On the acoustic efficiency of road barriers: The Reflection Index

Lamberto Tronchin

***Abstract*—** The transportation noise caused by roads and railways is often considered mostly the main cause of noise pollution in urban environment. In order to limit this annoyance, many barriers are realized in several different configurations. These barriers can be characterized by two indices: the reflection index for sound reflection and the insulation index for airborne sound insulation. Both of them can be measured following the method described in CEN/TS 1793-5 standard, based on impulse response measurements employing a pressure microphone. The method mandates for averaging results of measurements taken in different points in front of the device under test and/or for specific angles of incidence, employing the obsolete MLS signal for performing the measurements, which can cause severe artifacts due to nonlinearity and time-variance of the system. Furthermore, the CEN/TS 1793-5 standard presents some geometric problems, which could arise if the barrier does not reach a minimum height or if it has a very rough (scattering) surface. During the reflection index measurement on a barrier of limited height, the reflected sound can be contaminated by the ground reflection, compromising the fairness of the whole result. Also the insulation index can be affected by the height of the noise barrier, since the sound passing above the device under test can become mixed with the sound passing through it. It has been noticed how these practical problems, jointly with the assumption of a surface reflecting specularly in the final formula, can significantly over/under estimate the laboratory values of both the indices. Results of in situ tests based on CEN/TS 1793-5 will be shown in comparison with results obtained through a different approach, based on sound intensity measurements, and with the traditional tests performed in the lab.

***Keywords*—** Reflection Index; Noise barriers; DSP developments; Acoustic measurements; uncertainties.

I. Introduction

THE control of vehicles traffic flow in an urban environment is of a fundamental importance in the framework of the development of infrastructures in new residential and/or industrial zone of a growing city. If one wants to control the environmental impact of the new constructions, many physical polluting agents should be taken into account, such as noise and air pollution. As pointed by other researchers, very often the noise problem is not well considered in the design of a new infrastructure, since only in the late years, most of the European countries are issuing a formal reference regulation on the noise control matter [1-4]. Moreover, the noise problem is not felt very important for human health with respect, for example, to air pollution or electromagnetic fields. This is probably due to a low perception of the risk and of the possible damages of noise, especially before the problem occurs, i.e. before the noise source is operating.

The realization of noise barriers allows a reduction of noise perception at several receivers in the urban context, and a considerably enhancement of the quality of the life. However, the effectiveness of noise barriers is only recently standardized and could be evaluated by means of objective measurements, as described in the CEN/TS 1793-5 standard.

In this article, this procedure is analyzed and applied to two different road barriers. The experimental data are evaluated and commented with respect to the technical instrumentation that is required by the aforementioned standard.

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II. The CEN/TS 1793-5 standard

THE CEN/TS 1793-5 standard describes a way to calculate two indices, reflection index and sound insulation index, used to characterize barriers employed for rail and road traffic noise reduction. The standard aims to measure the “intrinsic” acoustic characteristics of the barriers, i.e. the physical effectiveness of them, without respect to the environment conditions (other noise sources, effect of diffraction of other buildings, ground effects, air temperature and humidity, etc.). For both the indices the method mandates for averaging results of measurements taken in different points in front of the device under test (sound insulation index) and/or for specific angles of incidence (reflection index). These indices are computed in one-third octave frequency bands; they describe how much the device under test reflects a sound wave back towards the source and how much the device under test attenuates a sound wave passing through (not above) the barrier.

III. The Reflection index

The reflection index aims to determine the sound absorption of the barrier. Instead of measuring the absorption, the standard requires to experimentally measure this acoustic parameter. The Equation (1) shows how to obtain the reflection index R_I for every one-third octave frequency band under test:

$$RI_j = \frac{1}{n_j} \cdot \sum_{k=1}^{n_j} \frac{\int_{\Delta f_j} \left| F\left[t \cdot h_{r,k}(t) \cdot w_r(t) \right] \right|^2 \cdot df}{\int_{\Delta f_j} \left| F\left[t \cdot h_i(t) \cdot w_i(t) \right] \right|^2 \cdot df} \tag{1}$$

where:

j is the index of the one-third octave frequency bands (100 Hz to 5 kHz);

$\boldsymbol{n_j}$ is the number of angles to average, which is frequency-dependent, as shown in Table 1;

$\boldsymbol{f_j}$ is the width of the *j*-th one-third octave frequency band;

F is the symbol of the Fourier transform;

t is the time counted since the instant when the pulse was emitted by the sound source;

$\boldsymbol{h_{r,k}(t)}$ is the reflected component of the impulse response at the *k*-th angle;

$\boldsymbol{w_r(t)}$ is the time window applied to the reflected component (i.e. the Adrienne window);

$\boldsymbol{h_i(t)}$ is the incident reference component of the free-field impulse response;

$\boldsymbol{w_i(t)}$ is the time window applied to the incident reference free-field component (Adrienne window).

