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EFFECT OF LOW-NOISE PAVEMENTS ON TRAFFIC NOISE PROPAGATION OVER LARGE DISTANCES: INFLUENCE OF GROUNDS AND ATMOSPHERIC CONDITIONS

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ABSTRACT

Researches carried out in the past fifteen years have made possible the identification and the classification of the acoustic performances of road surfaces for short distance in terms of vehicle pass-by L_{Amax}. At the beginning, 0/20 mm to 0/10 mm single layer porous asphalts were the only low-noise pavements to be used in France and western Europe. Since the last five years, new pavements composed of small size chippings (0/6 mm), spread in thin layer, have been studied. After measurements carried out according to standardized methods, they can be considered as low-noise pavements too. First experiments show that they can be used as much in suburban as in urban situations. These preliminary results found for road near-field configurations are confirmed for long range situations in terms of equivalent sound pressure levels L_{Aeq}, indicator more currently used for environmental nuisances.

1 - INTRODUCTION

Traffic noise is still considered as one of the most important source of discomfort by neighboring populations of high-trafficked roads. Before the introduction of low noise pavements, acoustical reinforcements of building facades and noise barriers were the only possibilities to control and abate traffic noise. These new kinds of low noise pavements permit to reduce traffic noise of a few decibels. The first results have been found for some pavements and for near-field configurations only. The question is: may we extend these first conclusions to other new types of pavements and for far-field conditions where ground and meteorological effects can widely influence traffic noise propagation? Using a theoretical procedure based on $L_{Amax} \rightarrow L_{Aeq}$ transfer for a realistic traffic configuration, and on the last models taking into account outdoor conditions including seasonal effects, this paper contributes to give an answer to this important question which is always asked by road manufacturers and local authorities.

2 - DEVELOPMENT OF THE METHOD

L_{Aeq} predictions in front of the facades, function of tire-road noise due to the various pavement surfaces, need the knowledge of the following minimum informations:

- the exact number of vehicles passing by the receivers during the day [6:00-22:00] and night [22:00-6:00] periods for each vehicle class: passenger cars (n_{PC}) and heavy trucks (n_{HT}),
- the reference speed of each vehicle class ($Speed_{Ref}$),
- the A-weighted pass-by maximum sound pressure level L_{Amax} (in global or third octave values) at a reference microphone located in the road vicinity, 7.50 m from the right lane axis and 1.20 m above the road surface, corresponding to each vehicle class, obtained through the standardized Statistical Pass-By method (SPB) developed in ISO standard 11819-1 [1],
- the number and width of traffic lanes,

- location of the receivers (distance and height),
- impedance values of the pavement and the neighboring grounds,
- position of the impedance discontinuity with respect to the various lane axis and the receiver positions,
- atmospheric conditions during the day and night periods.

From the global L_{Amax} or the L_{Amax} third octave spectrum, the $L_{Aeq}[T]$ for the reference period T can be obtained from the general equation [2]:

$$L_{Aeq}\left[T\right]\left(Speed\right) = L_{Amax}\left(Speed\right) + 10 \cdot \lg_{10}\left(\frac{\pi\ D}{Speed \cdot T}\right) \tag{1}$$

where D is the distance between the right lane axis and the reference microphone, T the reference period which is taken equal to 1 hour and " *Speed* " the mean speed of the flow.
Using Eq. 1, a first calculation is carried out at the reference microphone for the whole frequency range representative of traffic noise [100 Hz − 5 kHz]. Then, excess attenuations between the reference microphone and the various receivers are computed. Depending on the different atmospheric and ground conditions, appropriate predicting models can be used. Four various situations can be studied:

- Homogeneous ground and homogeneous atmosphere,
- Homogeneous ground and stratified atmosphere,
- Mixed ground and homogeneous atmosphere,
- Mixed ground and stratified atmosphere.

In fact, for realistic situations, the two last situations have only to be considered. Thus, it makes possible to take into account all the parameters which can influence the propagation: ground impedances, both in the vicinity of the source and the receiver, including impedance jumps, equivalent vehicle source height which has been found very close to the road surface (around 0.03 m [3]) and atmospheric factors through the vertical sound speed gradients. The last parameter is only considered for long range conditions.
In the case of a positive sound speed gradient representative of downwind or temperature inversion conditions (during night for example) and a homogeneous ground, the mean sound pressure level $\langle p^2 \rangle$ can be expressed as the sum of the contribution of each sound paths between the source and the receiver as follows [4]:

