predicting pavement response under traffic and environmental loading (i.e., stress, strain, and deflection) and relating these responses to pavement field performance. A research program has been developed at the Center for Pavement and Transportation Technology (CPATT) test track to investigate the impact of traffic and environmental parameters on flexible pavement response. This unique facility, located in a climate with seasonal freeze/thaw events, is equipped with an internet accessible data acquisition system capable of reading and recording sensors using a high sampling rate. A series of controlled loading tests were performed to investigate pavement dynamic response due to various loading configurations. Environmental factors and pavement performance were monitored over a two-year period. Analyses were performed using the two dimensional program MichPave to predict pavement responses. The dynamic modulus test was chosen to determine viscoelastic properties of Hot Mix Asphalt (HMA) material. A three-step procedure was implemented to simplify the incorporation of laboratory determined viscoelastic properties of HMA into the finite element (FE) model. The FE model predictions were compared with field measured pavement response. Field test results showed that pavement fully recovers after each wheel pass. Wheel wander and asphalt mid-depth temperature changes were found to have significant impact on asphalt longitudinal strain. Wheel wander of 16 cm reduced asphalt longitudinal strains by 36 percent and daily temperature fluctuations can double the asphalt longitudinal strain. Results from laboratory dynamic modulus tests found that Hot Laid 3 (HL3) dynamic modulus is an exponential function of the test temperature when loading frequency is constant, and that the HL3 dynamic modulus is a non-linear function of the loading frequency when the test temperature is constant. Results from field controlled wheel load tests found that HL3 asphalt longitudinal strain is an exponential function of asphalt mid-depth temperature when the truck speed and wheel loading are constant. This indicated that the laboratory measured dynamic modulus is inversely proportional to the field measured asphalt longitudinal strain. Results from MichPave finite element program demonstrated that a good agreement between field measured asphalt longitudinal strain and MichPave prediction exists when field represented dynamic modulus is used as HMA properties. Results from environmental monitoring found that soil moisture content and subgrade resilient modulus changes in the pavement structure have a strong correlation and can be divided into three distinct Seasonal Zones. Temperature data showed that the pavement structure went through several freeze-thaw cycles during the winter months. Daily asphalt longitudinal strain fluctuations were found to be correlated with daily temperature changes and asphalt longitudinal strain fluctuations as high as 650m/m were recorded. The accumulation of irrecoverable asphalt longitudinal strain was observed during spring and summer months and irrecoverable asphalt longitudinal strain as high as 2338m/m was recorded.

I. INTRODUCTION

Street development and recovery in the India is regularly embraced by the utilization of three primary kinds of asphalt: adaptable, inflexible and semi-unbending (or composite). Adaptable asphalts are described by their prompt usefulness, great riding quality and nonappearance of joints. Then again, unbending asphalts have an expanded bearing limit and a more extended life expectancy when appropriately outlined. Be that as it may, as far as solace (riding quality and clamor) for the clients, unbending asphalts have been losing prominence, to a great extent because of the nearness of transverse joints, required to battle warm developments of the solid section. All things considered, most unbending asphalts in the India are these days being overlaid by bituminous materials (at least one layers), getting to be in actuality semi-inflexible asphalts, i.e., the third kind of asphalts where the base includes using pressurized water bound materials and the surface contains bituminous material. The black-top surface enhances the riding nature of the asphalt and, when sufficiently thick limits the event of intelligent breaking which is regularly connected with warm developments (extension and constriction) of the inflexible help. The arrangement of splits through the entire thickness of the bound layers enables the entrance of water to the granular layers and sub grade, adding to an untimely asphalt disappointment.

A. Objectives

The greater part of grouted macadam applications in the INDIA, over the most recent couple of years, depend on a standard blend, intended for surface courses. Be that as it may, a further misuse of its attributes, which has not been examined, is the likelihood of utilizing it as a basic layer (base or fastener course) in an asphalt. Accordingly, the primary targets of this venture are identified with better understanding the properties of this sort of material, keeping in mind the end goal to have the capacity to anticipate its execution all the more sensibly and to plan asphalts fusing grouted macadams all the more precisely.

