DYNAMIC ANALYSIS OF ASPHALT CONCRETE PAVEMENT STRUCTURE

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ABSTRACT

A new solution for the dynamic analysis of asphalt concrete pavements under moving loads has been developed. The asphalt concrete pavement can be modeled in elastic or viscoelastic medium of multi-layered structure. The subgrade can be modeled as either a rigid base or a semi-infinite halfspace. The loads may be constant or arbitrary circular loads into one direction. The method utilizes the Complex Response Method of transient analysis with a continuum solution in the horizontal direction and a finite-element solution in the vertical direction.

This proposed method incorporates such important factors as wave propagation, inertia and damping effects of the medium as well as frequency-dependent asphalt concrete properties. The proposed method has been validated with the full-scale field truck test, which was conducted on instrumented asphalt concrete section on a test track at PACCAR Technical Center in Mount Vernon, Washington. Comparison with field strain data from full-scale pavement tests has shown excellent agreement. Theoretical results have shown that the effect of vehicle speed is significant and that it is in part due to the frequency-dependent properties of the asphalt concrete.

1. INTRODUCTION

Asphalt concrete pavement may consists of a thin covering surface course over a base course, subbase course, and compacted roadbed soil. The load caring capacity of a flexible pavement is brought about by the load distribution characteristics of the layered system. The highest quality layer is placed at or near the surface. Hence, the strength of the pavement is the result of building up thick layers and, thereby, distributing the load over the relative weak road bed soil.

Numerous asphalt concrete pavement response models have been written since the early sixties, ranging from an infinite beam on a Winkler foundation to a multi-layered system over an infinite half space. Widely used computer programs such as CHEVPC, ELSYM5(1) and BISAR are based on static linear elastic theory. Non-linear static Finite-Element computer programs include VESYS and MICH-PAVE(3). Dynamic models vary in complexity according to the structure analyzed and the loading.

A number of methods have been used to account for the moving effect of the load. They range from using the Dirac function, the Kronecker delta operator to pre-multiplying the load by time dependent

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deflection shape functions or applying a pulse load with a duration equal to the time taken to travel one tire contact length.

The new solution of this proposed method allows for moving transient loads. The solution is an important contribution to the field of pavement analysis because the effect of speed has been shown to be significant and can handle any load configuration such as truck axles or airplane landing gears.

2. PAVEMENT RESPONSE TO STATIONARY DYNAMIC LOADS

2.1 Structural Model

The problem of stationary dynamic surface circular loads on a linear visco-elastic layered medium overlaying a semi-infinite halfspace or a rigid bedrock is solved. The model consists of subdividing the natural layers within the pavement profile into thin sublayers which are assumed to extend to infinity in the horizontal direction. The displacements within each sublayer are assumed to vary linearly in the vertical direction; however in the horizontal direction, the displacements are required to satisfy the pertinent ordinary differential equations which are obtained from continuum theory.

By discretizing medium into fimite layers, the free motion at a given frequency consists of a finite number of wave modes which are obtained by solving an algebraic eigenvalue problem. These wave modes are used as shape functions to expand the displacements in the layered medium in terms of mode participation factors. Given the displacement field, the strains for each layer are determined by differentiation. The stresses in each layer are obtained assuming linear visco-elasticity. Finally, the layer effective stiffness matrix is obtained using the principle of virtual work, and the contributions from the individual layers are assembled to form the global stiffness matrix(5).

2.2 Method of Analysis

The stationary dynamic analysis is performed in the frequency domain using the Complex Response Method; transient loading are handled by Fourier transform techniques together with interpolation technique. Material damping is introduced by the use of complex moduli.

The computation steps used to calculate the response of the layered system subjected to stationary surface circular loads are as follows: (1) First, the dynamic loads are decomposed into harmonic components using the Fast Fourier Transform (FFT) algorithm; (2) next, Green's functions for displacements, stresses and strains are derived in the frequency domain from the solution of the eigenvalue problem. The response at each discretized frequency can thus be obtained by multiplying the Green's function by the complex amplitude of the loading at that frequency; and (3) the response computed in the frequency domain is then converted back to the time domain using the inverse Fast Fourier Transform. Details of the above solution techniques are described in (5).