Once the reflection index for all the bands has been calculated, it is possible to obtain a single value, expressed in dB(A), to characterize the road traffic noise reduction barrier in its totality. This is called DL_{RI} and it is defined as:

$$DL_{RI} = -10 \cdot \log_{10} \left[\frac{\sum_{i=m}^{18} \left(RI_i \cdot 10^{0.1 \cdot L_i} \right)}{\sum_{i=m}^{18} \left(10^{0.1 \cdot L_i} \right)} \right] \tag{2}$$

where:

m = 4 (number of the 200 Hz one-third octave frequency band);

$\boldsymbol{L_i}$ Relative A-weighted sound pressure levels (dB) of the normalized traffic noise spectrum, as defined in EN 1793-3, in the *i*-th one-third octave band.

Before using (1) and then (2) it is necessary to measure $\boldsymbol{h_i(t)}$ and all the $\boldsymbol{h_{r,k}(t)}$. The CEN/TS 1793-5 standard requires employing measurement equipment as sketched in Figure 1.

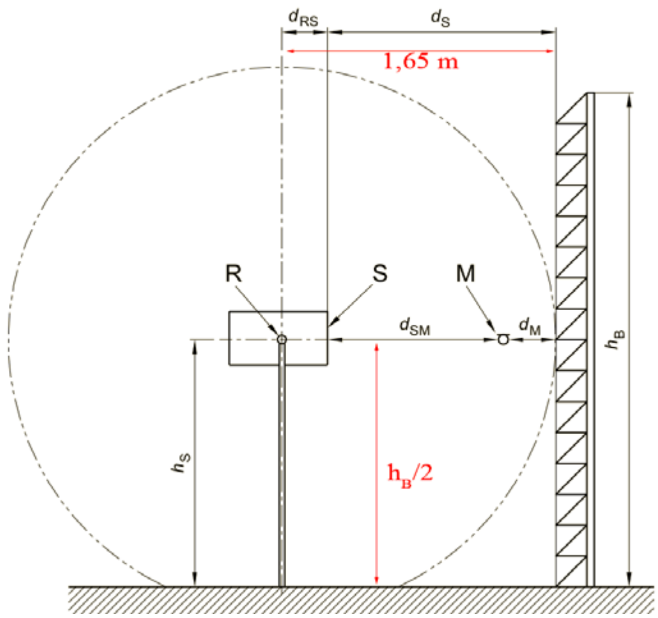

Figure 1. – Sound Reflection geometrical layout according to CEN/TS 1793/5

The equipment is composed of a single-way loudspeaker, a pressure microphone attached to the loudspeaker's case and a stand to hold them up. The stand shall rotate both in the vertical plane and in the horizontal plane (it depends on the barrier's height and width features) and shall be as high as half the barrier.

Due to the wavelength for each frequency, the standard requires to consider low frequencies (from 100 to 200 Hz) only for perpendicular measurements (i.e. 90 degrees), and only starting from 500 Hz all the angles could be considered in the formulas (1) and (2). More specifically, table n.1 contains all the angle relationships for each frequency.

Table 1. Frequency Band - angle relationship

f (Hz)	50°	60°	70°	80°	90°	100°	110°	120°	130°
100					X				
125					X				
160					X				
200					X				
250				X	X	X			
315		X	X	X	X	X	X	X	
400		X	X	X	X	X	X	X	
500	X	X	X	X	X	X	X	X	X
630	X	X	X	X	X	X	X	X	X
800	X	X	X	X	X	X	X	X	X
1000	X	X	X	X	X	X	X	X	X
1250	X	X	X	X	X	X	X	X	X
1600	X	X	X	X	X	X	X	X	X
2000	X	X	X	X	X	X	X	X	X
2500	X	X	X	X	X	X	X	X	X
3150	X	X	X	X	X	X	X	X	X
4000	X	X	X	X	X	X	X	X	X
5000	X	X	X	X	X	X	X	X	X

As mentioned above, the post processing of the impulse responses requires a new time-windows called Adrienne, as sketched in figure 2. In the left side of the windows it is necessary to employ half a Blackman-Harris window 1 ms long, whereas on the right side the half side of the Blackman-Harris must be 4.44 ms long.