As far as the particular research goals of this examination, they can be recognized as takes after Optimism grouted macadam blend configuration, as per the utilization of the material Check whether thermally-incited splitting is an issue, in asphalts with grouted macadam surface courses;

Determine the advantages of including a fortifying framework under a grouted macadam surface course;

Quantify the weakening rate of grouted macadam surface courses following the presence of splitting; Verify the connection between research center exhaustion execution of grouted macadams and their weariness life in an asphalt;

Develop an outline technique which sensibly predicts the life of an asphalt including a grouted macadam layer.

II. REVIEW OF "CUSTOMARY" ROAD PAVEMENT

A. Sorts And Design

In this part, an audit of the asphalt composes generally utilized as a part of street development is exhibited. Moreover, a depiction of the materials utilized as a part of every one of the development composes is talked about. The principle asphalt plan techniques are likewise portrayed keeping in mind the end goal to help the work completed amid the present venture.

A street asphalt can be characterized as a structure that offers help to the vehicles utilizing the street. Since the course determination process for the street does not more often than not consider the bearing limit of the establishment (soil, by and large), otherwise called the sub grade, a structure is important to withstand the vehicle stacks and to ensure a surface with satisfactory equality and slide protection from be utilized by vehicles, with adequate solace and security for the clients. Without this defensive structure, the monotonous burdens connected by the vehicles, together with unfriendly climatic conditions, would cause perpetual distortion or even disappointment of the sub grade. To limit the harm, an arrangement of layers is typically based over the sub grade to spread the heaps and disseminate the worries, at the sub grade level, to an adequate esteem.

Table 1: Basic characteristics of different street asphalt (Adjusted from Setyawan, 2003)

Type of Pavement	Advantages	Disadvantages
Flexible Pavements (Bitumen based)	Flexible, jointless, quickly serviceable, good riding quality	Limited service life, limited static bearing capacity
Rigid Pavement (Concrete)	High strength, high bearing capacity	Slow setting, joints, cracks, large layer thickness
Semi-rigid Pavement (Concrete and Asphalt)	High overall bearing capacity, good riding quality	Cracked base, reflective cracking, surface rutting susceptible
Semi-flexible pavement (Grouted macadams)	High strength, enhanced durability, flexible, jointless, quickly serviceable	Two stage construction of surface course

The semi-adaptable asphalt sort of development has been chosen for a definite examination in this undertaking. For the rest of this part, a portrayal of the materials utilized as a part of adaptable, unbending and semi-inflexible asphalts and their fundamental properties is made in the accompanying areas.

B. Surface course

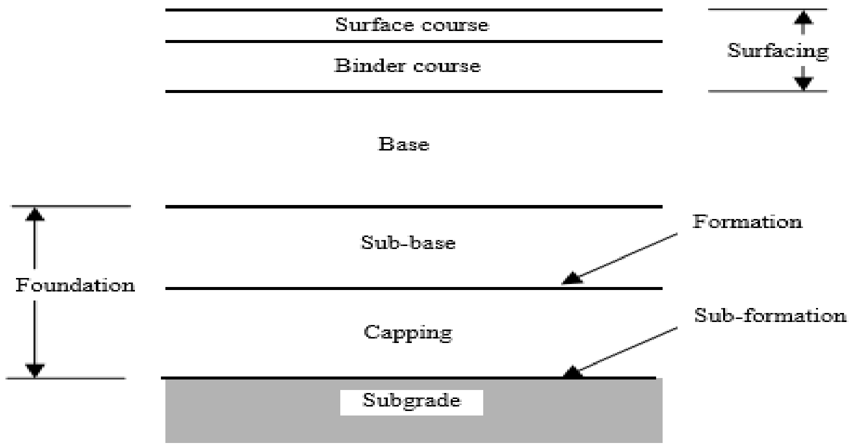

Figure 1 – Layers in a flexible pavement (Adapted from Read and Whiteoak, 2003 and Highways Agency, 1999)

f Degradation	isions
Cracking	Load associated cracking Thermal cracking Reflective cracking
Permanent Deformation	Rutting Settlement Local deformations
Loss of material	Fretting Ravelling
Movement of materials	Fatting-up

III. CONVENTIONAL" ROAD PAVEMENT TYPES AND DESIGN

The central point impacting fussing are the bitumen substance of the blend and the level of compaction. Loss of total can be expected to either loss of attachment between the total and the bitumen or fragile crack of the bitumen film interfacing particles of total (Read and Whiteoak, 2003).Raveling varies from the above in that it includes the culling out of surface total by activity with no loss of attachment of interior fines. It happens when singular total particles move under the activity of activity. In the event that the malleable pressure (initiated in the bitumen because of the development) surpasses the breaking quality of the bitumen, durable crack of the bitumen will happen and the total molecule will be confined from the street surface. In this manner, raveling is destined to happen at low temperatures and at short stacking circumstances when the firmness of the bitumen is high (Read and White oak, 2003).

