



## PRIMARY RESPONSE OF PAVEMENT VARIATION WITH CONSTRUCTION VARIABLES

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### ABSTRACT

Fatigue and rutting are two major modes of distress of flexible pavements that are typically characterized by the primary response of the pavement and so calculations of the pavement's structural responses should be measured carefully for more accurate predictions of pavement performance. Response to it, this task aims to predict the primary response of the forces using Influence Function and Peak Influence Function Method for several differences top layer pavement thicknesses. In this tasks, both the aforementioned critical responses were highlighted, that are horizontal tensile strain at the bottom of bound layers and the vertical compressive strain on top of the sub-grade layer, that relates to fatigue and rutting damage respectively. The vertical load applied to the surface is uniformly over a circular area, leading to an axial symmetric problem. The pavement structure was modeled as semi-infinite linear elastic system considering three layers; an asphalt surface layer, a granular base layer and semi-infinite sub-grade or soil layer. A multilayer linear elastic approach was used to calculate the response of the pavement structure under uniform contact stress. The simulation results were compared to the results from *BISAR* application. As a finding, the comparison between computed critical strains and output from *BISAR* and a good consensus was reached. The variation of radial and vertical strains at the bottom of asphaltic concrete and on top of the sub-grade layer is matched well and conforms to the capability of the programme that was developed.

**Keywords:** influence function, peak influence function, primary response, strain, resilient modulus.

### INTRODUCTION

In modern pavement design, there are two separate tasks involved. It includes computation of pavement response from the load and the prediction of pavement performance. The critical pavement response used in distress models is calculated in the pavement response models by applying vertical tyre-pavement contact stress to the pavement surface. The contact stress is typically assumed to be distributed evenly over a circular contact area in the vertical direction. At the bottom of the asphalt layer, the horizontal strains are responsible for fatigue. At the top of sub-grade, the vertical strains are the ones that are studied as they will be used to predict pavement rutting.

At constant static load, tyre loading is usually modelled as a circular area with uniform contact pressure loading on to the pavement's layer structure. The structures of road surfaces were traditionally considered to behave as continua, and have utilised the methods of continuum mechanics. In the 1940's, the theory of elastic layered systems was published by Burmister [1]. Layered elastic theory is the tool most often used to calculate flexible pavement response to vehicle loading due to its simplicity. Ullidtz and Huang extended a close-form solution for a two-layered linear elastic half-space problem to a three-layered system [2]-[3]. This linear elastic system allows for the super positioning of multiple wheels for example, the ELSYM computer programme [4]. Kenis then developed the VESYS program that is also based on the linear elastic response model in which the visco-elastic response was included by the use of the

'elastic-visco-elastic corresponding principle [5]. This approach was also applied in the NCHRP project [6]. Theoretical calculated stress and strains might also be obtained using software based on layered-elastic theory, for example KENPAVE. This software allowed the use of linear elastic, non-linear, and visco-elastic properties for up to 19 layers and also performed damage analysis. Other than that, other software with the same approach, developed as *BISAR* 3.0, *Elsym5* and *Everstress* 5.0. An alternative approach that was used for critical response computation is the finite element method. *MichPave* and *3D Mesh* using *ABAQUS* are examples of software that utilise this method.

### METHODOLOGY

In this study, a vertical load applied to the surface is uniformly over a circular area with a diameter measuring 0.3m, leading to an axial symmetric problem. Two dimensions of pavement systems need to be selected: the depth and the radius. Figure-1 shows the schematics of the pavement layer systems used in this study and details of the pavement structure as well as the pavement materials are listed in Table-1 (Refer [7] for detail of the correlations between the layer parameters). The coordinate system is chosen as such that  $x$  and  $y$  axes are on the surface of the pavement whilst the  $z$  axis is vertical to the  $x$ - $y$  plane and extends along the depth direction. The radius of the pavement structure is 2m and the depth of 1.5m was applied. In accordance, there are 21 grid points—all of which are equally spaced; 0.1m inside the



interval and 16 grid points between 0 to 1.5m inserted within the z interval.

