PROCEDURE FOR MEASURING THE SOUND ABSORPTION OF ROAD SURFACES IN SITU

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INTRODUCTION

As low-noise surfaces become an option more and more common in traffic noise control, a test method is required for measuring ***in situ*** the sound absorption of road surfaces. The method can be used for the determination of the absorption coefficient of road surfaces currently in use, as well as for the comparison of design specifications with current performance data after completion of the construction work.

The paper presents a method, to be included in a future ISO standard, based on the use of a sequence of impulses as test signal. This allows the acquisition of the impulse response of the material under test in situ. Depending on the selected test signal, it is possible to obtain valid results in presence of high level of non-stationary background noise. While an absolute calibration of the measurement system is not needed, a reference measurement is recommended.

The paper presents the comparison of the results obtained on a porous pavement, by two institutions (DIENCA and LCPC) using different test signals and post-processing softwares. The results show an encouraging good reproducibility and compare well on a wide frequency range with the predictions of a theoretical model of the acoustic behaviour of porous surfaces.

THE MEASUREMENT METHOD

General principle. A sound source and a microphone are placed over the surface under test (see figure 1). The sound source emits a transient sound wave which travels past the microphone position to the surface under test and is reflected. The microphone receives both the direct sound pressure wave travelling from the sound source to the surface under test and the sound pressure wave reflected by the surface under test. The ratio of the direct and reflected waves power spectra, corrected to take into account the path length difference between the two waves, gives the sound power reflection factor of the surface under test. From this, the sound absorption coefficient can be directly computed [1]:

$$\alpha(f) = 1 - \left|R_p(f)\right|^2 = 1 - \frac{1}{K_r^2}\left|\frac{P_r(f)}{P_i(f)}\right|^2 \qquad (1)$$

where: $R_p(f)$ is the sound pressure reflection factor of the surface under test; K_r is the geometrical spreading factor [1], accounting for the path length difference between the direct and the reflected sound pressure wave (see figure 1): $P_r(f)$ is the spectrum of the sound pressure wave reflected by the surface under test, as detected by the microphone; $P_i(f)$ is the spectrum of the sound pressure wave travelling from the sound source to the surface under test, as detected by the microphone.

The measurement must take place in an essentially free field, i.e. a field free from reflections coming from surfaces other than the surface under test. For this reason, the acquisition of an impulse response having peaks as sharp as possible is recommended: in this way, the reflections coming from other surfaces can be identified from their time delay and rejected. The test impulses emitted by the sound source can be repeated in time and synchronously averaged by the receiving device.

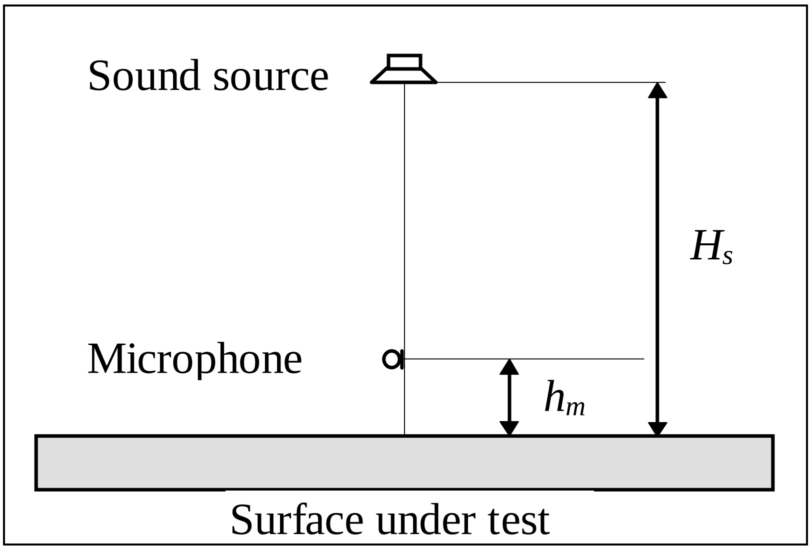

Figure 1. Sketch of the measurement set-up.