3. PAVEMENT RESPONSE TO MOVING DYNAMIC LOADS

3.1 Moving Load Representation

The moving wheel load sends stress waves as it approaches the fixed point, and theses waves propagate so that the effect of the load is felt by the fixed point in the pavement before and after the load is directly on top of it. These waves could be a combination of direct waves from the moving load and reflected waves from a layer boundary below the surface such that the net pavement response may be amplified or de-amplified, depending on radiation damping, relative to the stationary response. The SAPSI-M computer program computes the response of the multi-layered asphalt concrete pavement to moving transient loads. Figure 1 shows the schematic view of the model.

The moving load is modeled as a series of haversine pulses with their duration equal to the time required for the wheel to pass by a point in the pavement. In order to consider the moving load effect on the response at a fixed point in the pavement, it is necessary to include the effect of the load as it moves from one location in the pavement to the next and beyond the passage of the load by theses consecutive locations in space. Thus the response time history of the pavement at the fixed point is the sum of the time histories of the responses due to the load being at these consecutive positions in space. This insures continuity of loading in time and space as it moves from one location to the next.

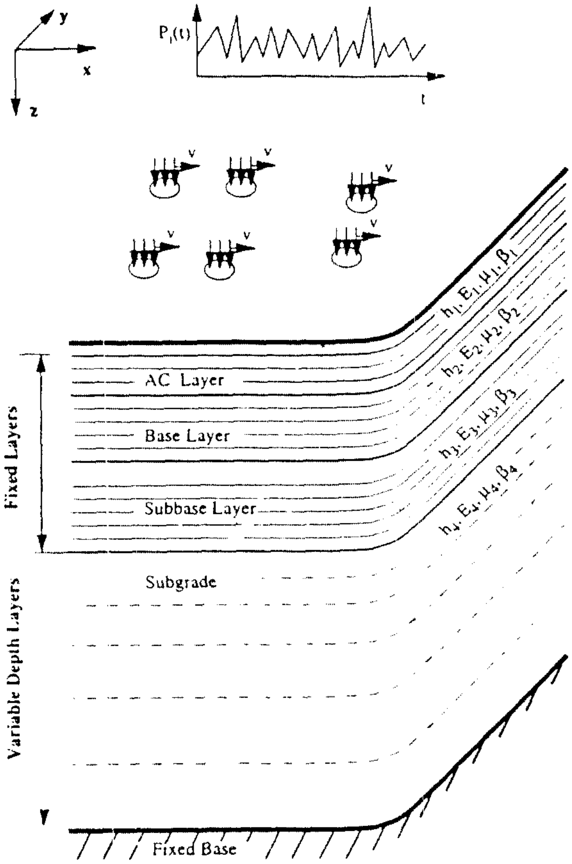

Figure 1. Schematic view of SAPSI-M model

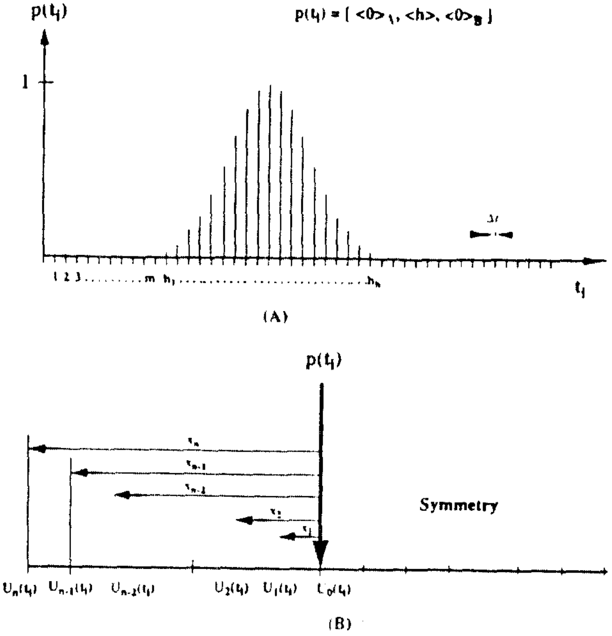

Figure 2. Interpretation of stationary loading

3.2 Pavement Response

First, the response at many points along the horizontal direction due to a stationary haversine pulse is calculated. Figure 2(a) illustrates the discretized pulse, which consists of a rest period of $A\delta t$, where δt is the time step, a haversine pulse with a duration equal to the time required for the wheel to pass by a point in the pavement, and another rest period of duration $B\delta t$. The total number of time steps should be a power of 2 in the Fast Fourier Transform algorithm. Figure 2(b) shows the response points in relation to the applied stationary load. The loading and all responses are in the same time domain. From Maxwell's reciprocity theorem, these results can be converted to responses at a fixed point subjected to a single dynamic loading at different locations in space. This conversion will make the responses corresponding to the different locations of the load in different time domains. In