inter•noise 96
25th Anniversary Congress – Liverpool

INCE: 24.9

INFLUENCE OF PROPAGATING EFFECTS ON THE ACOUSTICAL CLASSIFICATION OF ROAD PAVEMENTS

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1. INTRODUCTION

To control traffic noise around cities, noise barriers are often used. In many cases, it is possible to decrease the noise level by a pavement modification. Following researches carried out in France and many other European countries concerning the acoustical characteristics of road coatings, a first ranking of road pavements is now available [1]. This classification was performed in the near field of the road (7.50m, 1.20m). This result is interresting but not sufficient to predict the impact of these pavements in the close environment of buildings which are often situated several hundred metres from the road. The aim of this paper is to propose a theoretical method to predict a reference LAeq for each pavement class and each vehicle class (passenger cars and trucks) on a 1 hour reference time period, T_0. This method consists in calculating this LAeq value from the LAmax obtained by a statistical pass-by method, taking into account the various propagation effects function of the environmental situation (ground and meteorological parameters). From this knowledge, it will be possible to establish a new classification which will present a new interest for road planners and road manufacturers.

2. GENERAL PRESENTATION OF THE METHOD

Since approximately ten years, road pavements have been ranked using a statistical procedure. This method is nowadays an ISO standard [2]. The microphone is located in the near field of the road (7.50m from the road axis and 1.20m above the ground). Vehicles belonging to main classes (passenger cars, heavy trucks) are selected with respect to their acoustical signature by the operator, and their respective maximum sound pressure level, LAmax and speed are recorded. From this important set of measurements (80 valid vehicles for each class), a linear regression [LAmax versus lg_{10}(speed)] is carried out. The reference LAmax at the reference speed (Ref speed), function of the type of vehicles and type of roads (highway, main road, local road,...), is then computed. In order to collect more informations, it is possible to apply to same technique for each 1/3 octave bands. Following that way, we obtain the LAmax spectrum for each vehicle and pavement classes.

The general method consists : first, in computing the LAeq spectrum from the LAmax spectrum in the near field conditions, secondly, in predicting the attenuations due to the ground and atmospherical effects at the given distance, and finally, in computing the LAeq spectrum at the required distance.

3. DETAILS OF THE METHOD

The calculation of LAeq(T) from the LAmax(speed), is possible using the general equation [3] :

$$LAeq(T) = LA\max(speed) - 10.\lg_{10}\left(\frac{speed}{Ref\ speed}\right) + 10.\lg_{10}\left(\frac{\pi . R}{Ref\ speed . T}\right)$$

where R is the distance between the source and the receiver and T de reference period. For our purpose, $T = T_0 = 1$ hour. First, we compute $LAeq(T_0)$ spectrum by application of the previous equation at the reference distance (7.50m, 1.20m), for the whole frequency range, then, we predict the excess attenuations between the reference microphone and the measuring microphone located in the far field. These attenuations can be obtained using the theory of the sound propagation in the atmosphere including ground and meteorological effects. Depending on the atmospherical conditions, appropriate predicting models can be used [4-5].

Propagation aspects

In order to consider the conditions which give the highest sound pressure level at the receiver, we only used models for a homogeneous atmosphere (vertical sound speed gradient, $\partial c/\partial z = 0$) in one hand, and downward propagation ($\partial c/\partial z > 0$) in a second hand. The first case has already been widely published [4]. The mean sound pressure level $< p^2 >$ is given by the equation :

$$\langle p^2 \rangle = \frac{A_1^2}{R_1^2} + |Q|^2 . \frac{A_2^2}{R_2^2} + \frac{2\,|Q|.A_1.A_2}{R_1 R_2} \cos\left[2\pi f(\tau_2 - \tau_1) + \gamma\right]$$

where A_1 and A_2 are the direct and reflected wave amplitudes, R_1 and R_2 the direct and reflected path lengths, $(\tau_2 - \tau_1)$ the time delay between the direct and the reflected ray and Q the spherical reflection coefficient $\{Q = |Q|.\exp(i\gamma)\}$.