Signal subtraction technique. The overall impulse response measured over the surface under test consists of direct sound, reflection from the surface under test and other parasitic reflections. For further processing, the direct sound wave and the reflected sound wave from the surface under test must be separated. This can be done in the time domain in two different ways: 1) the direct and reflected waves can be windowed out from the overall impulse response, assuming sufficient time delays between them; 2) as an alternative, the direct sound wave is not windowed out from the overall impulse response; instead, it is simply cancelled from the overall impulse response by subtraction of an identical signal [2]. Of course, the incident sound wave must be exactly known in shape, amplitude and time delay. In principle, this can be obtained performing a free-field measurement with the same geometrical configuration of the set-up. In particular, the distance between the microphone and the sound source must be kept strictly constant. This signal subtraction technique allows to position the microphone very close to the surface while taking a temporal window for the reflected sound wave as large as allowed by the time delay between the reflected sound wave from the surface under test and the first parasitic reflection.

Reference measurement. Whatever the road pavement structure, often very small sound absorption coefficient values are measured in the low frequency range. Accurate values in this range are very difficult to obtain. Small variations of the sound pressure levels both of the direct and reflected signal can induce high discrepancies on the sound absorption values. This is due to the approximation concerning the frequency response of the entire system, which is assumed to be linear and frequency independent. In practice, this is not completely true. In order to avoid this problem, and in order to improve the accuracy of the method, a reference measurement performed on a totally-reflecting surface is used [3]. The reference measurement must be performed on a highly-reflecting surface, which shall be smooth, such as a smooth dense continuous concrete without joints. From the two measurements, one on the reference surface (sound pressure reflection factor $R_{\mathrm{p,ref,meas}}(f)$) and the other on the road surface under test (sound pressure reflection factor $R_{\mathrm{p,road,meas}}(f)$), the true sound pressure reflection factor of the road surface under test, to be used in eq. (1), is computed as:

$$R_{p,road}(f) = \frac{R_{p,road,meas}(f)}{R_{p,ref,meas}(f)} \qquad (2)$$

Test signal. An electro-acoustical source is used. This, receives an input electrical signal consisting of an impulse or a sequence of repeatable impulses. This is possible if the impulses are generated in a deterministic manner or if they are stored in an electronic memory. The crest factor of each impulse shall not be so high as to force the loudspeaker to operate in a non-linear manner. The usage of a maximum-length sequence (MLS) is recommended [1, 2] to get the maximum noise rejection [1], but other signals can be used, provided that the *S*/*N* is not compromised. The *S/N* ratio can be improved by repeating the same test signal and synchronously averaging the microphone response.

Expression of results. For the intended purpose, results are given in the one-third octave bands from 250 Hz to 4 kHz. If the acquisition and post-processing systems work in narrow bands, a synthesis algorithm to get the results in one-third octave bands is needed.

AN EXAMPLE OF APPLICATION

The outlined method was tested on the LCPC test track in Nantes, France, during an ISO working group meeting in January 1998. Measurements were done by two institutions (DIENCA, Italy, and LCPC, France) using different test signals and post-processing softwares. Data were processed on site and the results were obtained in few minutes.

Equipment and test signals. Both teams used the same loudspeaker, amplifier and microphone, but different equipment for impulse response acquisition and post-processing; they also used different test signals (see table 1). The loudspeaker was located at a height H_{s}=1,25 m above the road surface taken as reference plane, and the receiver microphone was located at a height h_{m}=0,25 m above the same reference plane. Both teams used the signal subtraction technique.

EQUIPMENT	DIENCA	LCPC
Loudspeaker	Audax HM 170Z0 in a closed cabinet	Audax HM 170Z0 in a closed cabinet
Amplifier	B&K 2706	B&K 2706
Microphone	Sennheiser KE 4	Sennheiser KE 4
Data acquisition	A2D-160 board + PC + MLSSA© software	HP 35665A FFT analyser
Post-processing	ALFA© software	LCPC software
Signal type	MLS	Sweep burst
Sample rate	75,5 kHz	30 kHz

Table 1. Equipment and test signals used by the two teams.

Chipping size	0/10 mm
Porosity	20 %
Thickness	0,04 m
Lifetime	8 years
Actual conditions	Good

Table 2. Characteristics of the porous asphalt.