order to bring all the different responses to the same time domain each response is shifted by a time period corresponding to the passage of the load from one location to the next. This is illustrated in Figures 3 (a) and 3 (b). The resultant response is obtained by adding up the response pulses corresponding to each location of the load. However, because the load pulses have a finite width they overlap with each other.

This translates to an overloading condition. This overloading depends on the duration of the haversine pulse and on the distance between consecutive response points. The resultant response needs to be scaled back by dividing it by an overload factor equal to the sum of contributing loads at a fixed time.

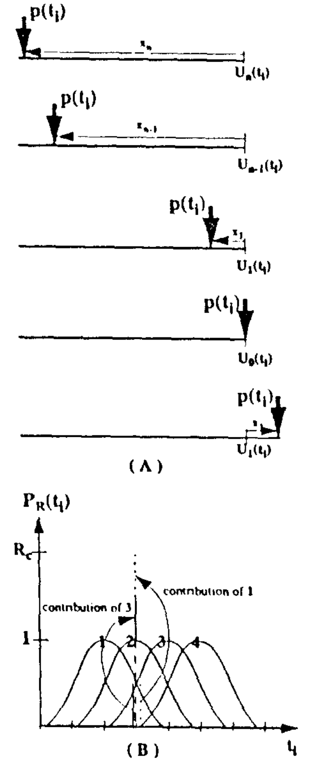

FIGURE 3. Interpretation of Moving Load Condition

(A) Quasi-moving loads and responses

(B) Sequence of moving load

4. VERIFICATION WITH FIELD TESTS

The new solution in SAPSI-M was used to analyze field data obtained from full-sale truck tests which were conducted in September 1993 at the PACCAR Test Track in Mount Vernon, Washington (2).

4.1 Field Tests

The truck used was a Peterbilt 359 truck with front and rear (tandem) axles were equipped with leaf-spring suspensions. Three truck speeds were used: 2.7, 32 and 64 km/hr. The tests were conducted in triplicates and according to a random order. A foil-type gauge manufactured by micro-Measurement was used to measure the various strain response.

4.2 Static Asphalt Concrete Properties

The elastic moduli for each of the layers in the pavement structure were obtained by backcalculation using deflection data from WSDOT's Dynatest 8000 FWD and the computer program EVERCALC. Layer thicknesses were obtained by coring. Table 1 shows the layer thicknesses and back-calculated layer moduli.

Table 1. Layer thickness and Properties

Layer	Thickness(mm)		Properties	
	Core 1	Core 3	Modulus(Mpa)	Poission Ratio
Epoxy	10	6	3,445	0.35
AC	124	124	3,878	0.35
Epoxy	10	32	3,445	0.35
Base	323	305	102	0.40
Subgrade	1,085	1,168	70	0.45
Stiff Layer			276	0.35

4.3 Dynamic Asphalt Concrete Properties

Two sets of profiles were used in the analysis frequency dependent and independent. The curves reported by Sousa (4) are used to describe the variation with frequency of the dynamic Young and shear moduli (|E*| and |G*|) as well as the damping ratio of the AC layer. The intercept for |E*| is obtained by iteration until the peak transient strain due to a unit FWD pulse is equal to the static strain which corresponds to the backcalculated AC modulus.

