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The Propagation Filter Between CPX and CPB Measurements

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Modeling the local propagation effects of tire-road noise : propagation filter between CPX and CPB measurements

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Abstract [493] The objective of this research is to find a relationship between the noise radiated by a tire rolling on a road surface, and the noise received along the road. The first one can be evaluated by close proximity (CPX) measurements and is useful for the optimization of tire and/or road parameters. The later is usually evaluated by pass-by noise measurements, and is a better indicator for environmental assessment. A modeling approach was developed, and validated experimentally by simultaneous CPX / CPB (Controlled Pass-By) measurements. The noise level difference between CPX and CPB measurement positions was predicted as a function of sound attenuation between sources and receiver positions for different typical road surface configurations. For CPB positions, 2D analytical propagation models were used. For CPX positions, 2D BEM models were used to predict the sound attenuation because of the proximity of the source. The tire emission was modeled by a point source at the center of each contact patch. Purely reflecting and porous road surface conditions were considered. A good agreement was found between predictions and measurements for both types of surface conditions.

1 INTRODUCTION

The acoustic characterization of road pavements is usually performed with pass-by measurements, where the sound level meter is placed at a fixed position on the road side. But with the current development of “close proximity” measurement methods where a microphone is fixed close to a tire and measures continuously the noise emitted while the tire is rolling, the problem of correlation between both measurements arises. Actually, the measured sound pressure levels are different, this difference is not constant and is mainly due to different geometrical configurations and different propagation paths.

In this paper, the difference in propagation filter is predicted by numerical calculation. By “propagation filter”, is designated the sound pressure level difference between close proximity measurement point and pass-by measurement point.

2 DEFINITIONS AND DESCRIPTION OF THE GENERAL CONFIGURATION

2.1 CPX and CPB measurement positions

2.1.1 CPX measurement positions

The geometrical configuration of CPX (Close ProXimity) measurement positions refers to the international standardization draft document ISO/CD 11819-2 [2], in which the sound pressure level must be estimated simultaneously at two fixed positions relative to the test tire (referred as CPX positions), such that the distance horizontally from the plane of the tire (undeflected) sidewall is 0.20 m. Both microphones shall be mounted at a height above pavement level of 0.10 m (figure 1).

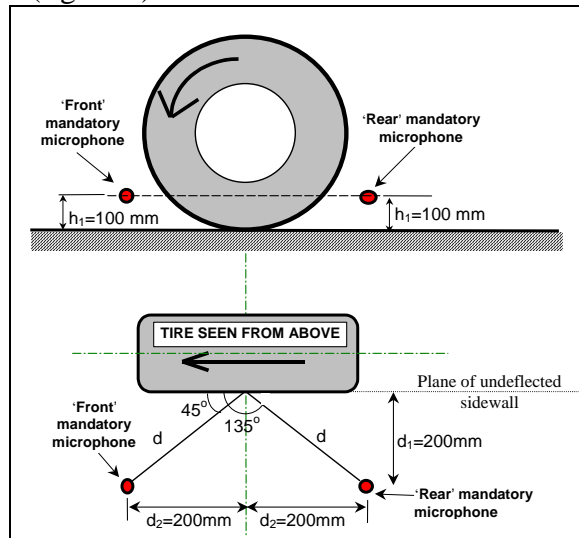


Figure 1 : CPX measurement positions

2.1.2 CPB measurement position

The CPB (Controlled Pass-By) position is fixed on the road side, 7.5 m distance from vehicle axis and 1.2 m above the ground level (figure 2). The measurement configuration and principle is described in ISO standard ISO 11819-1 [1] for Statistical Pass-By (SPB) measurements or in ISO 362 for vehicle testing. Here, only one vehicle with one set of tires is considered for a more accurate investigation on the propagation filter. Later, a further step in the research will be the correlation between standard CPX and SPB methods, where many vehicles of different types are measured in the traffic flow.