A. Design of Pavements

The plan of an asphalt involves the foundation of a structure that guarantees a decent execution of the asphalt under load applications and unfavorable climatic conditions. With the experience acquired throughout the years by analysts and establishments, a few techniques have been created for the outline of asphalts. These techniques are by and large arranged in three sorts, the experimental, the expository and the robotic strategies, albeit a few techniques utilize a blend of two kinds (AMADEUS, 2000).
Flow INDIA asphalt plan and auxiliary support hone has been created by a blend of viable experience, lab research and full-scale street trials. Basic plan measures for streets were first set out in Road Note 29, which was distributed in three releases in 1960, 1965 and 1970. It utilized the watched execution of various trial developments inside general society street organize as a reason for configuration bends relating activity stacking to subgrade quality (Hunter, 2000).

IV. DEVELOPMENT OF FOUR-POINT BENDING EQUIPMENT

In a recent inter laboratory campaign organised by RILEM 182-PEB Technical committee "Performance testing and evaluation of bituminous materials", 11 different test methods, comprising uniaxial tension/compression, 2-, 3- and four-point bending and indirect tension tests, were utilised in order to investigate fatigue characteristics of a dense graded asphalt concrete mixture (Di Benedetto et al., 2003; Di Benedetto et al., 2004). In that study, it was concluded that fatigue lives are significantly affected by the test method. Amongst the test methods studied, the Indirect Tension Test showed the shortest life duration, which, according to the authors, is probably caused by significant accumulation of permanent deformation in addition to fatigue damage. It was also the only test to be carried out in load control, which usually means a shorter fatigue life. Load conditions and testing set-up, together with sample size, were pointed out as the main reasons for the differences in fatigue life obtained for different beam tests. In order to study different alternatives to the standard mix design used by the project sponsors, and in order to better understand the fatigue properties of grouted macadams, a laboratory fatigue test, other than the more routine Indirect Tensile Fatigue Test (ITFT), was to be used. The objective was to select a test that simulates, in a more realistic way, the stress and strain conditions in a pavement layer. The test initially proposed comprised a load applied by a moving wheel on top of a grouted macadam beam, supported by a continuous rubber foundation. This test allows the beam to bend in a similar way to a pavement layer under moving traffic loads. However, as in the case of ITFT, it is difficult to separate the fatigue phenomenon from permanent deformation and the causes of specimen failure are not only restricted to fatigue. Therefore, other alternatives had to be considered.

A. Review of Fatigue Test Equipment

Rao Tangella et al. (1990) carried out a research programme with the purpose of reviewing various fatigue test methods and recommending the most appropriate method for defining the fatigue response of asphalt-concrete mixtures. The evaluated test methods were classified into the following categories: simple flexure, supported flexure, direct axial, diametral, triaxial, fracture mechanics, and wheel-track tests. These methods were evaluated based on simplicity, ability to simulate field conditions, and applicability of the test results to design a pavement against fatigue cracking. In the study, the repeated flexure test received the highest ranking, followed by the direct tension and the diametral (indirect tension) repeated load tests, these being highly ranked due to their simplicity, lower cost and shorter testing time.

Taking the aforementioned into consideration and looking to the objectives of the present research study, it was decided to develop a new equipment, to study the fatigue response of grouted macadams, using the principle of simple flexure. Among the available methods, the four-point bending test (also known as third point flexure) was chosen, since the failure of the specimen in this type of test occurs in an area of uniform bending moment, which is not the case in a centre point flexure test. Four-point bending also avoids the need to glue the specimen to an end plate, as in the cantilever (two-point) bending test, which can delay the test set up.