Refer to the Figure-1,  $h_1$ =asphaltic concrete (AC) thickness,  $h_2$ =thickness of the subbase layer,  $E_1$ ,  $E_2$  and  $E_3$  are the stiffness modulus of AC, subbase and subgrade layer respectively and  $\mu_1$ ,  $\mu_2$  and  $\mu_3$  are the Poisson ratio of each layer respectively. The pavement structure were modelled as semi-infinite linear elastic system considering three layers—an asphalt surface layer, a granular subbase layer and semi-infinite sub-grade or soil layer. For all analyses, the soil CBR is 5 percent which represents clayey soil. The value of sub-grade elastic modulus,  $E_3$  and Poisson's ratio for each layer is constant during the analysis. The modulus of sub-grade soil is defined using a correlation between CBR and sub-grade modulus, ( $E_3 = CBR \times 10$ ). The elastic modulus of the bituminous materials defined at a temperature of 27°C. A multilayer linear elastic approach was used.

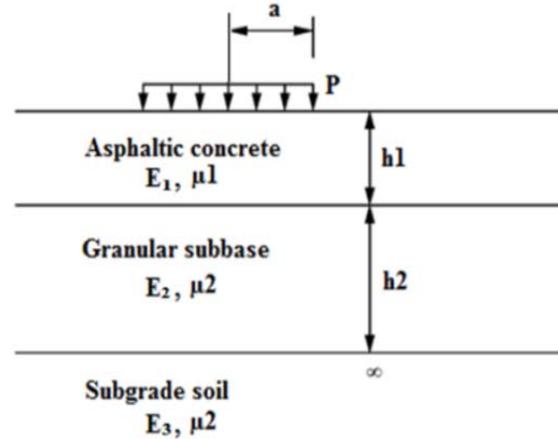


Figure-1. Pavement structure.

Table-1. Pavement structure characteristic.

Pavement layer	Thickness, (mm)	Air void content (%)	Volume of binder, (%)	Modulus (GPa)
Asphaltic layer	200	4	8	$E_1$ {Penetration Index (PI), AC temperature, AC volume of Void, AC volume of binder & Vehicle speed}
Granular Sub-base	200	-	-	$E_2 = 0.1E_1$
				$E_2 = 0.02E_1$
				$E_2 = 0.01E_1$
Subgrade Soil	infinite	-	-	$E_3$ (CBR - 5%)

The primary response of the load applied in the pavement was predicted using Peak Influence Function Method as the following equation (Refer [8-10] for further detail):

$$y(x) = F(x) \cdot I(V, x) \quad (1)$$

where,  $I(V, x)$  is the influence function for speed  $V$  and distance  $x$  from the point of application of the load. The vehicle is travelling at constant speed of 20m/s.

## RESULTS AND DISCUSSION

Figure-2 shows the tensile strain at bottom of asphaltic concrete (Strain at 0.2m in the legend) and vertical strain on top of subgrade layer (Strain at 0.4m in the legend). The simulation results have been compared to the results from BISAR application.

As shown in the figure, a good consensus was reached between computed critical strains and output from BISAR. The variation of radial and vertical strains at the bottom of asphaltic concrete and on top of the sub-grade layer is matched well and conforms to the capability of the programme developed to be used in the following tasks.