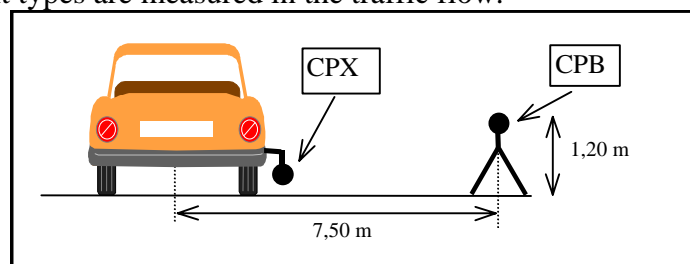


Figure 2 : CPB measurement position

2.2 Source assumption

When calculating the propagation filter, it is essential to know the source(s) and receiver(s) relative location. It is assumed that at CPX measurement positions, only the noise generated by the closest tire is estimated. It is further assumed that the tire source can be approximated by a point monopole source S_t located at the contact “point” (external border of the contact patch) between the tire and the road surface. It is also widely admitted that at the CPB measurement position, the rolling noise emitted by the vehicle when passing in front of the

measurement point, can be assumed as an equivalent point source S_{eq} , located on the vehicle path line (i.e. 7.50 m distance) and 0.04 m above the road surface. The 2D geometry of a section of the problem is summarized in figure 3. In a first approach, the sound reflections on car body are neglected.

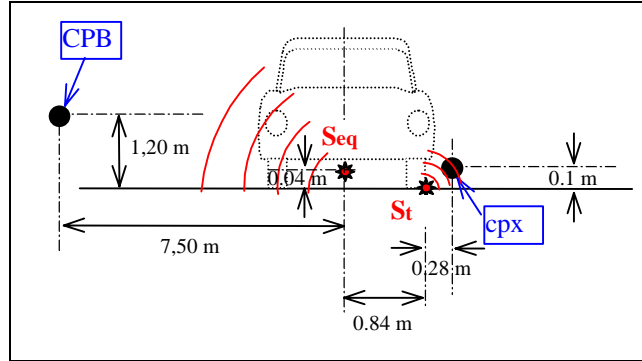


Figure 3 : Assumption of sources location

2.3 Definitions for sound attenuation

The propagation filter ΔL , is defined as the sound pressure level difference between the CPX measurement (L_{CPX}) and the CPB measurement (L_{CPB}) :

$$\Delta L = L_{CPX} - L_{CPB} \quad (1)$$

L_{CPX} is the sound pressure level measured at CPX position due to the S_t source, whereas L_{CPB} is the sound pressure level measured at CPB position due to the S_{eq} source. In the case of far field assumption, the sound pressure level at CPB position is :

$$L_{CPB} = L_{Weq} - 10 \log_{10}(4 \pi (r_{eq})^2) + Att_{CPB} \quad (2)$$

where L_{Weq} is the sound power level of the equivalent vehicle source S_{eq} , r_{eq} is the distance between the CPB measurement position and the equivalent vehicle source S_{eq} position, Att_{CPB} is the sound pressure attenuation between the CPB measurement position and the S_{eq} position relative to the free field. In the same way, the sound pressure level at CPX position can be defined by :

$$L_{CPX} = L_{Wt} - 10 \log_{10}(4 \pi (r_{CPX})^2) + Att_{CPX} \quad (3)$$

where L_{Wt} is the sound power level of the tire source S_t , r_{CPX} is the distance between the CPX measurement position and the tire source S_t position, Att_{CPX} is the sound pressure attenuation between the CPX measurement position and the S_t position relative to the free field. Note that in this last case, the far field assumption is valid only at higher frequencies (above 200 Hz). The combination of equations (1) to (3) gives :

$$\Delta L = (L_{Wt} - L_{Weq}) + (Att_{CPX} - Att_{CPB}) + 20 \log_{10}(r_{CPB}/r_{CPX}) \quad (4)$$

The last term of the equation (4) is purely geometrical and can be easily calculated. The prediction of sound power level difference and sound attenuation difference requires more work.

