OPTIMIZATION OF IN SITU NOISE BARRIER INTRINSIC CHARACTERISTICS MEASUREMENTS

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Abstract

Noise barriers intrinsic characteristics evaluation is fairly complicated if one aims at simulating barrier operating conditions. One of the most successful methods consists of *in situ* impulse response measurement, in particular by means of MLS signals combined with cross-correlation techniques. This has been adopted by a new CEN Technical Specification. Anyway, such a method has shown limitations and drawbacks.

The aim of the research is first of all to investigate the influence of various parameters, such as source characteristics, measurement apparatus geometry and signal processing technique, on the final results of the measurements. Correlation has been found between errors due to subtraction technique, used to isolate the reflected component, and differences observed in subsequent measures. Particular attention is also paid to barrier materials and shape; reflection coefficient measurements on low- as well as on high-absorptive barriers were performed. Finally, method repeatability and reproducibility were taken into account.

INTRODUCTION

Noise barrier acoustical intrinsic characteristics are needed for products qualification. Already issued European standards describe how to evaluate sound absorption and airborne sound insulation properties of a barrier in coupled reverberation rooms. However, these laboratory methods are far from the actual operating conditions of a noise barrier, in terms of acoustic field and way of assembly.

The European Committee for Standardization has recently issued a Technical Specification [1] for determining *in situ* the intrinsic characteristics of noise barriers. Such method can be used to qualify in a test field products to be installed along roads, railways etc., as well as to verify compliance of installed noise reducing devices to design specifications. It is an impulse technique, based on various Authors' contributions [2, 3] and it uses Maximum Length Sequences (MLS signals), which ensure good repeatability and noise immunity. Two specific quantities are introduced by the Standard, i.e. Reflection Index (*RI*) and Sound Insulation index (*SI*), giving global indications respectively on the reflection and airborne sound insulation properties of a noise barrier. Single-number ratings (DL_{RI} and DL_{SI}) are then derived from *RI* and *SI* using a normalized traffic noise spectrum.

The paper aims at critically analysing the method both from the theoretical and from the practical point of view, giving particular attention to reflection measurements. Indeed, sound insulation measurements have shown to be easier, more reliable and consistent with laboratory results [4].

IN SITU REFLECTION MEASUREMENT

According to CEN/TS 1793-5, Reflection Index measurements can be briefly described as follows. The measuring equipment, consisting of a sound source and a rigidly connected microphone, is located in front of the noise barrier (fig. 1). Equipment height from the ground h_S and source and microphone distances (d_S and d_M) from the surface have to be precisely known.

Two kinds of impulse responses must be recorded: overall response (OIR) $h_{o,k}(t)$, positioning the equipment in front of the barrier at a certain angle θ_k, and "free-field" response (FFIR) $h_i(t)$, avoiding to face any nearby object or surface.

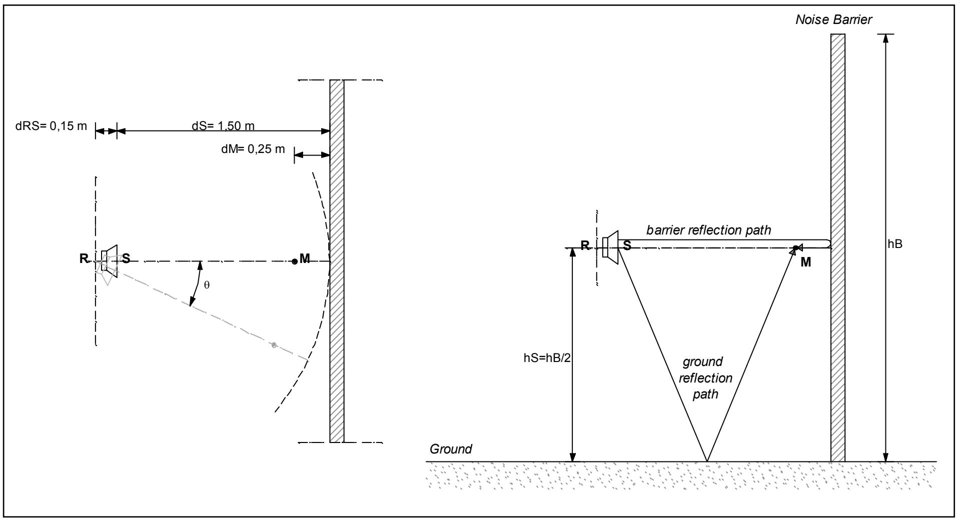

Fig. 1: measurement equipment configuration and geometry as prescribed in [3]. R: centre of rotation. S: sound source. M: microphone.