Figure 4 (c) and (d) shows the final curves used for the moduli and Poisson's ratio respectively.

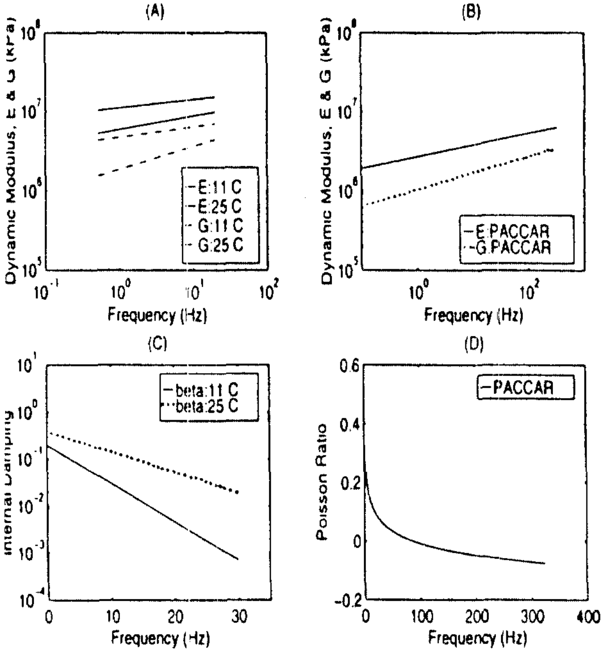

Figure 4. Variation of Asphalt Concrete Properties with Frequency. (A) Laboratory-measured dynamic moduli ; (B) Iterated dynamic moduli used in the analysis;(C) Laboratory measured material damping; (D) Poisson ratio used in the analysis

5. RESULTS OF ANALYSIS

5.1 Typical Response Curves

Typical response curves for longitudinal and transverse strain are shown in Figure 5 and Figure 6 respectively. Note that the steer and drive axles have different offsets from the measuring point. For this reason the peak strain magnitudes from the steer axle and the drive axle are very similar.

Figure 5 shows excellent agreement in magnitude and shape between the field measurements and the strains calculated using SAPSI-M. The curve shows a strain reversal from compression to tension as the load passes over the measuring point, and it is asymmetric.

The response curves for the transverse strain, on the other hand, do not show compressive strains as the load approaches and leaves the measuring point. Figure 6 shows good agreement between measured and calculated values, although not as good as for longitudinal strains. This could be due to the fact that the model in SAPSI-M is axisymmetric.