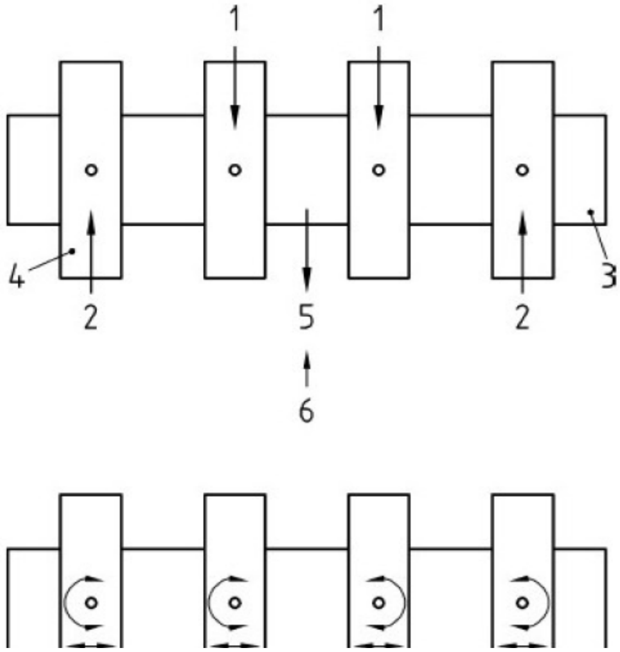

Figure 12–Loading scheme of the specimens in the four-point bending test BS EN 12697-24 (BSI, 2004d)

V. MATERIALS AND METHODS

A. *Analysis for Traffic Related Factors*

Traffic related factors like axle load configuration, tire imprint area, tire inflation pressure, numbers of wheel load repetition have significant effect in the design of flexible pavement system. Stress strain based analysis procedure is used in the finite element method to estimate those factors. Different loading conditions are selected to analyze pavement response. These represent the low, middle and high combinations of tire load and tire inflation pressure used for a given tire during the analysis. The low load high inflation pressure and the high load low inflation pressure combinations are not considered in this study as these conditions show extreme deviations from tire manufacturer recommended tire load/tire inflation pressure guidelines.

B. *Contact Area*

To calculate damages per pass by the wheel load in the pavement, it is required to identify the proper contact area. Contact area may be circular, rectangular, ellipsoid or another (termed as actual here) imprint area of a rectangle and two semicircles. Contact areas for different tire imprint are specified in Table 2. For the analysis and selection of the appropriate contact area, same tire pressure is applied for different imprint shape of equal contact area and thus the effect of maximum principal stresses and strains are measured. Tire contact dimension is selected from the suggested rules of PCA method, that is circular, rectangular or ellipsoid area which is equivalent to actual contact area and difference in stresses and strains are observed. To satisfy convergence criteria in finite element method, analyses is done for increasing amount of elements and thus observe the difference in results.

Table 2: Contact area for different tire Imprint shape Wheel pressure (MPa) Contact area (sq. mm

Imprint shape	Wheel pressure (Mpa)	Contact area (sq.mm)
Circular	0.67	60000
Rectangular	0.67	61575
Ellipse	0.67	60416
Actual	0.67	60318

Critical model dimension of roadway segment for the analysis is chosen as 10m by 5m to avoid the boundary effects. Material property and thickness of different layers) applied previously in pavement application shown in Table 3.

Table 3: Material property used in contact area and pressure analysis

	Asphalt surface	Base layer	Sub grade layer
Thickness (mm)	100	250	2000
Modulus of elasticity	2175	415	52
Poisons ratio	0.35	0.4	0.45

From the stress and strain comparisons shown in Fig. 17 and 18, it can be noted that the actual tire imprint area has greater values for stress and strain than all other possible tire area. Also, increasing the number of elements increases the degree of