A series of stresses and strains calculated for various  $E_1/E_2$  ratios were performed using the same

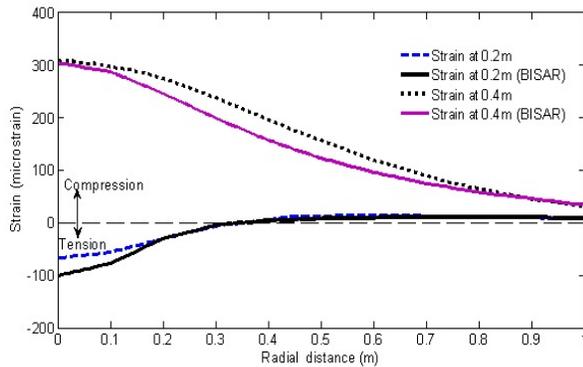
pavement model. As a results, Figure-4(a) and Figure-4(b) summarises the peak radial and vertical strains plotted as a function of  $E_1/E_2$  ratio from 1 to 100. It can be seen in this figure that a general trend has been observed for peak radial stress and strain to increase as the  $E_1/E_2$  ratio increase. Besides, for peak vertical stress, it might be divided into two phases. Initially, at lower  $E_1/E_2$  ratio (less than 25) the peak stress increases before it smoothly decreases until  $E_1/E_2$  is 100. The same pattern was observed for vertical strain.

In order to investigate the asphaltic layer thickness' dependency on the critical strain in pavements, a set of asphaltic concrete layer thickness that is, 0.2m, 0.25m and 0.3m, is chosen for analysis. As a result, Figure-5 is to prove when critical strain is plotted against radial distance. It can be seen that the general shape of both strain curves are similar, although, as expected, the peak strains for the thicker asphaltic layer have a significantly lower magnitude.

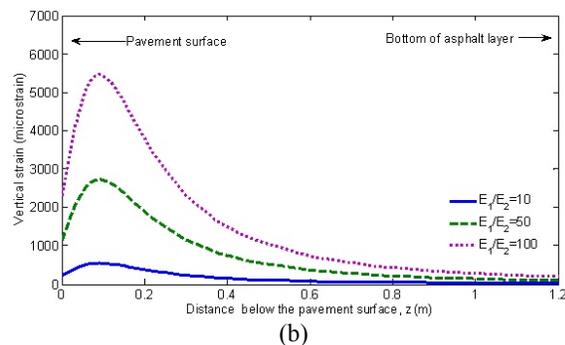
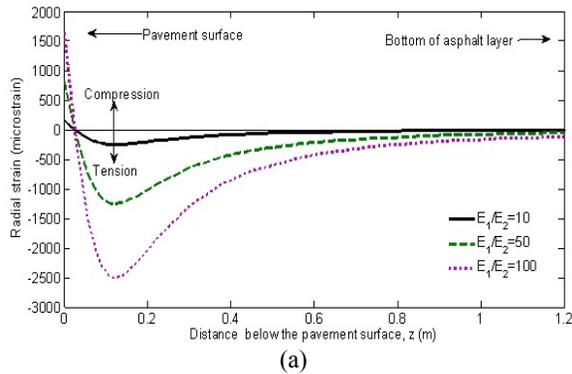
Figure-6 displays the tensile at the bottom of asphaltic concrete and compression strains on top of sub-grade soil for different degrees of temperature (low being 22°C and high being 32°C) and vehicle speeds (low being 15.6m/s and high being 25.6m/s). It can be seen in the



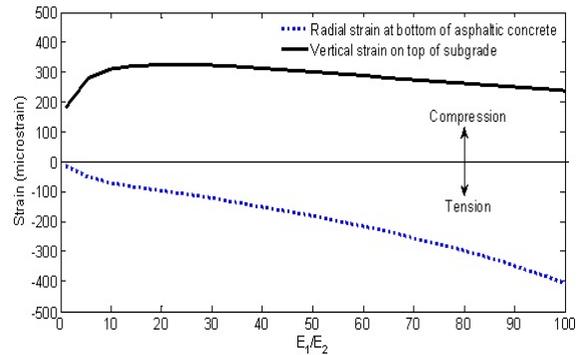
figure that at a higher temperature, strain increases approximately 1.6 times of that at a lower temperature. This happens due to the decreasing elastic modulus as temperature increases hence forth, higher critical strains are produced in the pavement. The plasticity deformation is greatest at high temperature. Therefore, experiencing high temperature for a long period of time, the majority of deformation defects may be caused from the plasticity of the surface's course. In addition, the effect vehicle speeds have on the strain is relatively less significant compared to that of asphaltic temperature.