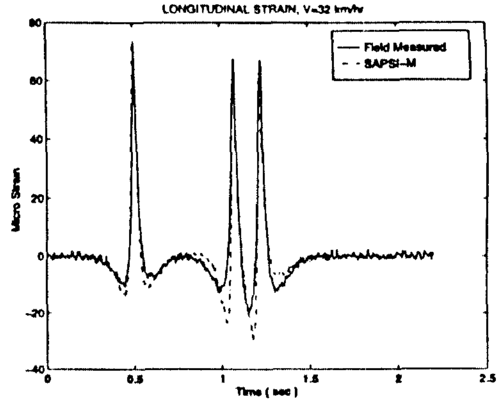

Figure 5. Typical response of longitudinal strain

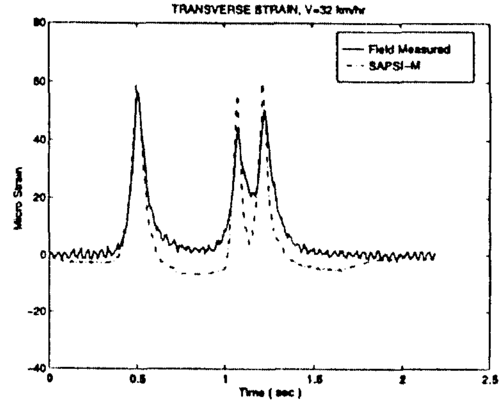

Figure 6. Typical response of transverse strain

5.2 The Effect of AC Properties

Figure 7 compares measured longitudinal strains and predicted values using both frequency dependent and frequency independent AC layer properties in Core 1, with the truck moving at increasing speeds. The field data and the calculated show a consistent decrease as the truck speed increases. Increasing the speed from creep to 64 km/hr causes the strain to decrease by about only 10% for the frequency-independent profile, while it is 28% for the frequency-dependent profile, and 32% for the actual tests. Clearly, the profile with frequency-dependent AC properties gives much closer results to the field data than does the profile with frequency-independent properties. This is an indirect field verification of the laboratory test results obtained by Sousa (4) and others indicating that the asphalt concrete properties are strongly dependent on the frequency of loading.

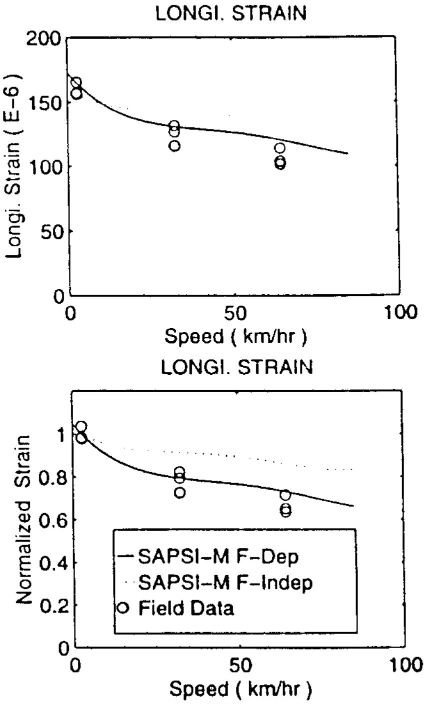

Figure 7. Comparison of strain at different speed-Core 1

5.3 Effect of Truck Speed

The effect of truck speed on longitudinal and transverse strain at the bottom of the AC layer is shown in Figures 7 and 8 for core 1 and 3 respectively. Both measured and calculated strains using the frequency-dependent profile show a consistent decrease as the truck speed increases. For core 3, increasing the speed from creep to 64 km/hr causes the predicted longitudinal strain to decrease by about 27% as compared to 30% in the actual tests.

6. CONCLUSION

A new method and associated computer program for the analysis of asphalt concrete pavements under moving loads have been developed. The program was verified with field data from full-scale pavement tests. The analysis has led to the following conclusions:

1. Agreement between SAPSI-M's predictions and field measurements was excellent for longitudinal strains and good for transverse strains, in both shape and magnitude.

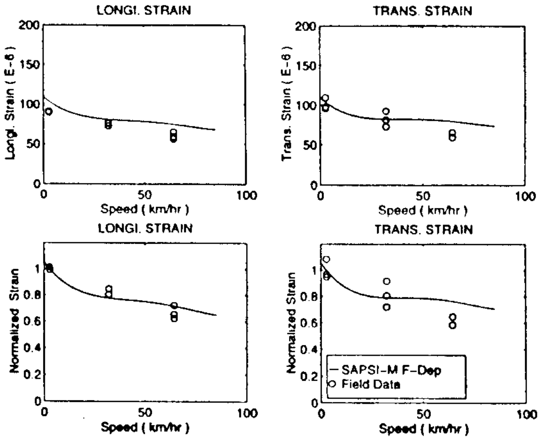

Figure 8. Comparison of strain at different speed-Core 3

2. The effect of truck speed on the response of asphalt concrete pavements is significant.
3. The speed effect on horizontal strain is in part due to the frequency-dependent visco-elastic properties of asphalt concrete.

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