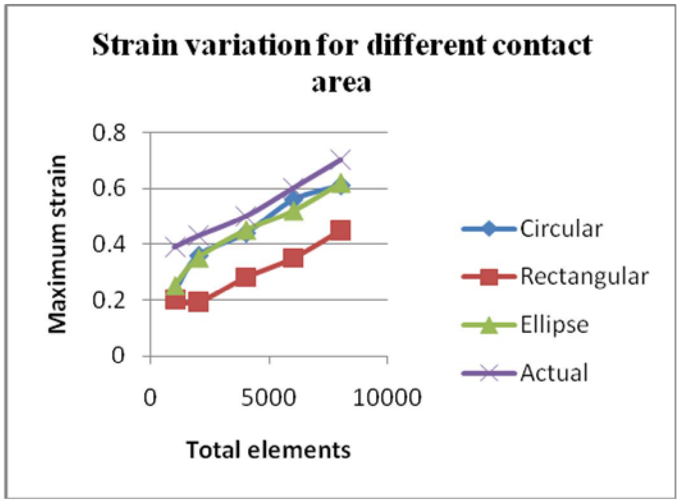

Figure 17: stress variation for different contact area

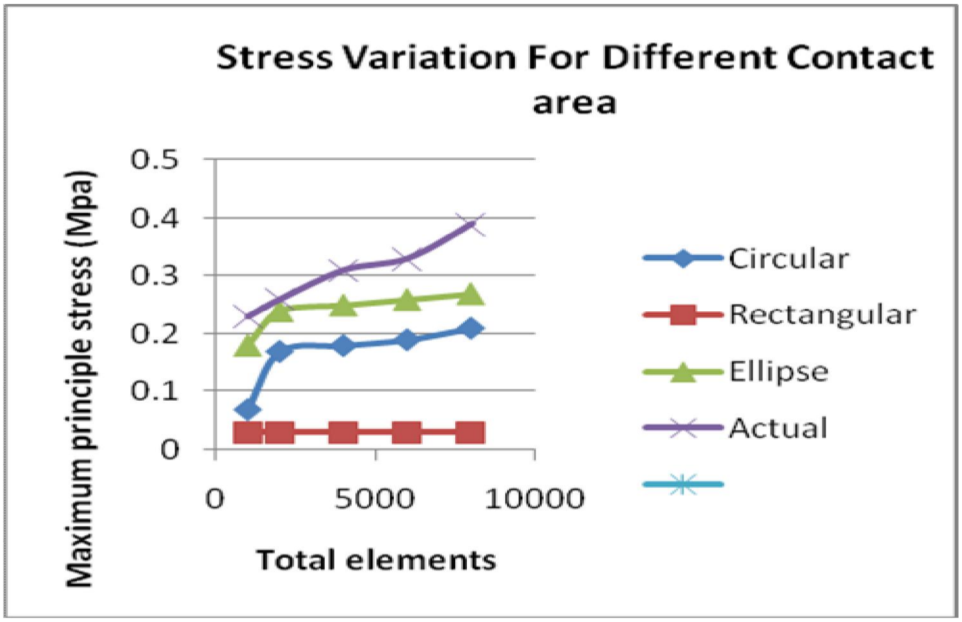

Figure 18: Strain variation for different contact area So, using circular, rectangular or ellipsoid areas instead of the actual tire imprint area are to be avoided if the actual condition for stresses and strains are to be taken into account accurately.

C. Tire pressure

Though uniform contact pressure throughout the contact area is assumed for previous study, it is not readily true. To investigate the effect of spatially varied tire pressure, it is assumed that two third of the total wheel load is applied in the centre rectangular region which is approximately half of the total contact area (145mm*200mm = 29000 mm 2) and other load in two semicircle regions**.** Effect of stress and strain values are observed for different wheel loads. Model geometry and material properties are same as previous. It is seen from Fig. 19, there is about 30% increase in stress due to varied contact pressure than constant pressure. Linear relationship exists in the figure indicates the static load application and linear analysis. But strain value does not vary significantly for spatially varied pressure (Fig. 20). So when strain is applied as design criteria, fatigue or permanent deformation for wheel load application, uniform contact pressure does not affect the result.