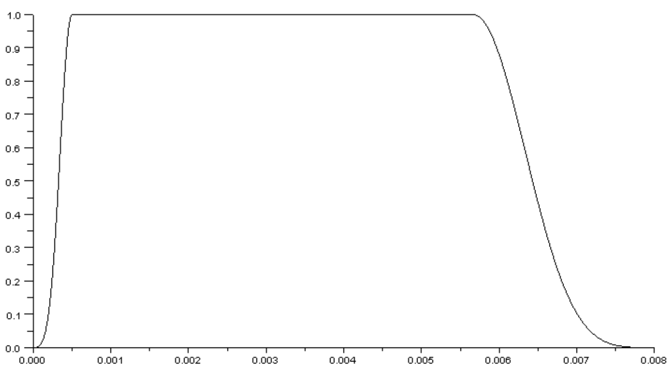

Figure 2. Adrienne window

Globally, the Adrienne windows is 7.9 ms long ($T_{W,ADR}$ = 7.9 ms), whereas the Blackman-Harris windows has four different components. In other words, $T_{W,BH}$ is the following (3):

$$w(t) := a_0 - a_1 \cos\left(\frac{2\pi t}{T_{W,BH}}\right) + a_2 \cos\left(\frac{4\pi t}{T_{W,BH}}\right) - a_3 \cos\left(\frac{6\pi t}{T_{W,BH}}\right) \quad (3)$$

where each constant is determined as following:

$$\left.\begin{array}{l} a_0 = 0.35875; \\ a_1 = 0.48829; \\ a_2 = 0.14128; \\ a_3 = 0.01168; \end{array}\right\rangle 0 \le t \le T_{W,BH} \quad (4)$$

As said before, $\boldsymbol{h_i(t)}$ is the incident impulse response in free-field condition. It is obtained by measuring the impulse response of the system when it doesn't point to the barrier, e.g. it faces the sky. $\boldsymbol{h_{r,k}(t)}$ is the reflection component of the impulse response when the measurement equipment points the barrier with the *k*-th incidence angle. $\boldsymbol{h_{r,k}(t)}$ is obtained subtracting the free-field impulse response from the measured *k*-th angle impulse response, which contains information about the direct and the reflected path: as the microphone is bonded to loudspeaker's case both the free-field and the *k*-th angle impulse response will contain the same incident component, so it can be cancelled by subtraction of the two waveforms.

The CEN/TS 1793-5 standard suggests to measure the impulse responses employing the Maximum Length Sequence (MLS) signal, although the Exponential Sine Sweep (ESS) signal could have been a better choice, thanks to its immunity to system's nonlinearities and time-variance [5-12].

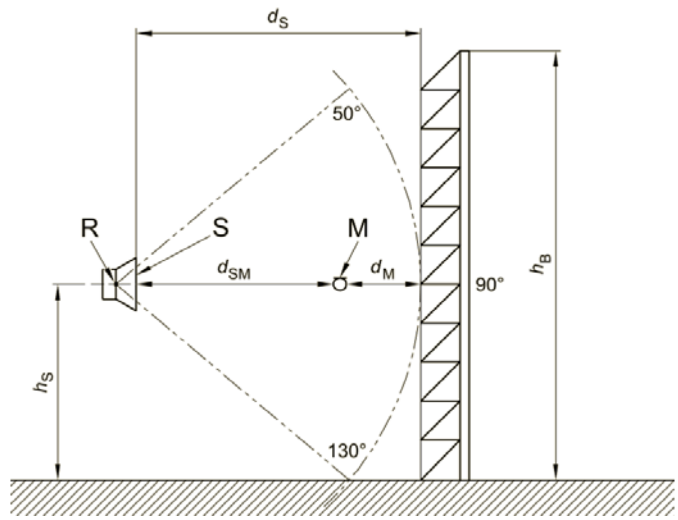

Figure 1. Vertical rotation of the measurement equipment according to CEN/TS 1793/5

It is well known how system's nonlinearities cause the appearance of spurious peaks in the impulse responses measured with the MLS method. Furthermore, time variance can significantly reduce the high-frequency contents of the measured impulse response, if synchronous averaging is employed, as it is common and recommended in the standard, for improving the Signal-to-Noise ratio when working with MLS [8-12].

Generally speaking, MLS is a method only suitable for laboratory measurements under controlled conditions; it should never be employed outdoors, for in-situ measurements. However, a careful usage of the MLS signal makes it possible to get impulse responses which are reasonably artifact-free, at least for the segments inside the time windows required for the processing. And the CEN/TS 1793-5 standard allows for usage of methods different from MLS, so in this work the ESS method was preferred.

After having measured the impulse response, it becomes necessary to apply the time-windowing to the initial part of the impulse response. The two functions $\boldsymbol{w_i(t)}$ and $\boldsymbol{w_r(t)}$ represent an analytically-defined window (Adrienne window) that has to be applied respectively to $\boldsymbol{h_i(t)}$ and $\boldsymbol{h_{r,k}(t)}$. The CEN/TS 1793-5 standard provides a well-documented way to do that.

The running time $\boldsymbol{t}$ is used to compensate for the linear attenuation of the amplitude due to the increasing travel path. Its origin is at the beginning of the impulse response acquired by the measurement chain: if $\boldsymbol{d_{sm}}$ represents the distance between the front panel of the loudspeaker and the microphone and $\boldsymbol{c}$ is the speed of sound, the zero-value of $\boldsymbol{t}$ is located $\boldsymbol{d_{sm}/c}$ seconds before the first peak of the impulse response.