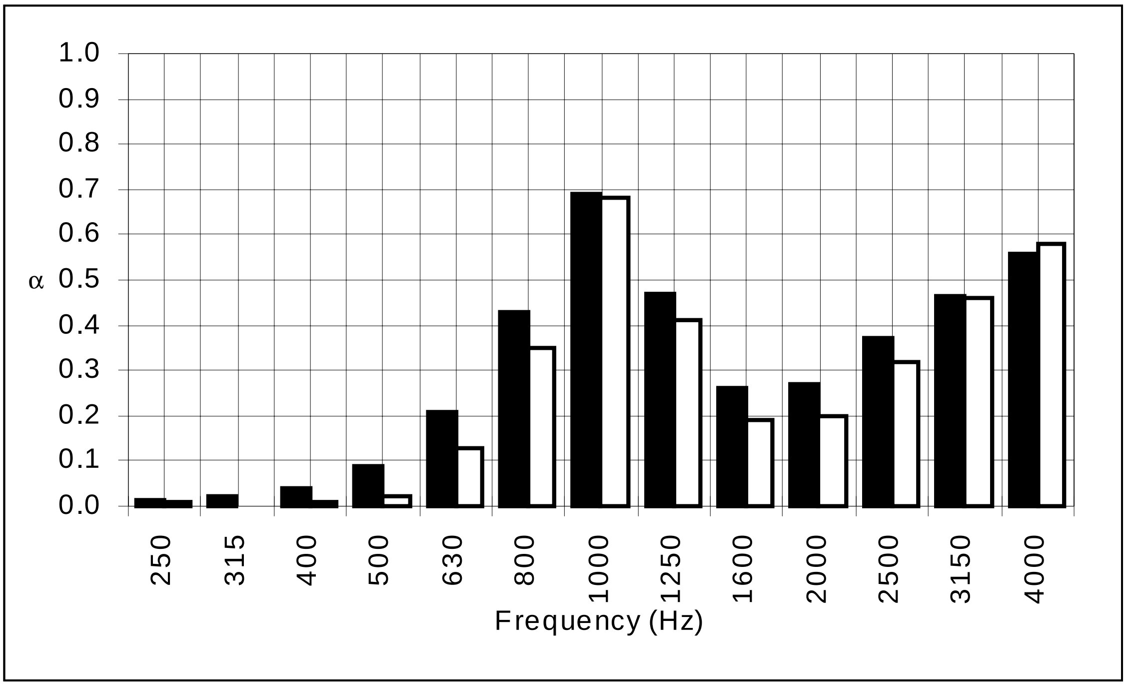

Figure 2. Results of the measurements done by DIENCA (black) and LCPC (white) on the same porous asphalt using different test signals and post-processing systems.

Road surface under test. Porous asphalt with the characteristics reported in table 2. During the test, the road surface temperature was about 5 °C; the wind speed was about 4 m/s and the ambient air temperature was 4 °C. It is worth noting that the night before the test it rained; a plastic covering was applied on the road surface spot selected for the test, but anyway some water probably infiltrated in the porous layer. This could change the absorption characteristics, particularly at high frequency.

Reference surface. The reference measurement was done on a plywood sheet 10 mm thick, large enough to include the active area (i.e. the surface area contained within the plane of reflection which, for a given incident signal, contributes to the formation of the reflected signal [1]).

Results of the measurement in one-third octave bands. They are shown in figure 2.

COMPARISON WITH A MATHEMATICAL MODEL

In order to check the reliability of the measurements, the experimental results of one of the teams have been kept also in narrow bands, and then compared with the results of a similar measurement taken (two days) before the rain and with the predictions of a theoretical model (figure 3).