3 MODEL FOR CALCULATING THE PROPAGATION FILTER

3.1 Calculation of sound power level difference

For the calculation of the difference in sound power level of the tire generated noise (S_i) and the vehicle equivalent noise (S_{eq}), the assumption is made that this later only results in the summation of the 4 tire contact noise source (no contribution from the engine, exhaust, transmission...), that these sources have the same power and are incoherent, and that the sound reflections on the car body can be neglected. Thus for $i=1$ to 4, the S_{ti} tire contact point source produces the sound level L_{ti} at CPB position located at a distance r_i (see figure 4) :

$$L_{CPB} = L_{Weq} - 10 \log_{10}(4 \pi (r_{eq})^2) + Att_{CPB} = L_{t1} \oplus L_{t2} \oplus L_{t3} \oplus L_{t4} \quad (5)$$

With

$$L_{ti} = L_{Wt} - 10 \log_{10}(4 \pi (r_i)^2) + Att_i \quad (6)$$

Where Att_i is the sound attenuation relative to free field between the tire source S_{ti} and the CPB measurement position. Considering the symmetry of the problem, the simplification applies :

$$L_{t2} = L_{t1} \text{ and } L_{t4} = L_{t3} \quad (7)$$

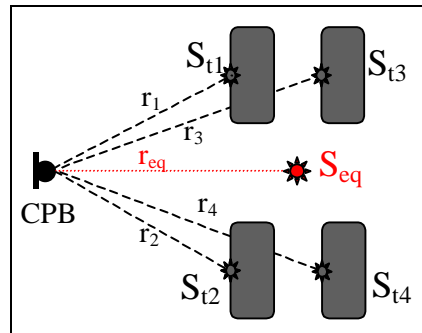


Figure 4 : Tire source contribution to CPB noise, at the four contact patches

The combination of the last three equations gives an expression of $(L_{Wt} - L_{Weq})$ as a function of Att_1 and Att_3 , Att_{CPB} , r_1 , r_3 and r_{eq} . When introduced in equation (4), this becomes :

$$\Delta L = Att_{CPB} - Att_1 - 20 \log_{10} \left(\frac{r_{CPX}}{r_1} \right) - 10 \log_{10} \left(1 + \left(\frac{r_1}{r_3} \right)^2 10^{\frac{Att_3 - Att_1}{10}} \right) - 10 \log_{10}(2) \quad (8)$$

In the case where the entire surface between the vehicle and CPB position is purely reflecting, then $Att_1 = Att_3 = Att_{CPB} = 6$ dB for all frequencies, and equation (8) simplifies to a constant value :

$$\Delta L = 10 \log_{10} \left(\frac{r_1^2 r_3^2}{2 r_{CPX}^2 (r_1^2 + r_3^2)} \right) \quad (9)$$

3.2 Sound attenuation calculation

3.2.1 Sound attenuation at CPB position (Att_1 and Att_3)

For the calculation of attenuation at the CPB position (Att_{CPB}), the semi-analytical model by Rasmussen [3] was used. It is a rather simple and quick calculation scheme, that can take into account finite or infinite surface impedance, and impedance discontinuity effects. Actually, 5 site configurations were studied which are depicted in figure 5. In the first one, all the surface between vehicle and microphone is purely reflecting, on the second one all this surface is sound absorbing in the way of a porous road surface, and in the last 3 configurations,

impedance discontinuities are introduced between the measured road surface and the shoulder or other lanes.