IV. Operative problems

A. Minimum height for R_I Index

The CEN/TS 1793-5 places some constraints which should be met to properly employ the described experimental method for RI index measurements: width and height of the barrier, in particular, should reach some specific minimum values.

Figure 4 shows how to define the minimum theoretical barrier height which maintains enough delay for the sound wave reflected from the ground, avoiding that its time-of-arrival becomes too close to the time-of-arrival of the sound reflected from the barrier.

As shown in figure 4, when the microphone is maximally angled towards the ground (with an aiming angle of 40 degrees below horizontal, i.e. $\alpha = 130°$), it receives three wave-fronts: the direct sound from the loudspeaker (source S), the reflected sound from the barrier (image source S') and the reflected sound from the ground (image source S'').

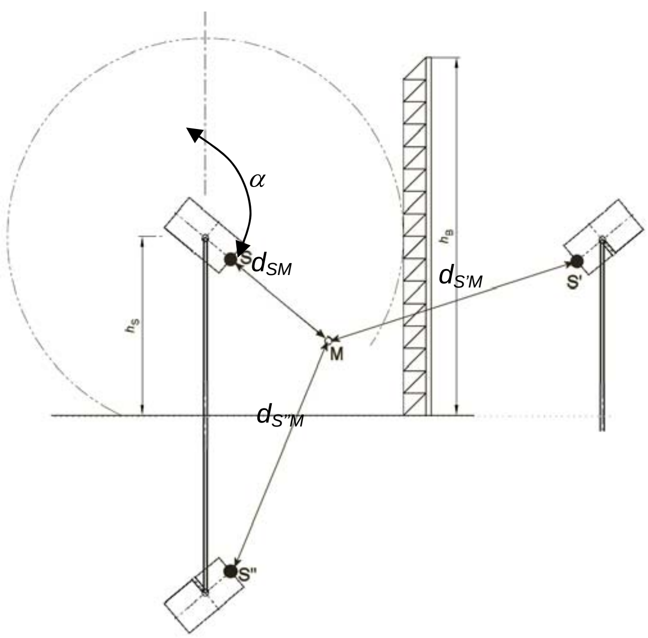

Figure 4 – Mirror images sources

By simple trigonometric calculations it is possible to obtain the three time-of-arrivals (formula 5):

$$
\begin{aligned}
t_o &= \frac{d_{SM}}{c} \\
t_b &= \frac{d_{S'M}}{c} = \frac{\sqrt{[d_{SM} \cdot cos(\alpha)]^2 + [2 \cdot (d_{SM} + d_M) - d_{SM} \cdot sin(\alpha)]^2}}{c} \\
t_g &= \frac{d_{S''M}}{c} = \frac{\sqrt{[d_{SM} \cdot sin(\alpha)]^2 + [h_b + d_{SM} \cdot cos(\alpha)]^2}}{c}
\end{aligned}
\tag{5}
$$

These formulas could provide a realistic estimate of the time-of-flight of the three signals. Indeed, these formulas *do not* correspond to the indication found at point 4.4.6 of the CEN/TS 1793-5 standard, which instead suggest as the time-of-flight for the sound reflected from the barrier, the following expression:

$$t_b = \frac{d_{S'M}}{c} = \frac{d_{SM} + 2 \cdot d \cdot M}{c} \tag{6}$$

which is correct only in case of $\alpha = 90°$. If now we assume that:

$$\boldsymbol{d_{SM}} = 1.25\text{m} \; ; \; \boldsymbol{d_M} = 0.25\text{m} \; ; \; \alpha = 130° \tag{7}$$

we can find the minimum height of the barrier for which the delay between the sound reflected from the ground and the sound reflected from the barrier is equal or greater than 7.2 ms (the remaining length of the Adrienne window located after the nominal point of arrival of the sound reflected from the barrier):

$$h_b \geq 5.35 \text{ m} \tag{8}$$

A simple geometrical construction shows that the ground reflection always arrives before the sound diffracted by the upper free edge of the screen, and thus, if the condition (8) is met, the measurement is correct at every angle.

The CEN/TS 1793-5 mandates for a minimum width and height of 4 meters for the acoustic element, which is clearly not enough for ensuring to get impulse responses not contaminated from the ground reflection. The standard recommends employing horizontal rotation, instead of vertical rotation, for samples having limited height and conspicuous wideness and distance between posts. However it is common to find barriers having height smaller than 5.35 m, and with distance between posts even smaller (typically 3.00 m), as reported in the paragraph 5: in these cases it is not possible to avoid contamination by the ground reflection if the vertical rotation is chosen, but it isn't either possible to avoid contamination from post's reflection if the horizontal rotation is chosen.

