On the acoustic efficiency of road barriers. The Sound Insulation Index

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Abstract—

The noise caused by road and railway traffic is increasing every day and it is commonly considered the main cause of noise pollution in urban environment. In order to limit this annoyance, many different typologies of barriers are realized in several different configurations. Following the European standards, these barriers can be characterized by two indices, i.e.: 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 MLS signal for performing the measurements, which can cause severe artifacts due to nonlinearity and time-variance of the system, and is nowadays surclassed by other acoustic signals. 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. As demonstrated in a similar article, 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. On the other hand, 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 and with the traditional tests performed in the laboratory.

Keywords— Sound Insulation Index; Noise barriers; DSP developments; Acoustic measurements; uncertainties.

I. Introduction

THE pollution caused by 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, the procedure illustrated in the aforementioned European standard is analyzed and applied to two different road barriers. Whilst the Reflection Index was theoretically and experimentally analyzed in another article, this article will focus on the Sound Reflection Index, which is widely considered as the reference parameter for determining the efficiency of a road barrier.

The experimental data are evaluated and commented with respect to the technical instrumentation that is required by the aforementioned standard, and the acoustic signal that is expressly required by the standard to make the “in-situ” measurements.

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II. The CEN/TS 1793-5 standard

The road barriers could be described for two different characteristics. The first one is the extrinsic effectiveness of the road barriers. This parameter relates the physic dimension of the barrier (height, length, etc.) with the geometry of the location (height of the surrounding buildings, eventual absence or presence of trees, hills, valleys, etc.). The aim of this parameter is to measure the A-weighted sound pressure level at the position of the receivers, and therefore it could measure whether the road barriers fail or not to reduce considerably the road noise at the position of the receiver.

However, the extrinsic effectiveness could not provide a method to measure the intrinsic effectiveness of the barrier. The intrinsic effectiveness should measure the effectiveness of the barrier itself, without considering the environmental conditions, and it is necessary to verify the proper realization of the barrier and of the material utilized for the construction.

This means that the in-situ testing should consider only the intrinsic characteristics of the barrier.
In order to measure the intrinsic acoustic characteristics of road barrier, the European Union has adopted the CEN/TS 1793-5 standard. This standard describes a way to calculate two indices, i.e.: Reflection Index and Sound Insulation Index, used to characterize barriers employed for road traffic noise reduction. 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 Sound Insulation index

In order to properly measure the Sound Insulation Index, the aforementioned standard requires employing a specific sound source. The sound source must be realized using a loudspeaker having the following characteristics:

The loudspeaker must have only one driver;

The loudspeaker mustn’t have any door;

The loudspeaker mustn’t have any active component (e.g. (crossover filters);

The loudspeaker must have a uniform frequency response (from 100 Hz to 5 kHz);

The loudspeaker must have an Impulse Response shorter than 3 ms;

The dimensions of the loudspeaker must be within the following values: 0.40 m x 0.285 m x 0.285 m (length x wide x height).

The movement of the loudspeaker and of the microphone must be within an error of 1%.
The equation (1) shows how to obtain the sound insulation index SI for every one-third octave frequency band.

$$SI_j = -10 \cdot log_{10}\left\{\frac{\sum_{k=1}^{n}\left(\frac{d_k}{d_i}\right)^2 \cdot \int_{\Delta f_j}\left|F\left[h_{t,k}(t)\cdot w_{t,k}(t)\right]\right|^2 \cdot df}{n\cdot\int_{\Delta f_j}\left|F\left[h_i(t)\cdot w_i(t)\right]\right|^2\cdot df}\right\} \quad (1)$$

where:

- $\boldsymbol{n}$ = 9, is the number of scanning points;
- $\boldsymbol{f_j}$ is the width of the *j*-th one-third octave frequency band (between 100 Hz and 5 kHz);
- $\boldsymbol{F}$ is the symbol for the Fourier transform;
- $\boldsymbol{h_{t,k}(t)}$ is the transmitted component of the impulse response at the *k*-th scanning point;
- $\boldsymbol{w_{t,k}(t)}$ is the time window applied to the transmitted component (i.e. the Adrienne window, Figure 1);
- $\boldsymbol{d_k}$ is the geometrical spreading correction factor for the transmitted component at the *k*-th scanning point (Table 1);
- $\boldsymbol{d_i}$ is the geometrical spreading correction factor for the reference free-field component (Table 1);
- $\boldsymbol{h_i(t)}$ is the incident reference of the free-field impulse response;
- $\boldsymbol{w_i(t)}$ is the time window applied to the incident reference free-field component (Adrienne window).