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

A_i and A_j are the attenuations due to atmospheric absorption, r_i and τ_i are respectively the curved path length and the travel time of the ray i. N is the total number of rays including the direct one and Q_i is the spherical reflection coefficient function of the surface impedance Z. For the direct path, we assume Q_1=1. For natural grounds or dense road surfaces, a Delany and Bazley impedance model [5] is used while an appropriate phenomenological one including thermal and viscous dependences [4] is used for porous pavements.
In the case of more realistic situations including both an impedance discontinuity and a positive sound celerity gradient, the sound pressure level can be modeled through an adaptation of the Rasmussen approach [6] given by the following equation:

$$p = \frac{D_d}{16\pi^2} \exp\left(-i\pi/4\right)\sqrt{8\pi k} \cdot \int_0^{z\ \max} \varphi\left(z\right)dz \tag{3}$$

where:

$$\varphi\left(z\right) = \frac{e^{2i\pi f(\tau_1+\tau_3)}}{r_3\sqrt{r_1 r_3\left(r_1+r_3\right)}} + \frac{Q_1' e^{2i\pi f(\tau_2+\tau_3)}}{r_3\sqrt{r_2 r_3\left(r_2+r_3\right)}} + \frac{Q_2' e^{2i\pi f(\tau_1+\tau_4)}}{r_4\sqrt{r_1 r_4\left(r_1+r_4\right)}} + \frac{Q_1' Q_2' e^{2i\pi f(\tau_2+\tau_4)}}{r_4\sqrt{r_2 r_4\left(r_2+r_4\right)}} \tag{4}$$

D_d is the distance between the discontinuity and the receiver, r_i and τ_i are respectively the curved path length and the travel time of the direct and reflected rays on both sides of the discontinuity calculated according to [7]. Q_1' and Q_2' are the two spherical reflection coefficients function of the angle of incidence at each calculation step, for the road pavement and the neighboring ground respectively. In this procedure, the vertical sound speed gradient is considered as linear until a height of 10 m and constant afterwards. According to this procedure, we can compute the various $L_{Aeq}\ [T]$ to be directly compared in one hand to in situ experimental data recorded for various pavement categories, and useful to characterize the acoustic effect of those pavements for a reference traffic situation, in another hand. Knowing the L_{Aeq}[1 hour] for one vehicle representative of each vehicle family (PC and HT), the $L_{Aeq}[T]$ for a typical traffic flow on the various day and night periods can be obtained by summation of the respective energies of each vehicle as follows:

$$L_{Aeq}\left[T\right] = 10 \cdot \lg_{10}\left[\frac{1}{T}\left(n_{PC} \cdot 10^{0.1L_{Aeq,PC}} + n_{HT} \cdot 10^{0.1L_{Aeq,HT}}\right)\right] \tag{5}$$

where n_{PC} and n_{HT} are, respectively, the number of passenger cars and heavy trucks in the traffic flow during the period *T*. $L_{Aeq,PC}$ and $L_{Aeq,HT}$ are the L_{Aeq} for one representative vehicle of each family on the reference period of 1 hour.

3 - COMPARISON BETWEEN PREDICTION AND MEASUREMENT

Results for 12 pavement families are shown in Table 1. The computed values of L_{Aeq}[1 hour] for a real traffic flow, are directly compared to measurements. Depending on the site, these comparisons are carried out at various distances (30, 60 and 120 m) and heights (1.20, 2.50, 3, 5 and 10 m). In order to have global view of the situation for all the pavements, results are given: in terms of absolute value of the mean difference between prediction and measurement ($|\Delta\,(pred./meas.)|$), range of variation and number of measurements. The calculations have been performed from Equations 1, 3, 4, 5.

Type of pavement	Pavement family	$\lvert\Delta\,(pred./meas.)\rvert$	Range of variation	Nb. Meas
L.N.P.*	0/6 Porous asphalt (PA)	0.5 dB(A)	[-0.9; +0.0]	2
L.N.P.*	0/10 Porous asphalt (PA)	1.2 dB(A)	[-2.3; +1.1]	11
L.N.P.*	0/6 Very thin asphalt concrete (VTAC)	1.1 dB(A)	[-1.8; +0.5]	6
L.N.P.*	0/10 Very thin asphalt concrete (VTAC)	0.7 dB(A)	[-1.8; +0.5]	7
I.P.*	0/14 Porous asphalt (PA)	0.5 dB(A)	[-1.3; -0.1]	3
I.P.*	0/10 Asphalt concrete (AC)	1.5 dB(A)	[-3.1; +1.4]	6
I.P.*	0/10 Ultra thin asphalt concrete (UTAC)	1.1 dB(A)	[+0.4; +2.1]	3
I.P.*	Cold-applied slurry surfacing (CASS)	0.4 dB(A)	[-0.8; +0.1]	3
N.P.*	0/14 Asphalt concrete (AC)	1.4 dB(A)	[-3.0; +2.1]	6
N.P.*	0/14 Very thin asphalt concrete (VTAC)	1.6 dB(A)	[+0.3; +2.9]	12
N.P.*	6/10 Surface dressing (SD)	1.5 dB(A)	[-2.6; -0.6]	5
N.P.*	Cement concrete (CC)	1.8 dB(A)	[-2.5; -0.9]	10