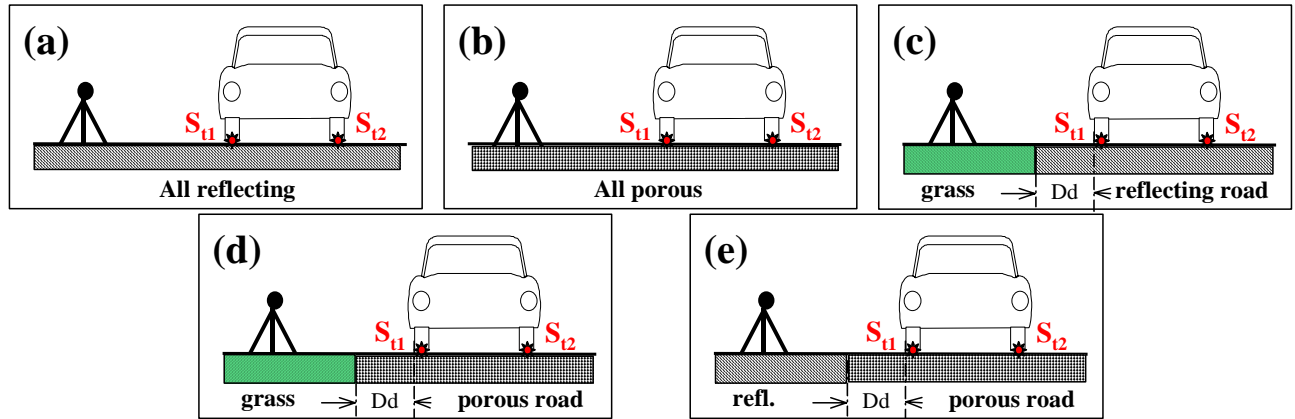


Figure 5 : Description of possible road / shoulder surface configurations

For reflecting road surfaces (all impervious pavements), the boundary condition is an infinite acoustic impedance. For the surface covered by grass, the finite acoustic impedance is predicted with the famous Delany and Bazley model [4], and requires one single parameter, the specific flow resistance R_s . A local type of reaction is assumed on this surface. On the porous road surface, the local reaction assumption is not valid and the angle of incidence of the waves impinging on the surface must be considered. The acoustic impedance of such material is described by Hamet et al. model [5], using 3 parameters : the porosity Ω , the specific flow resistance R_s , a shape factor K (or “tortuosity”). For both sound absorbing surfaces, the layer effect on normal acoustic impedance can be introduced with an additional parameter, the layer thickness e .

As an illustration, the resulting sound attenuations for the nearest tire source (Att_1) are presented in figure 6 for the 5 site configurations described in figure 5, with $Dd = 2$ m. The parameters for the absorbing boundary conditions are $\{R_s = 200 \cdot 10^3$ MSK Rayls ; $e = 0.012$ m $\}$ for the grass, and $\{R_s = 37 \cdot 10^3$ MSK Rayls ; $\Omega = 17\%$; $K = 2.5$; $e = 0.004$ m $\}$ for the porous asphalt pavement.

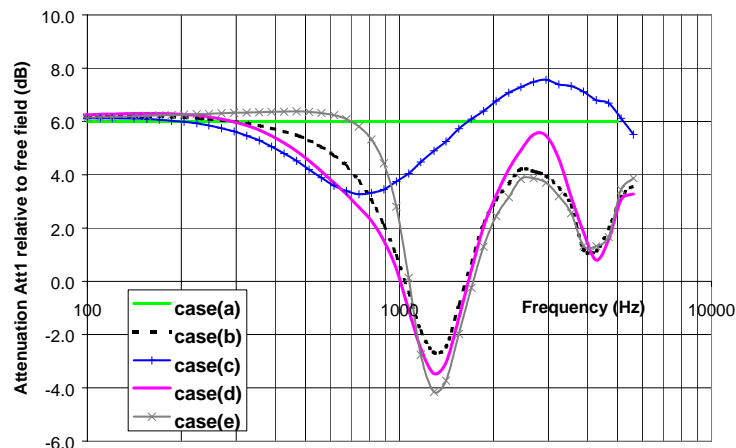


Figure 6 : Sound attenuation relative to free field (Att_1) calculated between tire equivalent source S_{11} and CPB position, for configurations in figure 5