Before using (1) and then (2) it is necessary to calculate $\boldsymbol{h_i(t)}$ and all the $\boldsymbol{h_{t,k}(t)}$. The standard CEN/TS 1793-5 suggests employing a measurement system sketched in Figure 2 and Figure 3. The equipment is composed of a loudspeaker and its own stand, a panel with 9 predefined positions in which a pressure microphone will be hosted and a stand for it, as depicted in Figure 3. Both the stands need to be as high as the half of the barrier.
The standard introduces the time domain Adrienne windows. 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. Globally, it 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 (2):

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

where each constant is determined as following:

$$\left.\begin{array}{l} a_0 = 0.35875; \\ a_1 = 0.48829; \\ a_2 = 0.14128; \\ a_3 = 0.01168; \end{array}\right\rangle 0 \le t \le T_{W,BH} \quad (3)$$

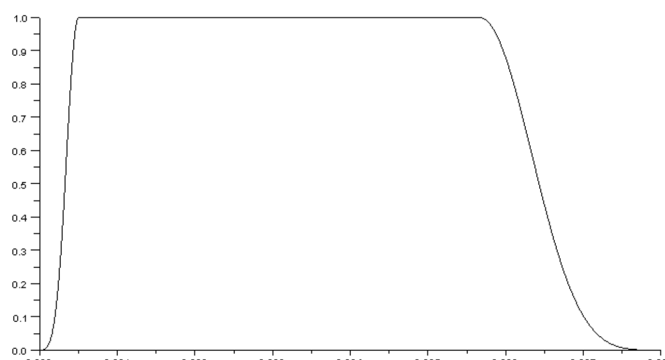

Figure 1. Adrienne window

Table 1 reports the geometrical spreading correction factor for the transmitted component at the *k*-th scanning point, and the geometrical spreading correction factor for the reference free-field component.

Table 1

d_1	$\sqrt{d_i^2 + 2 \cdot s^2}$ #
d_2	$\sqrt{d_i^2 + s^2}$ #
d_3	$\sqrt{d_i^2 + 2 \cdot s^2}$ #
d_4	$\sqrt{d_i^2 + s^2}$ #
d_5	$1.25+t_b$#
d_6	$\sqrt{d_i^2 + s^2}$ #
d_7	$1.25+t_b$#
d_8	$\sqrt{d_i^2 + s^2}$ #
d_9	$\sqrt{d_i^2 + 2 \cdot s^2}$ #
d_i	$1.25+t_b$#
s	*0.40 m*
t_b#	Barrier thickness (m)#

Once the sound insulation index for all the bands has been calculated, it is possible to obtain a single value, in dB(A), to characterize the road traffic noise reduction barrier in its totality:

$$DL_{SI} = -10 \cdot \log_{10} \left[\frac{\sum_{i=m}^{18} \left[10^{0.1 \cdot (L_i - SI_i)} \right]}{\sum_{i=m}^{18} \left(10^{0.1 \cdot L_i} \right)} \right] \tag{4}$$

where:

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

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.

Figure 3 shows how to position the equipment for the reference ***h_i(t)*** measurement: the loudspeaker is perfectly in line with the microphone, placed in the 5-th position of the panel of Figure e 2, at a well-defined distance d_t.

The standard requires to use the MLS signal to obtain the impulse response. However, this signal is now surclassed by the ESS signal, since it has been demonstrated that nonlinearity artifacts could contaminate the initial component of the impulse responses, which could cause the measurements to fail to determine the correct value that are necessary for the computation described in the aforementioned CEN Standard [5-12].

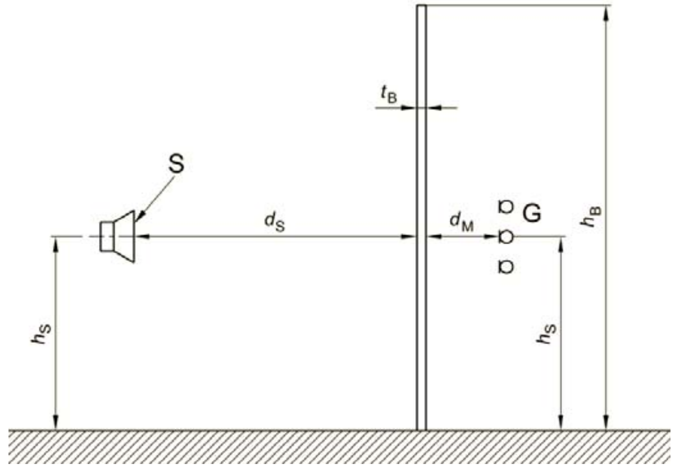

Figure 1 – Sound Insulation geometrical layout according to CEN/TS 1793/5

The terms $w_i(t)$ and $w_{t,k}(t)$ represent an analytically-defined window (Adrienne window) that has to be applied respectively to $h_i(t)$ and $h_{t,k}(t)$. CEN/TS 1793-5 standard provides a well-documented way to do that.