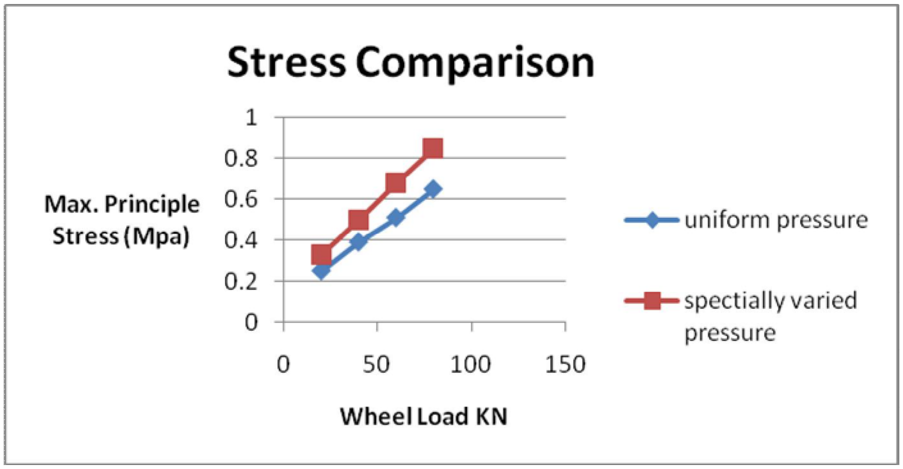

Figure 19: Stress comparison for different tire inflation pressure

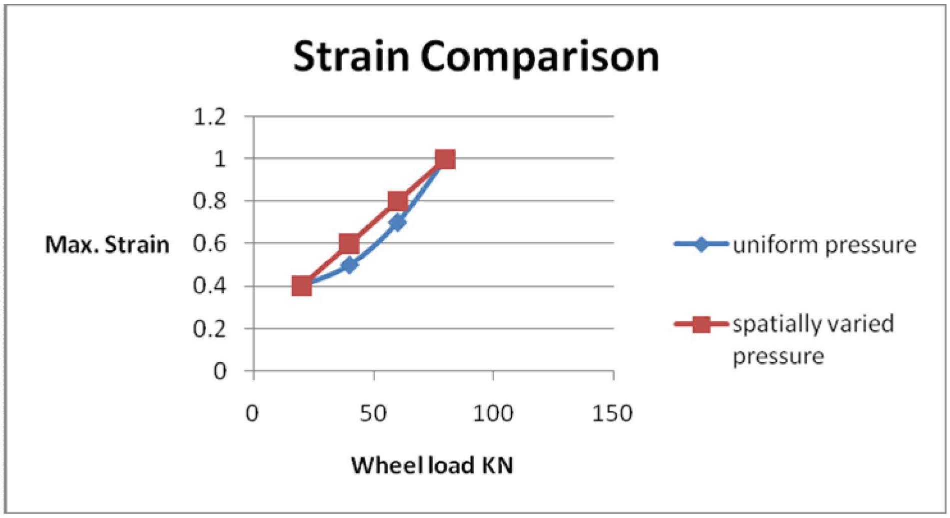

Figure 20: Strain comp Chapter 6

VI. RESULTS AND ANALYSIS

The results of the calculations based on linear-elastic theory are presented in Figures 22-32 on appendix A. An E2 value of 50MPa was often used to conservatively represent the worst scenario. In this analysis as well as in Figures 25-32, negative (-) and positive (+) refer to compressive and tensile, respectively, and 80kN-700kPa to axle load and tyre pressure.

A. Stress-Strain Distribution

Figure 25 shows the stress-strain distribution within the asphalt surfacing layers for the selected thickness 20, 50, 75, 150 and 200 mm, respectively, for the same traffic loading and material elastic constants. In all the surfacing , there is a high concentration of compressive (negative) stresses in the immediate top zone (Figure 25 (a)). The 20mm surfacing is virtually subjected to compressive stresses within the entire surfacing depth and there are no tensile stresses. The verticacompressive stress at the botm is almost equal to the tyre-surface contact stress (0.7MPa), and hardly decreases over the surfacing depth. A higher vertical load is thus transferred to the immediate underlying layers. The intermediate surfacing 50 and 75 mm exhibited the highest magnitude of horizontal stress and strain as well as vertical strain compared to the 20, 150, and 200 mm surfacing . In the thicker surfacing base (200mm), the vertical stress significantly decreased with depth, and is infact reduced by about 75% from 0.7MPa at the top to about 0.18MPa at the bottom. Much traffic loading is absorbed within the layer depth compared to the 20mm surfacing. Like for the intermediate surfacing , horizontal stresses change from compression (negative) in the top zone to tension (positive) at the bottom. However, the horizontal stress magnitude is relatively lower than for 50, 75 and 150 mm, where as it is all compressive for the 20mm surfacing (Figure 5 (a)).The horizontal strains are all compressive (negative) within the 20mm surfacing(Figure 25 (b)). This is an indication of less sensitivity to fatigue. In the other layers, the trend is the same as for the horizontal stress, and again the intermediate layers exhibited more sensitivity in terms of strain magnitude. The vertical (compressive) strains generally increased with depth, and are in fact tensile (positive) in the immediate top zone of the 20, 50 and 75 mm thickness. This is due to the effect of the horizontal stresses and the Poisson's ratio. It must be observed that, in all the layers, horizontal stresses are compressive (negative) in the top zone. Also from the vertical strain profile, the marked influence of the Poisson's ratio on the thin and intermediate surfacing is evident. From the above analysis, it appears that thick asphalt layers (surfacing and base) significantly contribute to the structural integrity of the pavement structure and are regarded as structural members. Thin asphalt surfacing layers appear to be essentially load transfer components with little susceptibility to fatigue damage, but require high strength support layers to sustain the traffic loads.