3.2.2 Sound attenuation at CPX position (Att_{CPX})

Because of the proximity between the source S_t and the measurement point CPX, the analytical propagation model used in the previous case is not suitable here. Thus a BEM

model was found more suitable for the prediction of this sound attenuation. With this model, all types of boundary conditions seen previously can be introduced. Furthermore, it will be possible with such a model, to introduce later, a more complex geometry, with sound reflection on the car body, or tire sidewall, or wheel rim. The results of attenuation calculation as a function of frequency are presented in figure 6 for both road surface boundary conditions, reflecting or porous. Due to close proximity between source and receiver, no surface impedance discontinuity needs to be considered here.

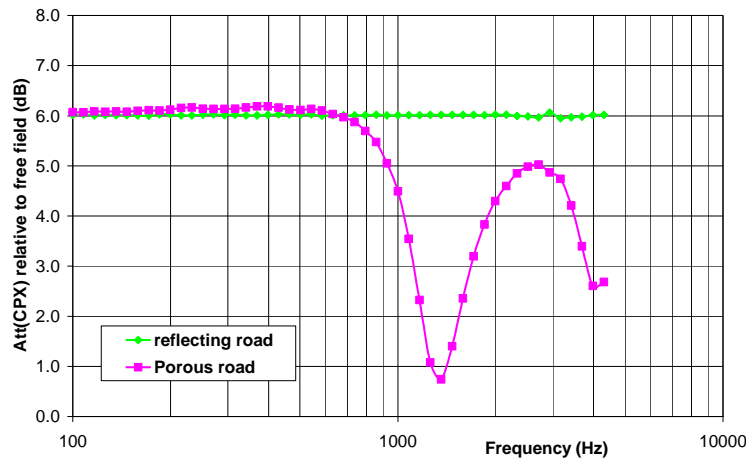


Figure 7 : Sound attenuation relative to free field between tire source and CPX position (BEM model)

4 EXPERIMENTAL VALIDATION

4.1 CPX and CPB measurements

In the experimental assessment, a CPX-test vehicle was used as a controlled pass-by (CPB) noise source. The vehicle was fitted with only one set of tires during the measurements. These were standard tires for passenger car available on the market (Michelin Energy XH1 ref. 195/60/R15). When the vehicle passes by at a stabilized speed, the maximum sound pressure level at CPB position is recorded along with the vehicle speed measured with a radar. A total of 8 runs at speeds ranging from 70 km/h to 110 km/h was performed.

Simultaneously during the pass-by, CPX measurements were performed at the two microphones located close to the back right wheel (i.e. as far as possible from the engine and exhaust pipe), at the positions defined in figure 1. Many investigations have been made to check the immunity of acoustic measurements to the aerodynamic noise, to the vibration of the mounting bars, and to the noise from the engine and other tires. Details can be found in [6]. The acoustic signal acquisition starts automatically at a given position on the road (located by a reflector), and simultaneously, a tachometric signal is delivered every wheel full rotation (approximately 2 m). This later gives an indication of the distance, the instantaneous speed, and sets the “period” on which the noise level is integrated. In this way, noise levels (and spectra) at each microphone are evaluated for constant length segments. Here, the sound pressure levels were averaged over a total distance of 20 m on the road (i.e. 10 wheel rotations), 10 m before and 10 m after the CPB position, so that approximately the same segment of road surface is characterized. In the ISO document [2] the CPX sound pressure level is actually an arithmetic average between the two microphones.