Due to these limitations, in most cases the CEN/TS 1793-5 is not applicable: but the standard does not explicitly declare these geometrical constraints, and it does not suggest an alternative measurement method when these constraints are not verified. As a consequence, wrong test reports can be obtained following the letter of the standard, with reference to the Sound Reflection Index.

B. Scattering surfaces

For RI index measurements, the computation formula (1) inherently assumes that the reflection is specular, and that the reflected sound appears to be originated from a sound source located in the "mirror image" position.

As a consequence, the amplitude of the reflected sound is "boosted" by multiplying it for the running time $\boldsymbol{t}$, which is perfectly correct for a specular reflection, as the sound diverges over a sphere which radius is equal to the path travelled, and hence is proportional to the time required for travelling such distance.

But, when the surface of the barrier is very rough, it behaves as a scattering surface. This means that every point of the

barrier becomes a secondary source of uncorrelated noise, radiating a sound wave which attenuates following a much more complex law.
In order to compare the behavior of a specular surface with a completely-scattering surface, a simulation with the computer program Ramsete [13, 14] has been performed. Ramsete is a software normally utilized in room acoustic simulation, and could give very précis results in comparison with experimental data [14].
Figure 5 shows the geometry of the test case: it is a barrier having a height of 6 m, a length of 18 m, without posts, and thus not encountering any of the geometrical problems outlined in the previous paragraphs.
The sound source and the microphone are located in the standard positions for the normal-incidence test ($\alpha = 90°$).

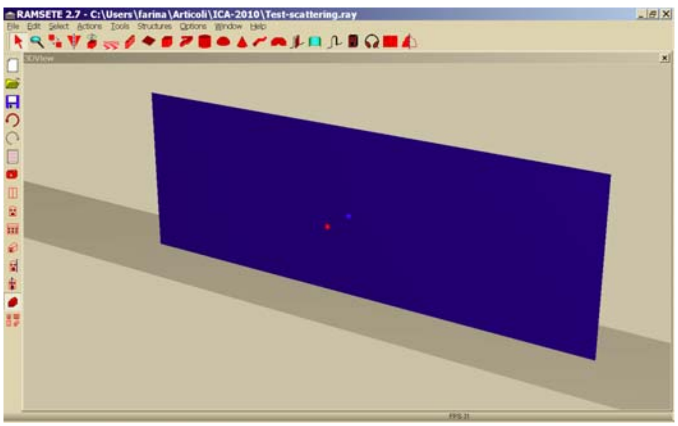

Figure 5. Geometry for the scattering test case

Figure 6 shows the computed impulse responses for the case of a completely reflecting surface (RI = 1 at every frequency), and considering the surface perfectly specular (scattering coefficient s = 0) and perfectly diffusive (scattering coefficient s = 1).

Applying eq. (1) at the results of these two simulations, the following values of RI are found:

Table 2: R_I for specular or scattering surfaces

Reflection Index 100% specular Barrier	1.000
Reflection Index 100% scattering Barrier	3.067

In the case of the scattering barrier, the result is clearly wrong. Multiplying by ***t*** the amplitude of randomly-scattered sound over-corrects the late arrivals [15, 16].