B. Variation of the Asphalt-Surfacing Layer Thickness (h) and Modular Ratio (E1/E2)

The results for a composite modulus (E2) of 50MPa are plotted in Figure 6. The surfacing (h) was varied from 20 to 200 mm, and the modular ratio (MR) from 1 to 20. The traffic loading remained constant at 80kN-700kPa. A similar stress-strain profile was obtained for E2=400MPa, except the horizontal strains were of smaller magnitude.

C. Variation of the Composite Elastic Modulus (E2)

Figure 27 shows the effect of the composite modulus (E2) of the immediate underlying layers on the stress-strain response of the asphalt layer for the selected thickness 20 and 150 mm, for the same traffic loading of 80kN-700kPa.

D. The Effects of the Poisson's Ratio

Results for the selected asphalt layer thickness are shown in Figure 28 . Traffic loading of 80kN- 700kPa and a composite modulus of E2 = 400MPa with a modular ratio (MR) of 5 were used. The notation 0.25/0.25 on the horizontal axis in Figure 28 indicate that the Poisson's ratio for the asphalt layer is 0.25 and it is also 0.25 for the composite underlying layers.

E. The Effect of Traffic Loading

Figure29 shows a simultaneous change in both axle loading and tyre pressure for an arbitrary selected thin surfacing (30mm) and E2, 200MPa. As expected, stresses and strains substantially increased as the traffic loading was increased. This is the normal material response to loading, and implies more pavement damage as evident from the relative fatigue lives shown in Figure 11. The highest stress-strain values (Figure 29), and the lowest number of fatigue load cycles (Figure 31) are shown for 120kN-1000kPa traffic loading compared to 80kN-520kPa. For axle load variation at constant tyre pressure,

F. Relative Fatigue Life (Nf)

Equation 6 (page 25) with fatigue regression coefficients; f1= 0.0796, f2= 3.291, and f3= 0.854 was used for calculating the relative fatigue life (number of load repetitions) of the asphalt layer (Asphalt Institute, 1993; and Huang YH, 1993) based on tensile strains at the bottom zone. Regression coefficient f1 is inclusive of the crack propagation factor. The elastic modulus E1 was expressed in MPa and strains in microns (unit-less).

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H. NF Versus H and Modular Ratio (MR)

In thin surfacing (≤50mm) fatigue life is highest, and tends to decrease with increasing modular ratio (Figure 30). This concurs with the tensile strains plotted in Figures 6-8. The least number of fatigue load cycles was obtained at 20 modular ratio. In the thicker surfacing (≥100mm), relative fatigue life increased with modular ratio. In contrast to the thin surfacing, the highest number of fatigue load cycles for 150mm was obtained at a modular ratio of 20. The intermediate surfacing layers 50mm to 100mm appeared to be less affected by the modular ratio, but had the least fatigue life. With the exception of MR = 1, their relative fatigue life fell below 1x106 load cycles.

I. NF Versus Mr, Axle Loading, And Tyre Pressure.

The relative number of fatigue load cycles to failure versus modular ratio for the four different traffic loading, for similar material constants are shown in Figure 31. The least number of fatigue load cycles was obtained under the high traffic loading, 120kN-1000kPa. This is an indication of more damage compared to the other traffic loading. At modular ratio of 10, the 80kN-700kPa traffic loading had a relative fatigue life of about 5x106 load cycles whilst 1200kN-1000kPa had only 0.2x106. This represents a reduction of about 96% in fatigue life, clearly indicating the potential damage of high traffic loading. Figure 31, further indicates that the thin surfacing layer (30mm) has relatively high fatigue life at low modular ratios. The effect of tyre pressure is also evident when comparing the relative fatigue lives of 80kN-520kPa and 80kN-700kPa at 20 modular ratio.