Measurements at nine different angles (a “rotation”) in front of the barrier are prescribed to evaluate normal and oblique incidence performances. Equipment rotation can be carried out either on the horizontal or the vertical plane, depending on the system geometry: it was performed on the horizontal one, in this case. Each overall impulse response contains a direct component, a component reflected from the barrier and reflections from other surrounding surfaces (“parasitic”): the first two components have to be separated, while the third one has to be cancelled out.

Reflected component $h_{r,k}(t)$ separation can be performed either through time windowing or implementing a subtraction technique: the latter is prescribed by the CEN in order to find a trade-off between signal amplitudes (decreasing when source-microphone distance increases) and time window length (and consequently low frequency limit):

$$h_{r,k}(t) = h_{o,k}(t) - h_i(t),\; k = 1...9 \tag{1}$$

Parasitic reflections are then cancelled out by time windowing: shape, length and placement of the window can influence results. The so-called “Adrienne” window $w(t)$ has been created to achieve a good time resolution and, at the same time, avoid as much as possible leakage effects in the frequency domain (see fig. 2a).

$$\begin{aligned} h'_{r,k}(t) &= h_{r,k}(t)\cdot w_r(t),\; k = 1...9 \\ h'_i(t) &= h_i(t)\cdot w_i(t) \end{aligned} \tag{2}$$

where $w_r(t)$ and $w_i(t)$ are respectively the reflected and direct component windows.

As far as the window length, it can be verified that prescriptions are correct for noise barriers at least 4 m high (neglecting diffusion from lateral edges). Indeed, in case of smaller heights, parasitic reflections are likely to be included within the time window for the reflected impulse response, consequently overestimating the Reflection Index. Therefore, the difference between barrier reflection at normal incidence and ground reflection arrival times was used to evaluate the window length when the sample was less than 4 m high (see fig. 1 on the right). The minimum length used in the following calculations was 5.2 ms, corresponding to an estimated low frequency limit of 240 Hz.

The direct component window $w_i(t)$ has to be placed so as its flat portion begins 0,2 ms before the direct component peak; as far as the reflected component window beginning, the time delay $\tau = 2d_M / c$ is added to this time instant. The reflected component window must be stopped before the first parasitic reflection occurs: it was considered to come from the ground, as no other parasitic reflections (i.e. from guard-rails) within the OIRs could be clearly distinguished.

Having isolated direct and reflected components according to (2), a signal amplitude correction for geometrical spreading is needed: with the assumption of spherical propagation, this can be carried out by time multiplication of the signals.

This is easier than using a geometrical correction factor directly in the frequency domain, as suggested in ISO 13472-1 [5], when dealing with oblique incidence:

$$h''_{r,k}(t) = h'_{r,k}(t) \cdot t,\ k = 1...9$$
$$h''_i(t) = h'_i(t) \cdot t \tag{3}$$

Finally, third-octave band power spectra have to be calculated from the windowed, corrected signals. Reflection Index can be regarded as a global sound power reflection coefficient, as it is evaluated through an area-average procedure:

$$H_{r,k}(f) = \Im\left[h''_{r,k}(t)\right] = \int_{-\infty}^{+\infty} h''_{r,k}(t) e^{-i2\pi ft} dt,\ k = 1...9$$
$$H_i(f) = \Im\left[h''_i(t)\right] = \int_{-\infty}^{+\infty} h''_i(t) e^{-i2\pi ft} dt \tag{4}$$

$$RI_j = \frac{1}{n_j} \sum_{k=1}^{n_j} \frac{\int_{\Delta f_j} \left|H_{r,k}(f)\right|^2 df}{\int_{\Delta f_j} \left|H_i(f)\right|^2 df} \tag{5}$$

In formula (5), j is the index of the one-third octave band and $n_j \leq 9$ is the number of angles on which to calculate the average (depending on the band).

Reflection Index measurements have pointed out some limitations and drawbacks as limited reproducibility, dependence on various parameters (i.e. equipment geometry and characteristics), elaborated signal processing procedures, availability of a source with a flat frequency response in the desired range.

EXPERIMENTAL PROCEDURE AND RESULTS

A digital acquisition system was used to generate the source signal, record the microphone one and simultaneously perform the cross-correlation between them to obtain the impulse response. Commercial products have been chosen for some components of the measurement chain: 01dB Symphonie PC-based 2 channel front end, GRAS 40AR ½” condenser microphone and dBFA32 Real Time Frequency Analysis software. As far as the source, a custom one (CS, 10” woofer) was firstly built for preliminary measures following prescriptions in [1]. Then, a commercial, more stable apparatus was tested: 01dB Adrienne Package (AP, see fig. 3), equipped with a two-way coaxial speaker (Bouyer CP 2050). It is an integrated amplifier and its frequency-response is electronically flattened (± 3 dB in the 200-15000 Hz range). Impulse responses were recorded using order 16 MLS signal at 51200 Hz of sampling frequency with 64 averages. Matlab routines were written on purpose for all the post-processing procedures.