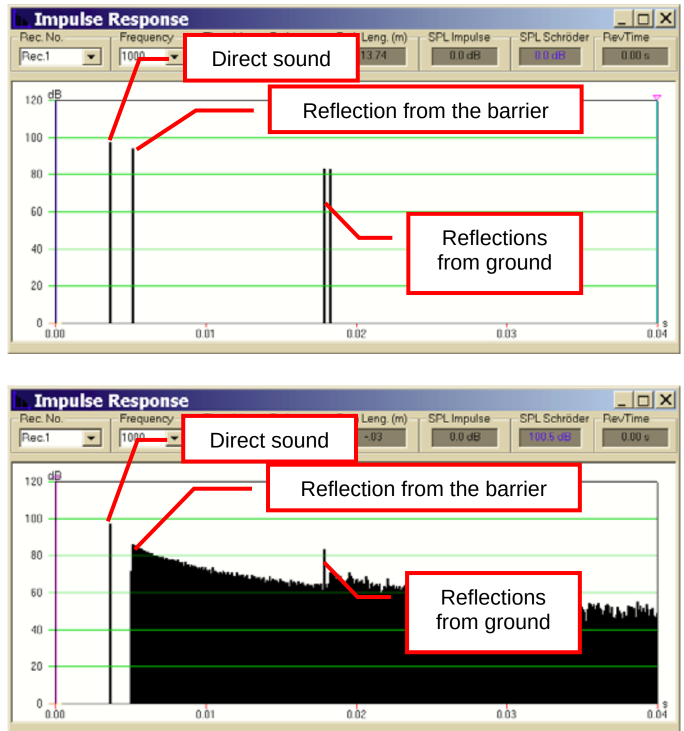

Figure 6. Impulse Responses computed by Ramsete

If one could integrate all the reflected energy for an infinite time, in front of an infinite scattering surface, one would find that the total reflected energy is exactly equal to the incident energy, as the surface is not absorbing any energy, therefore the total energy flux going towards the surface should come back.
However, due to the limited length of the Adrienne window, only the energy reflected by a portion of the scattering surface is being integrated. Let's call K the factor, lesser than 1, expressing the ratio between the energy reflected by this portion of the surface and the total reflected energy (which is equal to the total incident energy, as our surface has no absorption).
Considering that the Adrienne window limits the energy integration to a time interval approximately long 5.4 ms after the beginning of the reflected energy, in the case of the normal incidence measurement the value of the factor K is equal, approximately, to 0.93262.
The value of the reflection index RI could be computed making the ratio between the energy reflected by the measured surface and the energy which would be reflected by an ideal surface having a reflection index =1.

$$RI_j = \frac{\int_{\Delta f_j} \left|F\left[h_r(t)\cdot w_r(t)\right]\right|^2 \cdot df}{K \cdot \int_{\Delta f_j} \left|F\left[h_i(t)\cdot w_i(t)\right]\right|^2 \cdot df} \qquad (9)$$

Applying the above formula (9) to the results of the numerical simulation visible in Figure 6, an almost correct value for RI is found:

$$RI_{scattering} = 0.99958 \qquad (10)$$

Of course, in case of measurements at 9 incidence angles, 9 different values for the factor K should be used. Thus, the complete formula for computing RI of a scattering surface is:

$$RI_j = \frac{1}{n_j} \cdot \sum_{k=1}^{n_j} \frac{\int_{\Delta f_j} \left| F\left[h_{r,k}(t) \cdot w_r(t)\right] \right|^2 \cdot df}{K_k \cdot \int_{\Delta f_j} \left| F\left[h_i(t) \cdot w_i(t)\right] \right|^2 \cdot df} \tag{11}$$

This means that the usage of eq. 1 yields completely wrong results for a 100% scattering surface, and instead eq. (11) should be used.

However, a typical rough noise barrier will not be 100% scattering, nor 100% specular: at different frequencies, the barrier will exhibit a variable scattering coefficient, ranging between 0 and 100%. And, as the value of the scattering coefficient is not known, it is impossible to establish what percentage of the reflected energy is specular, and what percentage is scattered.

We conclude therefore that the whole procedure cannot work for measuring RI of a partially-scattering rough surface.

V. Experimental measurements

The techniques described by the CEN/TS standard was utilized to determine the reflection characteristics of two road barriers located at “Grande Viabilità Triestina” between Cattinara and Patriciano (Trieste, Italy), on the highway toward the Slovenian border.

Barrier “A” is made by metallic panels; it has a height of 5 meters and a thickness of 0.20 meters.

Barrier “B” is made by wood; it is 2 meters tall and 0.12 meter thick.

The first barrier is a common typology, utilized in several contexts, since it is a relatively cheap barrier that could reach up to 8 meter of height. The second barrier is a rather common barrier in urban context, because it is made of wood and it has a relatively low urban impact in the area. On the other hand, this typology of barrier is more expensive than the first one, and could reach not more than 4 meters height. An image for each of the road barriers is reported in figures 7 and 8.

In order to calculate the Reflection index, a specific loudspeaker was chosen, accordingly to the requirements reported in the CEN/TS standard. The microphone was located in front of the barrier as described previously, and rotated accordingly to the CEN/TS 1793-5.

The measurements if the impulse responses were performed both using the MLS signal as specifically requested by the standard, and the ESS signal that avoids contaminating the initial component of the IRs with the distortion components that are due to nonlinearity in the loudspeaker and the microphone.

Figure 7 Steel and PMMA barrier

Figure 8 Wooden barrier

Afterwards, a specific tool was afterward developed in Scilab environment [17-18], in order to filter in time domain the IRs following the Adrienne window, and to calculate from the measured IRs the Reflection index for both the road barriers.

Both the barriers were compared with the laboratory measurements. The figure 9 and 10 reports the experimental in-situ values for the two barriers.

Considering the results of the measurements, the metal and PMMA barrier showed a more uniform distribution of the absorption for all the frequencies; on the other hand, the wooden barrier resulted with high values of RI at low and high frequencies.