J. Nf Versus Axle Loading

Figure 32 shows the effect of variation of axle loading on the relative fatigue life of the respective asphalt surfacing layers. The tyre pressure was maintained constant at 700kPa, and the material constants remained unchanged. It is clearly evident that the thin surfacing layers have higher fatigue life, which appears to increase with axle loading, and it is infact over 5 x 106 load cycles for 20 mm Up to about 75mm, the highest fatigue life is shown for 200kN, which is about 150% overload above 80kN standard axle load. The relative fatigue life of the 100mm surfacing appear to be little affected by axle loading, whilst in the thicker layers, the relative number of fatigue load cycles to failure decreased with increase in axle loading.

K. NF Versus Tyre Pressure.

For similar axle loading and material constants, the relative fatigue life of all the layers decreased with increase in tyre pressure (Figure 32). For all the values of h, the smallest number of fatigue load cycles is indicated for 1000kPa and the highest for 520kPa. However, the intermediate surfacing layers have the least relative fatigue life, whilst the 20mm exhibited the best fatigue performance followed by the 200mm surfacing base.

L. Discussion

It has been analytically shown that tensile strains as well as relative fatigue damage in the thick asphalt bases decrease with both thickness and material stiffness. In the thin surfacing, tensile strains and fatigue damage increase with both surfacing thickness and material stiffness. Tensile stresses generally increase with material stiffness. Tensile stresses, strains, and fatigue damage increase with traffic loading, particularly in the thicker surfacing bases (>50 mm), and appear to be more sensitive to change in tyre pressure than axle loading. High traffic loading should thus be effectively controlled to reduce pavement damage. The Poisson's ratio has no significant effect on the stress-strain response of the asphalt layer particularly thicker ones. In the thinner surfacing like 20mm, the effect may be substantial, and the best performance appears to be at lower values. Thin surfacing contribute little to the structural integrity of the pavement structure. They merely act as load transfer members with little susceptibility to fatigue damage. Failure design criteria for such pavement structures should be based on the underlying layers to limit deformation. Thicker asphalt-surfacing (>50mm) are structural members with great potential for load protection against damage in the lower layers. The stress-strain variability with the surfacing thickness and material elastic constants implies that a balanced combination of these parameters is inevitable to achieve optimal pavement response and performance. For instance, it appears unwise to use a very stiff thin surfacing or a thick surfacing base with very low modulus value. The effect of the modular ratio is also quite significant and needs to be taken into account when designing. This calls for a balanced design approach. The high three-dimensional compressive stress concentration in the top zone needs to be checked against permanent deformation. A constitutive surface rut model based on compressive stresses as well as shear failure (shear stress model) needs to be developed to check surface deformation in the asphalt surfacing layers.

VII.CONCLUSION

Application of the software ABAQUS for the particular design features, like traffic related factors, is quite reasonable applying in the analysis of pavement performance of present roadway and finding total traffic carrying capacity of the existing pavement. Thus this paper documents the preliminary research of traffic related factors in the design of flexible pavement under specific material properties, model geometries etc Based upon the results presented in this study, tire imprint area is needed to be rectangle with two semicircles at both sides. Circular, rectangular or ellipsoid tire contact area is not appropriate because they generate fewer amounts of stresses and strains for the equal area. Tire pressure is never being uniform throughout the imprint area. Varied test indicates that parabolic variation of tire pressure which is constant only within the center region of contact area. Implication of stress strain behavior in the design phase of flexible pavement is quite massive work. This paper has included a very small part of it. The major limitation here is pavements are generally subjected to moving truck loads instead of static loads and material response is viscous elastic. Further study on the effect of moving loads and asphalt viscous elasticity is warranted. Again, stress, strain and deflection will be further implemented in pavement failure criterion, fatigue and permanent deformation and then be used in calculating ESAL for varying axle load condition. Sufficient governmental funding is needed to invest in laboratory based test environment to validate the software application and thus develop an economical design procedure based on finite element analysis.

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