A measurement campaign was carried out aiming at examining sensitivity of the method to different parameters: source characteristics and type, barrier geometry and materials, post-processing techniques, specific problems related to oblique incidence. Three different samples (fig. 3) of actually installed noise barriers were tested: an old perforated metal barrier (sample B), a recently installed perforated metal-PMMA barrier (sample C), and a recently installed perforated metal-PMMA barrier, equipped with anti-diffraction device (sample D). Reflection Index for each of them was measured using the above mentioned equipments, during different sessions.

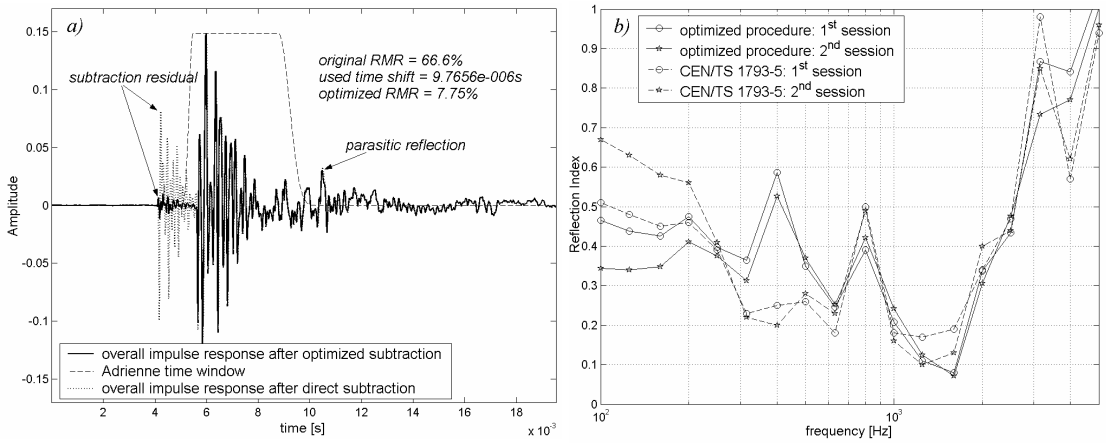

Fig. 2: subtraction residual effect. a) example of an OIR after subtraction. b) RI values obtained with the two procedures on sample D with AP source.

As far as the measurement procedure, subtraction residual influence was observed to be mostly significant. Misalignments of free-field and overall impulse responses can involve significant residuals in the reflected component: this obviously induces errors in the resulting calculations. Following suggestions by De Geetere *et al.* [6] and Morgan *et al.* [7], impulse response interpolation through zero-padding and time shifting in the frequency domain were performed to minimize subtraction residual amplitude: the relative magnitude of residual (RMR, as defined in [7]) was evaluated for each overall impulse response. In fig. 2b, optimization effects are shown: RI measurements seem to be more repeatable (solid lines), but wide oscillations still appear. By the way, it was rarely possible to obtain very low RMR values, particularly at oblique incidence: indeed, direct components of OIRs and FFIRs were actually different in shape and not just time-shifted because of changes in air temperature and source-microphone distance. More stable and lower subtraction residuals were obtained with the one-way source CS: it has been supposed that a two-way speaker impulse response needs higher sampling frequency, as it shows sharper peaks (see fig. 3). However, the chosen acquisition system can not support sampling over 51.2 kHz.

In the frequency domain, subtraction residuals seem to have higher high-frequency content with respect to the reflected spectrum, at least for the AP source.

Moreover, as previously noticed by other Authors, the reflected spectrum shows amplitude oscillations, as a “comb filter”, which are even amplified after the amplitude correction.

Fig. 3: the three noise barriers tested “in situ” (from left to right, sample B, C and D). On the right, 01dB Adrienne Package is shown.

Source characteristics’ influence on results is shown in fig. 4a. RI was evaluated for sample B using the two sources. FFIRs were recorded for AP both positioning horizontally and vertically the speaker axis. Repeatability is very good above 400 Hz for measurements with the commercial apparatus (low frequency limit was around 300 Hz in this case, according to [1]). On the other side, an indication of reproducibility is given from results obtained with the two sources: AP showed a flatter frequency response than CS in the useful range (100-5000 Hz), but, as mentioned, subtraction residuals are lower with the latter. It is not straightforward to follow the Technical Specification as to the sound source: repeatability gets worse with the one-way source, probably because of lower S/N ratios.

In fig. 4b amplitude correction method and equipment height effects are shown. As to the first, time multiplication and geometrical correction have been applied, to be comparable, to measurements at normal incidence in front of a very reflective wide brick wall. The two methods are not strictly equivalent: in particular, geometrical correction seems to give higher results. The equipment height affects window length, as mentioned, and therefore low frequency limit: this implies a poorer reproducibility in a rather wide frequency range (below 600 Hz).