Table 1: Mean differences between predicted and measured L_{Aeq}[1 hour] for various pavement families (* L.N.P.: Low-noise pavement, I.P.: Intermediary pavement, N.P.: Noisy pavement).

The first results given in table 1 show that the mean differences between predicted and measured L_{Aeq}[1 hour] are never greater than 2 dB(A), whatever the pavement family and the distance. Therefore, obtaining such an accuracy, requires a good knowledge of all the physical parameters to be introduced in the model (road and neighboring ground impedances, source and receiver heights, distances, vertical sound speed gradients). As an example, if we do not consider the impedance discontinuity between the road and the close environment or if we modify the equivalent source height (0.20 m instead of 0.03 m), $|\Delta\,(pred./meas.)|$ can increase until 3 or 4 dB(A) [8]. Figure 1 shows one of the spectral comparisons at a distance of 120 m.

Another comparison between prediction and measurement ($|\Delta\,(pred./meas.)|$) has been carried out on the L_{Aeq}[6:00-22:00] and L_{Aeq}[22:00-6:00], for two porous pavements (0/6 and 0/14), at 30 m and 100 m. As reported in Table 2, the discrepancies are always lower than or equal to 2 dB(A) which is still acceptable with respect to the authorized standardized deviation close to 3 dB(A).

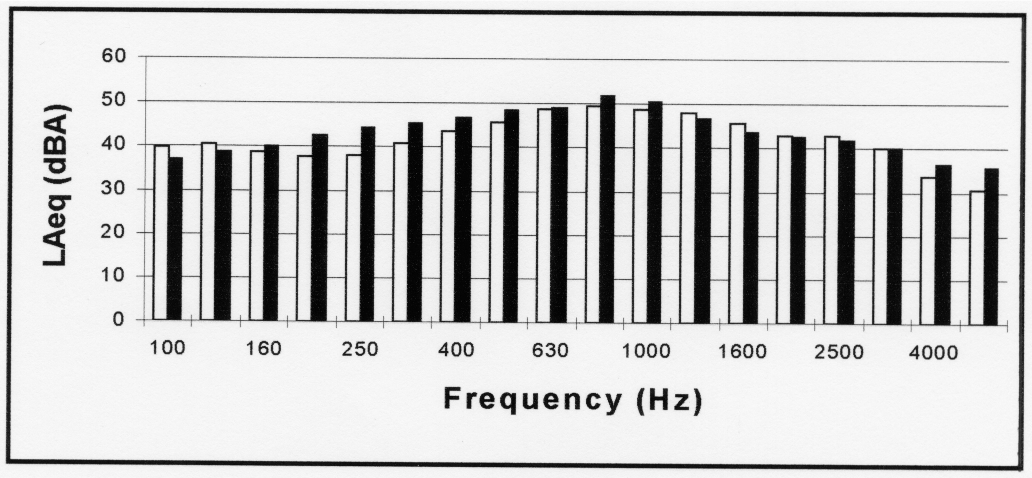

Figure 1: L_{Aeq} [1 hour] at 120 m − comparison between experiment (o) and prediction (n).

Pavement	L_{Aeq}[6:00-22:00] $\lvert\Delta\,(pred./meas.)\rvert$		L_{Aeq}[22:00-6:00] $\lvert\Delta\,(pred./meas.)\rvert$	
	30 m	100 m	30 m	100 m
0/6 Porous asphalt (PA)	0.6 dB(A)	-0.4 dB(A)	0.2 dB(A)	-1.2 dB(A)
0/14 Porous asphalt (PA)	1.9 dB(A)	0.3 dB(A)	2.0 dB(A)	0.6 dB(A)

Table 2: Differences between predicted and measured L_{Aeq}[day] and L_{Aeq}[night].