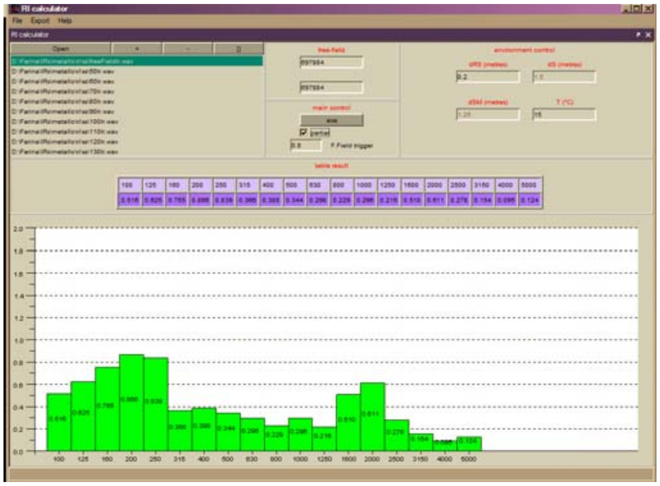

Figure 9 - Steel and PMMA barrier - Reflection Index - $DL_{RI} = 4.52 \quad [dB]$

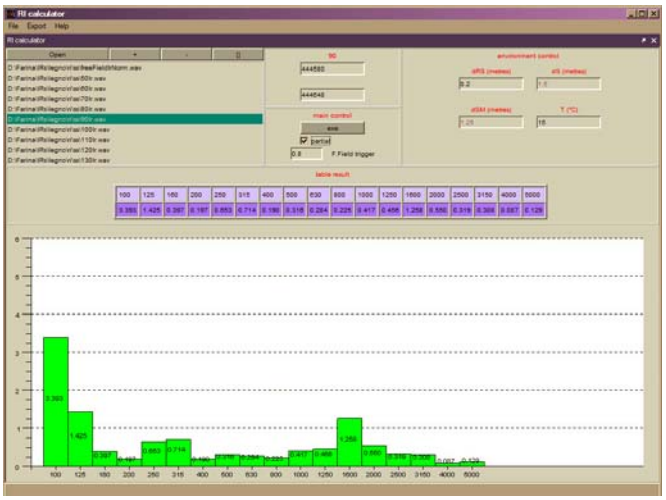

Figure 10 - Wooden barrier - Reflection Index - $DL_{RI} = 3.41 \quad [dB]$

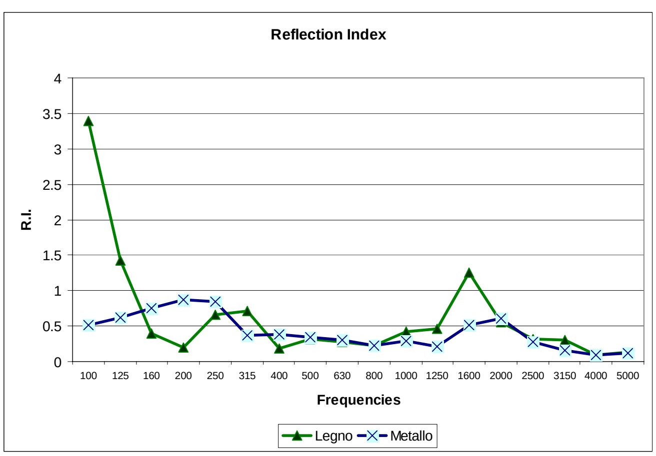

Figure 11 - Reflection Index RI for the two barriers - comparison

In order to properly evaluate the intrinsic characteristics of the road barriers, it is important to note that they could also act as a sound source, since the noise emission of cars and trucks could provoke a vibration of several components that could result as a noise source. This phenomenon is typically found especially in the metal barriers and PMMA barriers, which could strongly vibrate during the transit of heavy trucks, as normally happen on the highways. For these reasons further experimental measurements are planned, in order to determine the value of the Intensity of Acoustic Radiation (IAR) of the barriers [19, 20], and relate RI with IAR. The Intensity of Acoustic Radiation could be easily determine the relation between vibration of metallic (or PMMA) surfaces with sound emission.

VI. Sound Intensity Measurements

It has been shown how results obtained using CEN/TS 1793-5 for sound reflection tend to underestimate the barrier performance: in general, lab results are not comparable with "in situ" results and the final classification of the device can be very different.
An alternative measurement method, making use of Sound Intensity, has been attempted, based on the theoretical formulation presented in [18].
This method has been applied to the measurement of the absorptive/reflective properties of a third type of barrier (namely, barrier "C"), made of concrete and expanded clay, which is shown in the following figure 12.

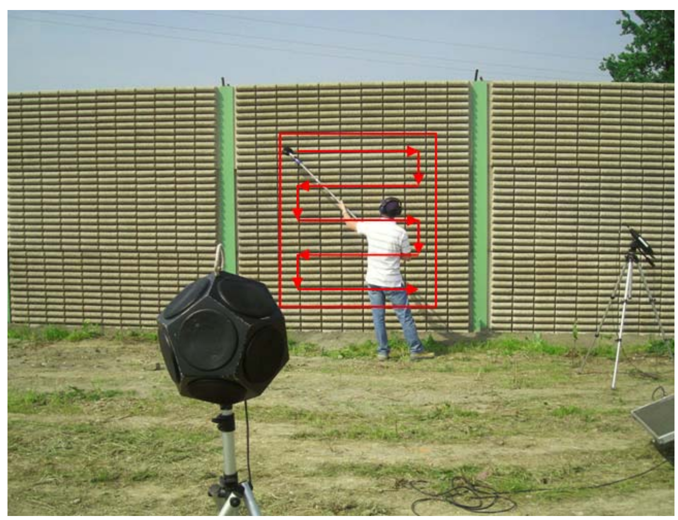

Figure 12. Sound Intensity measurement (manual sweep) of barrier "C"