The second situation corresponds to a downwind propagation or a propagation in a temperature inversion (night). In that case, many curved sound rays can reach the receiver. The mean sound pressure level < p^2 > can be expressed as the sum of the contributions of each ray as follows :

$$\langle p^2 \rangle = \sum_{i=1}^{N} \frac{A_i^2.|Q_i|^2}{R_i^2} + 2\sum_{i=2}^{N}\sum_{j=1}^{i-1} \frac{A_i|Q_i|.A_j|Q_j|}{R_i R_j}.\cos\left(2\pi f(\tau_j - \tau_i) + \mathrm{Arg}\left(\frac{Q_j}{Q_i}\right)\right)$$

A_i is the attenuation due to atmospheric absorption, R_i and τ_i are the curved path length and the travel time of the ray, N is the total number of rays including the direct one and Q_i is the spherical reflection coefficient function on the reflection angle ψ_i and the number of reflections n_i. $\left\{Q_i = [Q(\psi_i)]^{n_i}\right\}$. For the direct path, we assume $Q_1 = 1$.

In those two formulations, it is possible to introduce turbulent effects by adding fluctuating terms to the amplitude and the wavenumber terms. In the calculation, these effects are considered through the fluctuating index of refraction < μ^2 > and a scale of turbulence L.

To get the final attenuation, depending on the atmospherical conditions, we compute one of the previous equations both for the reference microphone and the measuring microphone. The difference between those two results is then reported for each frequency on the LAeq spectrum at the near field reference. So, a new spectrum at the far field receiver is obtained. If necessary, a global LAeq can be calculated by a simple recomposition.

For the computation of the sound attenuations, several simplifying hypothesis are used. At the reference point, we assume the source and the receiver both located above a surface having an impedance corresponding to the road pavement (Source height = 0.20 m for passenger cars and 0.80m for heavy trucks, Receiver height = 1.20m). Depending on the structural composition of the pavement surface layer, different impedance models are used. A Delany/Bazley model [6] for dense and reflecting pavements and a phenomenological model [7] for porous asphalts. For the receiver located in the far field, we assume that the propagation only occurs above the adjacent ground which is also modelled by a Delany/Bazley model. Considering the receiver height (from 3 to 10 m) and the large distances with respect to the distance between the road axis and the roadside, this approximation which does not take into account the impedance discontinuity seems to be relevant. The results presented in the following sections validate this hypothesis.

In addition, we assume different propagation conditions between day and night. Thus, For the daytime period, we assume a « homogeneous » condition and for the nighttime period we assume a « downward » propagation.

Final calculation

By application of this procedure, a LAeq(1h) can be calculated for one vehicle corresponding at each class and for the various road pavements. If we want to determine a LAeq for one typical traffic flow on both reference periods [6h-22h] and [22h-6h], the respective energies for each vehicle have just to be summed as follows :

$$LAeq(T) = 10.lg_{10}\left[\frac{1}{T}\left(n_{PC}.10^{0.1LAeq_{PC}} + n_{HT}.10^{0.1LAeq_{HT}}\right)\right]$$

where n_{PC} and n_{HT} are respectively the number of passenger cars and heavy trucks in the flow during the period T, and $LAeq_{PC}$ and $LAeq_{HT}$ are the LAeq for one passenger car and one heavy truck on the reference period T_0. By application of this procedure, we obtained the following results.

4. THEORETICAL RESULTS

The calculations have been carried out for three kind of well acoustically separated pavements : A Surface dressing, a bituminous concrete and a porous asphalt. The physical parameters of each surface to be introduced in the impedance models are : For the two dense pavements, σ (airflow resistance) = 10^5 rayls cgs, and for the porous asphalt, σ = 10 rayls cgs, Ω (porosity) = 20%, K (structural factor) = 3.5 and e (thickness) = 0.04m.

Concerning the adjacent ground, σ = 300 rayls cgs has been selected. The geometrical set-up is displayed on Fig. 1.

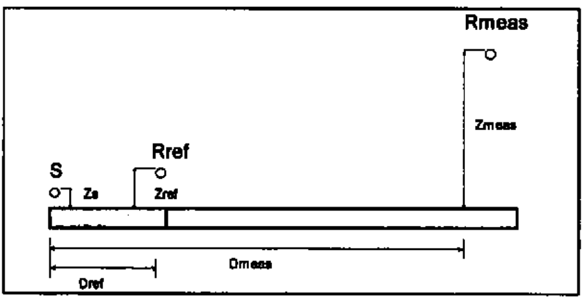

Fig. 1. Geometrical set-up of the simulation

The results presented here correspond to calculations carried out for the following situations : z_s, z_{ref} and D_{ref} mentioned in the previous section, $D_{meas} \in$ { 30m, 100m, 200m } and z_{meas} is 5m for D_{meas} = 30m, and 10m elsewhere. Table 1 contains the LAeq(1h) for one passenger car and one heavy truck, for the three pavements mentioned above and for various vertical sound speed gradient conditions. Table 2 presents the values of day and night LAeq for a simulated traffic of 35000 vehicles per day with a daytime heavy trucks percentage of 12% and a nighttime percentage of 20%, for summer atmospherical conditions ($\partial c/\partial z = 0$ for [6h-22h] period and $\partial c/\partial z = 0.25$ for [22h-6h]). Table 3 is similar to table 2 for winter atmospherical conditions ($\partial c/\partial z = 0.25$ for [6h-9h] period, $\partial c/\partial z = 0$ for [9h-18h] and $\partial c/\partial z = 0.25$ for [18h-6h]).