4 - THEORETICAL SIMULATIONS FOR A REFERENCE TRAFFIC SITUATION

From the previous results, the theoretical approach can be considered as validated. Thus, it is now possible to calculate the day and night impact of all the pavement families for distances between 7.50 and 200 m, for an identical reference traffic situation, and for summer and winter atmospheric conditions. For this purpose, we consider a 2 ×2 lanes road on which the vehicles are running with the reference speed ($Speed_{Ref}$), 100 km/h for the passenger cars and 80 km/h for the heavy trucks. The simulated traffic level is about 35 000 vehicles per day, with a day-time heavy trucks percentage around 18 %, and a night-time percentage around 27 %, i.e. 27 068 passenger cars and 4 798 heavy trucks in the period [6:00-22:00] and 2 460 passenger cars and 674 heavy trucks in the period [22:00-6:00]. The atmospheric conditions are simulated through the vertical sound speed gradient. For summer conditions, we consider $\partial c/\partial z = 0$ for the period [6:00-22:00] and $\partial c/\partial z = 0.25$ for the period [22:00-6:00], while for winter conditions, we assume $\partial c/\partial z = 0.25$ for the period [6:00-9:00], $\partial c/\partial z = 0$ for the period [9:00-18:00] and $\partial c/\partial z = 0.25$ for the period [18:00-6:00]. In the calculation, the new very thin asphalt concretes (VTAC-Type 2) which have a porosity close to 20 % are considered as thin layer porous asphalts (0.015 m < thickness < 0.03 m). The oldest one (VTAC-Type 1) which have a porosity around 10 % are considered as reflecting pavement. We assume the neighboring grounds as grass. The various results compared to a reference 0/10 asphalt concrete (0/10 AC), at the distance of 200 m are detailed in Table 3 and Table 4.

	0/6	0/10	0/6	0/14	0/10	0/14	0/14	0/10		6/10-2/4
	PA	PA	VTAC	PA	AC	AC	VTAC	VTAC	CC	SD
L_{Amax}(PC)	-5.8	-3.4	-2.8	-0.8	0	+2.3	+2.7	+3.1	+3.8	+4.9
L_{Amax}(HT)	-1.5	-0.6	-0.4	+2.9	0	+4.4	+3.8	+5.9	+3.6	+3.8
L_{Aeq} (day)	-5.9	-5.0	-2.6	-0.3	0	+3.5	+3.6	+1.3	+2.4	+3.9
L_{Aeq} (night)	-5.6	-4.9	-2.5	+0.1	0	+3.3	+4.0	+1.5	+2.3	+3.7

Table 3: Differences between pavements expressed in terms of L_{Amax} (7.50 m; 1.20 m) and L_{Aeq}[day] and L_{Aeq}[night] at a distance of 200 m for summer conditions.

	0/6	0/10	0/6	0/14	0/10	0/14	0/14	0/10		6/10-2/4
	PA	PA	VTAC	PA	AC	AC	VTAC	VTAC	CC	SD
Δ(night/day) Summer	-4.7	-4.9	-4.9	-4.6	-5.0	-5.2	-4.6	-4.8	-5.1	-5.2
Δ(night/day) Winter	-5.8	-6.1	-6.0	-5.8	-6.2	-6.2	-5.8	-6.1	-6.3	-6.4
Δ(Summer/Winter)	-1.1	-1.2	-1.1	-1.2	-1.2	-1.0	-1.4	-1.3	-1.2	-1.2

Table 4: L_{Aeq} differences between various periods (night and day) and (summer and winter) at a distance of 200 m.

5 - DISCUSSION

The first results presented in the two previous tables lead to the following discussion. On the one hand, we observe (Table 3) that the pavement classification obtained in the vicinity of the road is approximately conserved at a distance of 200 m in spite of the propagating effects. This is mainly the case for the low-noise pavements (0/6 and 0/10 PA and 0/6 VTAC). Regarding the intermediary and noisy pavements the ranking can change a bit between the near and the far field. As an example, we can point out the 0/10 VTAC which has a better behavior in the far field. That can be explained by the spectral composition of the emitted noise and the propagation conditions. On the second hand, we observe that the impact of the atmospheric conditions (night/day) or (summer/winter) are almost identical for the whole pavements (Table 4). These differences can easily be explained by the influence of the positive vertical sound speed gradient. Finally, we can confirm the validity of the predicting model which gives nice comparisons with measurements for all the pavement families and more particularly for the new low-noise formulations which seem to be of great interest for urban situations.

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