Two "scanning" measurements are performed moving the Sound Intensity probe very close to the barrier surface, and keeping a minimum distance from ground, barrier's top edge and posts. The loudspeaker radiates pink noise, and the averaging lasts for a couple of minutes, so the measurement is very fast.
The Sound Intensity analyser measures three physical quantities: Active Intensity (AI), Sound Pressure (SP), and

Particle Velocity (PV). From the latter two, a derived quantity, the Energy Density (ED) is found:

$$ED = \frac{1}{2} \cdot \left[\rho \cdot PV^2 + \frac{SP^2}{\rho \cdot c^2} \right] \tag{12}$$

The reflection coefficient r and the absorption coefficient α can finally be obtained by the ratio of AI and ED:

$$r = \frac{1 - \frac{AI}{ED \cdot c}}{1 + \frac{AI}{ED \cdot c}} \qquad \alpha = 1 - r \tag{13}$$

Figure 13 shows the comparison between the absorption coefficients α measured "in situ" by means of the sound intensity method, with the value measured in the laboratory according to ISO 354, and with the value computed back from the reflection index obtained by employing the CEN/TS 1793-5 method ($\alpha = 1 - RI$).

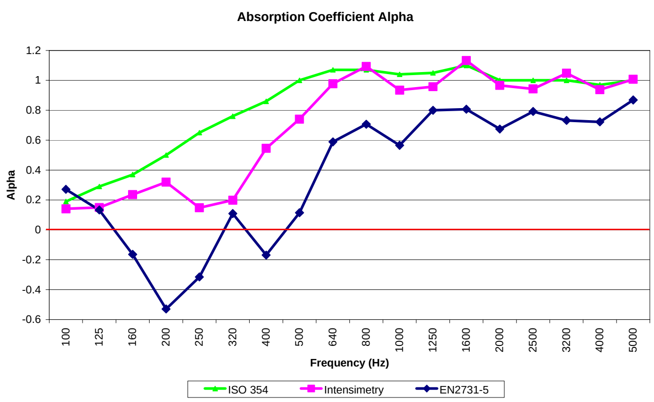

Figure 13. Sound Intensity measurement results (barrier "C") vs. ISO 354 and CEN/TS 1793/5

It can be seen how, at low-medium frequencies, the CEN/TS 1793-5 method provides completely wrong results, with values of Reflection Index greater than 1, and hence "negative" values of α.

Table 7 shows the single-number rating of this barrier based on the three measurement methods:

Table 7. Single-rating numbers comparison (reflection)

	DL_a Laboratory	DL_{RI} Intensimetry	DL_{RI} CEN/TS 1793/5
Barrier "C"	15.5 [dB]	8.6 [dB]	3.3 [dB]

Using the new Sound Intensity method, the measured data are more closely comparable with the laboratory test and therefore the final classification of the barrier will be in line with the manufacturer's declaration, proofing compliance of the tested sample with the minimum limits required.

The whole measurement procedure lasts less than 20 minutes, thus ensuring to get good time invariance of the system, and to be able to repeat the assessment of many samples in a single work day.

VII. Conclusions

The experiments here illustrated underline the difficulties on achieving good results compared with the laboratory data. The Reflection index results obtained by "in situ" method did show systematic underestimation of the effectiveness of the devices. The final single-rating number obtained for both barriers "A" and "B" is approximately 4 times lower than the laboratory value. It has been noticed how scattering surfaces effects and ground reflections could falsify the result. The scattering problem has been addressed and a new formula (11) has been proposed instead of (1). However it has been noticed how this new approach could not be used for "real world" barriers because of the lack of knowledge of the frequency dependent scattering coefficient: thus, this systematic error cannot be avoided.

As a consequence, it becomes necessary to review the CEN/TS 1793-5 standard. One possibility to improve the measurement method could be to add the intensimetric method to obtain the sound absorbing coefficient of the barriers, since the "in-situ" measurements are much closer to the laboratory measurements. This method could give much more realistic evaluation of the reflection index on barrier.

The measurement of Intensity of Acoustic Radiation could also improve the efficiency of the in-situ measurements, since the road barriers could become a noise source due to the vibration caused by the transit of heavy vehicles (as trucks). Moreover, the formulation of the RI index should consider also the scattering coefficient of the material, since this effect could considerably influence the efficiency of the barriers.

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