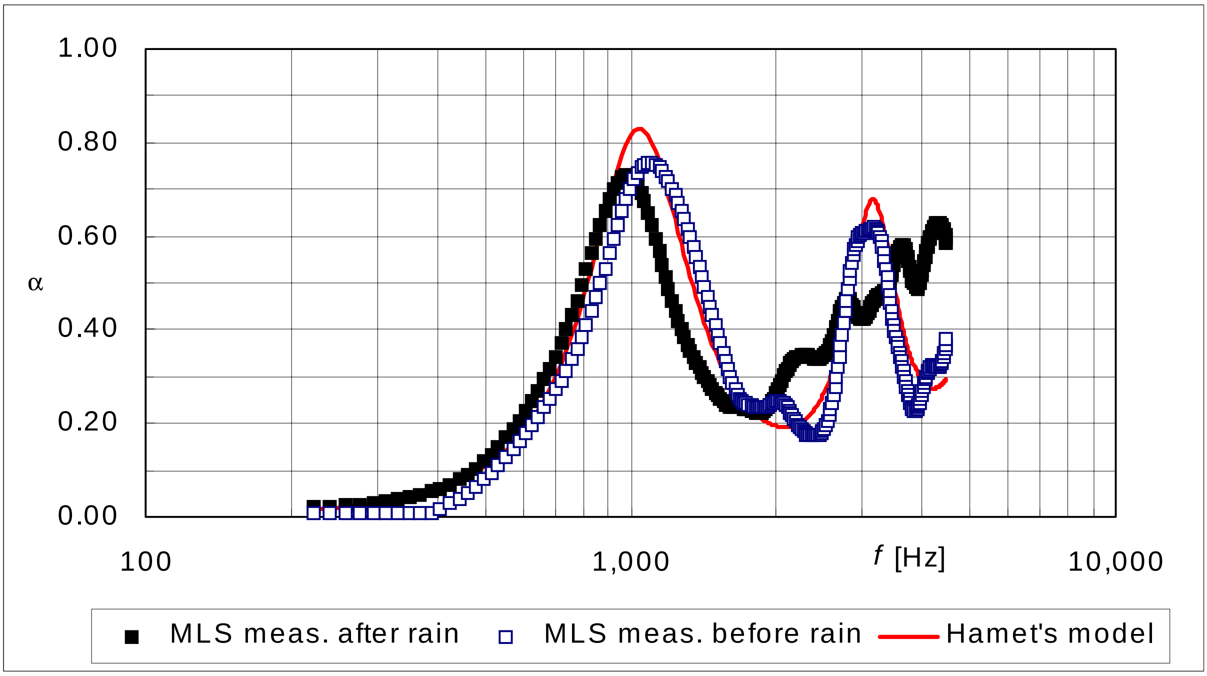

Figure 3. Comparison of the narrow band measurement results by DIENCA after rain (black squares) and before rain (empty squares) with the prediction of the Hamet's model (s = 40 mm, Ω = 0.20, k_{st} = 2.9, σ = 47000 kg/m^{3}s) for the same porous layer.

The selected model was the well-known Hamet’s mathematical model [4, 5]. In the present case, the following values of the characteristic parameters were assumed: porosity $\Omega = 0.20$ (nominal value), flow resistivity $\sigma = 47000$ kg/m^{3}s (measured on a bore core at LCPC), structure factor $k_{st} = 2.9$ and, in addition, a thickness $s = 40$ mm.

CONCLUSIONS

The method proved to be robust enough and easy to use. Post-processing can be performed directly on site. Even if the two teams used different test signals and post-processing softwares, the results obtained during the same test show an encouraging good reproducibility over the whole frequency range of interest (figure 2).

When taken in narrow bands, the experimental results compare fairly well with the predictions of a theoretical model of the acoustic behaviour of porous surfaces (figure 3). In particular, the measurement done before the rain could detect the first and the second absorption peak predicted by the theoretical model, which assumes a perfectly dry porous layer. The measurement done after the rain shows that the method can detect the changes induced on absorption characteristics by water infiltration; these changes are particularly evident above 2 kHz.

The experimental results already obtained are largely sufficient with respect to the goals mentioned in the introduction.

Using the same measurement procedure with a different geometrical arrangement of the source and the receiver, it is also possible to determine the sound absorption coefficient at an oblique incidence. Introducing the appropriate changes in the post-processing software, the acoustic impedance of the surface under test can be obtained. This flexibility of the method is very useful to obtain representative acoustic properties of road surfaces relevant to traffic noise propagation.

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