***Table 1**. LAeq(1h) for 1 vehicle*

		Surface Dessing			Bitum. Concrete			Porous Asphalt		
		30m	100m	200m	30m	100m	200m	30m	100m	200m
P	$\partial c/\partial z = 0$	40.0	32.3	24.2	38.5	30.6	22.2	30.7	23.6	16.0
C	$\partial c/\partial z = 0.25$	40.0	32.1	30.1	38.5	29.8	28.7	30.7	24.6	20.8
H	$\partial c/\partial z = 0$	50.2	42.5	37.1	47.6	39.8	34.6	38.9	32.5	27.9
T	$\partial c/\partial z = 0.25$	50.2	41.7	42.3	47.6	39.2	39.3	38.9	32.4	30.7

***Table 2**. LAeq(T) for 35000 vehicles per day (summer conditions)*

	Surface Dessing			Bituminous Concrete			Porous Asphalt		
	30m	100m	200m	30m	100m	200m	30m	100m	200m
6h -22h	76.9	69.2	63.0	75.3	67.5	61.5	66.4	59.7	54.1
22h - 6h	69.9	61.6	61.6	68.2	59.6	60.3	59.2	52.8	50.5
Δ(day/night)	7.0	7.6	1.4	7.1	7.9	1.2	7.2	6.9	3.6

***Table 3**. LAeq(T) for 35000 vehicles per day (winter conditions)*

	Surface Dessing			Bituminous Concrete			Porous Asphalt		
	30m	100m	200m	30m	100m	200m	30m	100m	200m
6h -22h	76.9	69.0	66.0	75.3	67.1	64.6	66.4	59.9	55.8
22h - 6h	69.9	61.6	61.6	68.2	59.6	60.3	59.2	52.8	50.5
Δ(day/night)	7.0	7.4	4.4	7.1	7.5	4.3	7.2	7.1	5.3

Table 4 deals with the evolution of the differences between the different pavements with respect to the bituminous concrete for the LAeq(T) and LAmax. For this comparaison we choose, for the LAeq(T) the value at 200m, for summer conditions.

***Table 4**. Evolution of differences between pavements*

	Surface dressing	Bituminous Concrete	Porous Asphalt
Lamax(PC)	+ 6.0	0	- 3.2
LAmax(HT)	+ 1.4	0	- 3.9
LAeq(6h-22h)	+ 1.5	0	- 7.4
LAeq(22h-6h)	+ 1.3	0	- 9.8

5. FIRST EXPERIMENTAL RESULTS

First experimentations having carried out on two of the three previous pavements (Surface dressing and Porous asphalt in good condition). Table 5 explicits the comparison between the predicted and the measured LAeq on 1 hour recordings. On the first site (Surface dressing), the daily traffic was about 11000 vehicles, while the second site (Porous asphalt) was less trafficked, about 8000 vehicles per day. In both cases the heavy trucks percentage was similar (≈ 12 %).

***Table 5**. Comparison prediction - experiment*

	100 m			200 m		
	Model	***Experiment***	***Δ***	***Model***	***Experiment***	***Δ***
Surface Dressing	64.9	64.2	0.7	58.7	57.4	1.3
Porous Pavement	53.0	53.7	0.7	46.3	45.1	1.2

6. DISCUSSION

The results presented here are twofold. First, we observe that the pavement ranking is conserved between the near and the far field, and seconly, that the differences are not similar depending on the period (day, night, winter or summer) and the composition of the traffic. This can be explained by the differences in the spectral composition of the emitted noise (passenger cars or heavy trucks) and the atmospherical conditions. The interest of such a model is to be able to represent a large number of situations. This is confirmed by the comparison between predictions and experiments which shows a rather nice agreement. This is a first stage which has now to be completed by other measurements on other kinds of pavement in order to extend these first interesting conclusions.

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