Fig. 5 shows RIs averaged for the three samples, evaluated with the described optimized procedure. All of them have large oscillations, though showing a generally expected behaviour: indeed, single-number ratings of sound reflection for the three samples were $DL_{RI,B}$ = 4.8 dB, $DL_{RI,C}$ = 0.5 dB, $DL_{RI,D}$ = 4.9 dB. Very low values are typical of reflective barriers, as sample C; sample B and D, on the other side, show similar performance Even if subtraction residual can deeply affect amplitude of such oscillations, it seems not feasible to get completely rid of them.

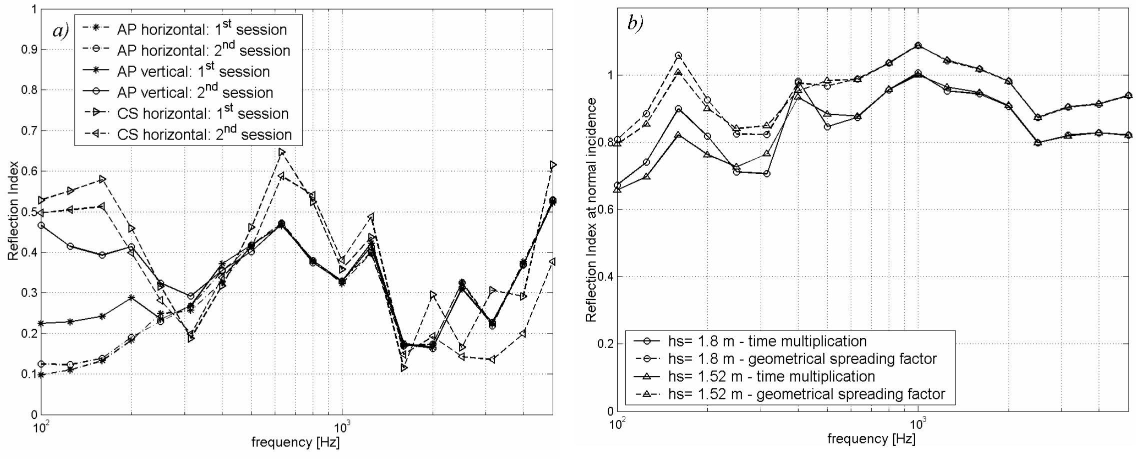

Fig. 4: a) Sound source influence and method's repeatability (measurements on sample B). b) Amplitude correction and equipment height effects (measurements at normal incidence on a wide brick wall).

Another reason could be found in the presence of reflective surfaces (i.e. guard-rails) within the sampled area: even if such area should be free of surfaces other than the barrier itself, an actual *in situ* measurement cannot often avoid it, as in the present application. A technical specification on *in situ* measurements should foresee and face these kinds of problems.

CONCLUSIONS

An *in situ* method described in the recently issued CEN/TS 1793-5 has been studied as an attractive technique to characterize noise reducing devices. Anyway, when using it for product qualification and design optimization, it should fulfil different requirements to be effective: repeatability, reproducibility and physical significance are some of them. At this stage of development, these goals have shown to be only achievable at the expense of using procedures of increasing complexity, thus compromising *in situ* measurement usefulness.

An optimized procedure has been characterized, focusing on some steps of Technical specification: source choice, equipment geometry, subtraction technique, time windowing and signal amplitude correction. This way, RI results are likely to be more consistent to the physical phenomenon of sound propagation around a noise barrier in actual operating conditions. An extended experimental campaign has to be carried out to verify such optimized procedure, looking at different materials and shapes. Nevertheless, a deeper theoretical investigation is needed to compare experimental results with model-based indications, so as to confirm whole method's reliability.

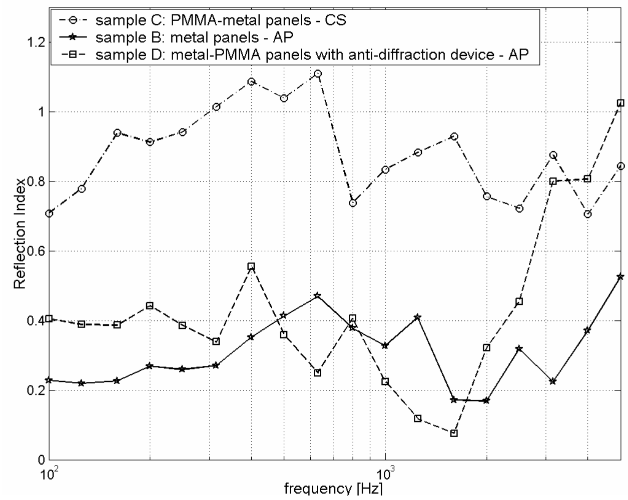

Fig. 5: average RIs of the three samples evaluated with optimized procedure.

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