For each run, the sound pressure level (L_{\max} in the case of CPB, $L_{\text{eq}[20\text{m}]}$ in the case of CPX) are plotted against the logarithm of speed, and a linear regression calculated. The reference sound pressure level characterizing the road surface is given by the value of the regression

line at the reference speed, here 90 km/h. An example of regression on global sound pressure levels is shown in figure 8 for the measurements on the purely reflecting road surface. Similar analysis is performed for each third-octave band results in the range [400 Hz – 4 kHz].

This experiment was performed on two different road pavements : one reflecting (Dense Asphalt Concrete), the other porous (Porous Asphalt Concrete). The geometry of the measurement site is similar to what is described in figure 3 and figure 5 case(a) and case(e) with $Dd = 1.0$ m.

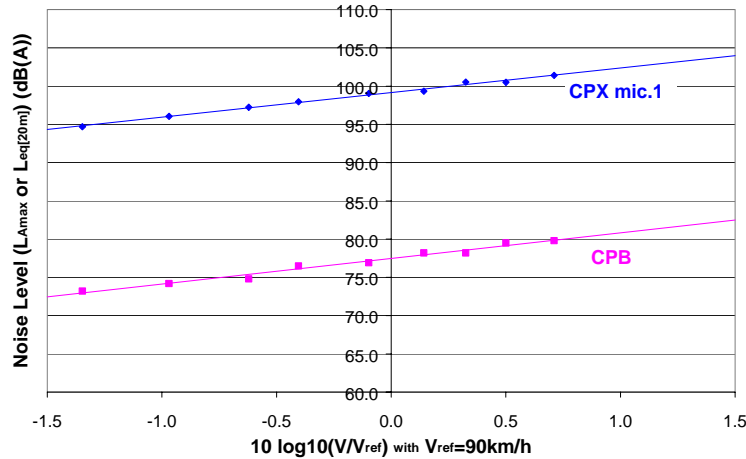


Figure 8 : Global sound pressure levels measured on reflecting road surface, and regression line

4.2 Comparison model - measurements

The difference in sound pressure levels (propagation filter) resulting from both regressions at 90 km/h for CPX and CPB measurements are calculated and compared with the predictions, for both road surface types (table 1).

$\Delta L(90 \text{ km/h})$ (dB(A))	Reflecting Road Surf.		Porous Road Surf.	
	Measurements	Calculation	Measurements	Calculation
Meas Mic1	21.9	-----	21.9	-----
Meas Mic2	23.2	-----	24.6	-----
Avg ISO (Mic1+2)	22.5	22.0	23.3	24.7

Table 2 : Attenuation filters between CPX and CPB on both surfaces

The agreement between global experimental results and calculation is good, 0.5 dB(A) difference for the reflecting road surface, and 1.4 dB(A) for the porous road surface. According to the prediction, the propagation filter is higher in the case of porous surface (+2.7 dB(A)). The spectral comparisons between [400 Hz - 4 kHz] are presented in figure 9 for the reflecting road surface, and in figure 10 for the porous road surface. In the first case, there is a frequency effect observed on the measured filter, that the model does not take into account. This could be due to an interference of sound waves on the car body. In the case of porous road surface, the variation of the filter with frequency is similar between measurements and calculation, although the estimated values are much higher than the measured ones, especially in the high frequency range. This is attributed to a possible over-estimation of the absorption of the porous road in the model. Actually, the road surface is partially clogged, and sound absorption measurements should be repeated in order to refresh the 3 parameters of the porous model. However, all these spectral results are consistent, considering that they all result from sound pressure level differences, each level being measured or predicted with a certain inaccuracy. Deviations in the measured filter up to 1 or 2 dB(A) may not be significant. The

estimation of parameters introduced in the model may also introduce deviation in the calculations.