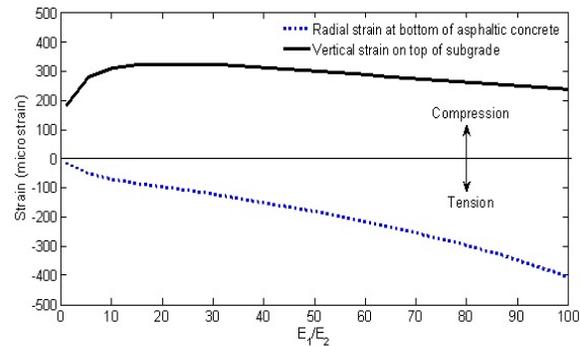
**Figure-2.** Comparing predicted radial strain (bottom of asphaltic concrete) and vertical strain (top of sub-grade) as a function of radial distance with result from BISAR. The surface vertical load is 30Kn.



**Figure-3.** Radial compression and vertical tension strains as a function of depth using different  $E_1/E_2$ .

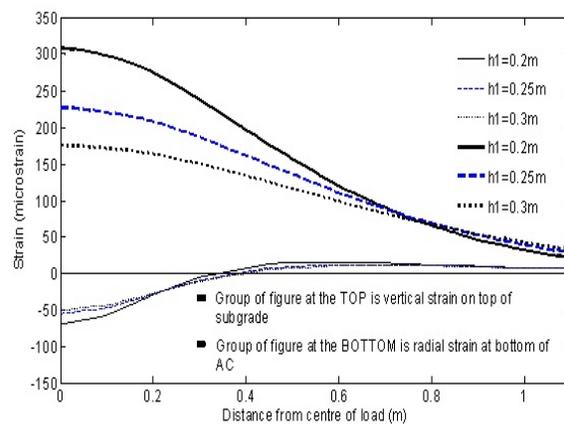


(a) Radial stress (at the bottom of asphaltic concrete) and vertical stress (on top of sub-grade) at the centreline of load as a function of different modulus ratios.

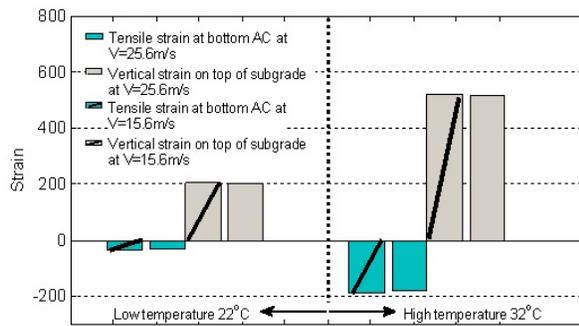


(b) Radial strains (at the bottom of asphaltic concrete) and vertical strains (on top of sub-grade) at the centreline of load as a function of different modulus ratios.

**Figure-4.** Critical responses as a function of asphaltic concrete modulus to sub-base modulus.



**Figure-5.** Radial strains (at bottom of asphaltic concrete) and vertical strains (on top of sub-grade) as a function distance for the centre of load using different asphaltic concrete thickness.



**Figure-6.** Radial strains (bottom of asphaltic concrete) and vertical strains (top of sub-grade) as a function of temperatures and vehicle speeds.

## CONCLUSIONS

From the analysis, the following can be drawn:

- The elastic modulus of the asphaltic material varies with asphaltic concrete thickness. Increase in the  $E_1/E_2$  was seen to significantly increase critical stresses/strains for fatigue and rutting failure tremendously.
- Stress produced by vehicle loads spread throughout pavements at different weights. The maximum influence function is vertically under the center of load.
- The compression influence function on top of the subgrade layer is approximately 3.5 times larger than tension influence function at the bottom of the asphaltic layer.

## ACKNOWLEDGEMENTS

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