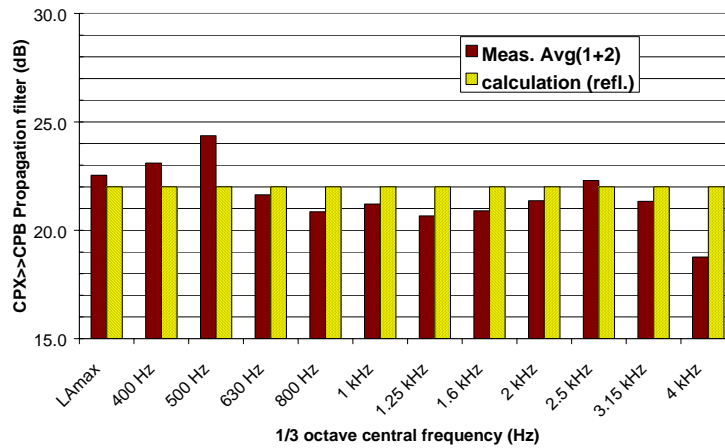


Figure 9 : Attenuation filter between CPX and CPB measurements, on the reflecting road surface

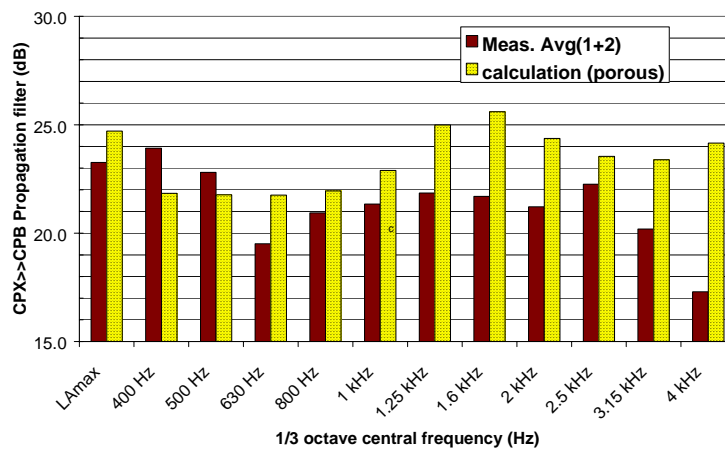


Figure 10 : Attenuation filter between CPX and CPB measurements, on the porous road surface

5 CONCLUSIONS

In this paper, a simple model for predicting the propagation filter between CPX (Close ProXimity) and CPB (Controlled Pass-By) measurements was presented. This method makes use of well-known propagation models, and thus requires a geometrical description of the measurement site and an acoustical description of the boundary condition on the surfaces involved (shoulder, road surface(s)...). A comparison with experimental results on two road surfaces, one traditional reflecting and one porous, gave fairly good agreement. This could be improved by a more accurate determination of the parameters of the porous asphalt tested. The prediction will also be improved by taking into account the sound reflections on the car body. Furthermore, more site and vehicle configurations need to be tested for a better assessment, and to end-up finally in a relationship between CPX and Statistical Pass-By (SPB) measurements.

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REFERENCES

- [1] ISO 11819-1:1997, Acoustics – Measurement of the influence of road surfaces on traffic noise – Part 1 : statistical pass-by method, Geneva, 1997
- [2] ISO/CD 11819-2, Acoustics – Measurement of the influence of road surfaces on traffic noise – Part 2 : close-proximity method, draft document, 2000.
- [3] K.B. Rasmussen, A note on the calculation of sound propagation over impedance jumps and screens, *Journal of sound and Vibration* **84**, pp. 598–602, (1982)
- [4] M.E. Delany, E.N. Bazley, Acoustical properties of fibrous absorbent materials, *Applied Acoustics* **3**, pp 105-116, (1970).
- [5] J.F. Hamet, M. Bérengier, “Acoustical characteristics of porous pavements : a new phenomenological model”, in *Proceedings of Internoise 93*, Louvain, 1993, pp 641-646.
- [6] F. Anfosso-Lédée, “ The development of a new tyre-road noise measurement device in France”, in *Proceedings of SURF 2004 (5th symposium on pavement road characteristics)*, to be held in Toronto, june 2004