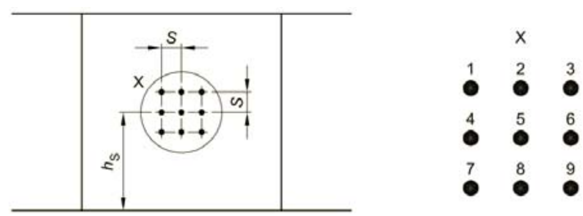

Figure 2 – Sound Insulation geometrical layout according to CEN/TS 1793/5

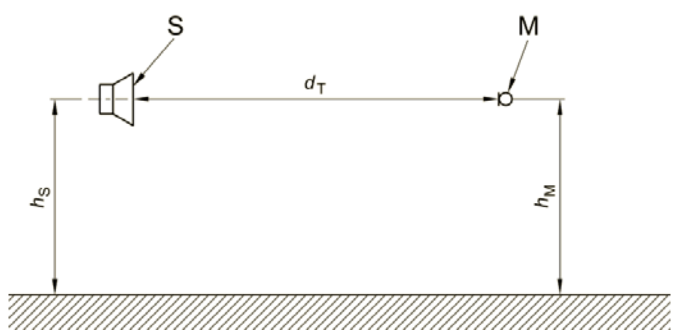

Figure 3 – Reference measurement according to CEN/TS 1793/5

It is necessary to replicate the whole SI procedure both in front of the element and in front of the post (if present). Whenever possible, two single-number rating shall be derived to indicate the performance of the product: one for elements and the other for posts.

The standard provides also information about how to measure Sound Insulation for not-plane barriers. In this case, it is necessary to evaluate the proper geometric conditions as depicted in the figure 4.

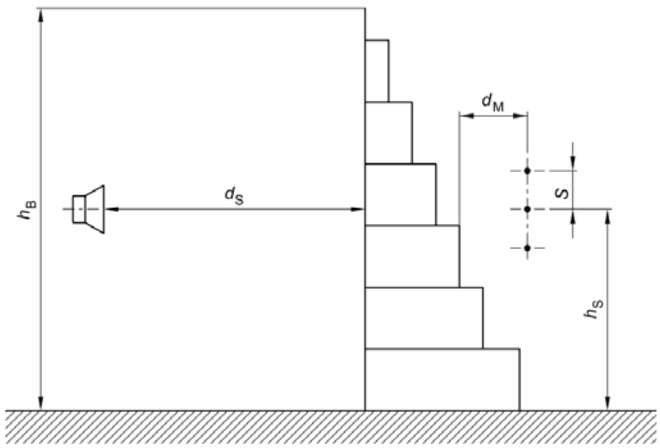

Figure 4 – Reference measurement for non-plane barriers, according to CEN/TS 1793/5

IV. Operative problems

A. Minimum height for S_I Index

In Sound Insulation Index, width and height of the barrier are very limiting factors. In the Sound Insulation Index formula (1), we see the component of the impulse response transmitted through the barrier in its numerator.

The measurements of the direct component of SI could depend on the ground diffraction and lateral scattering. The standard provides a graph which illustrates the frequency validity depending on the height of the barrier. Figure 5 report the relation between height and frequency limit. It could be observed that the minimum height for considering low frequencies (100 Hz) should be 5.5 meters.

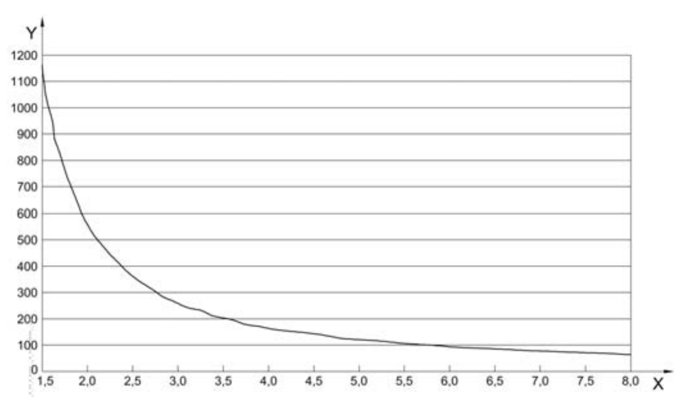

Figure 5 – Frequency limitation and height of the barriers, according to CEN/TS 1793/5

By properly placing the Adrienne window, in principle it should be possible to insulate that component. An impulse response, measured by the pressure microphone on the right stand, is composed by a direct component, a transmitted component, a diffracted component and by parasitic reflection; however, as it can be seen in Figure 6, separating these components can be difficult.

As both stands need to be placed at half the height of the barrier, if the barrier's height is too small, the diffracted component has not enough delay for the transmitted component to extinguish, before the arrival of the diffracted one.

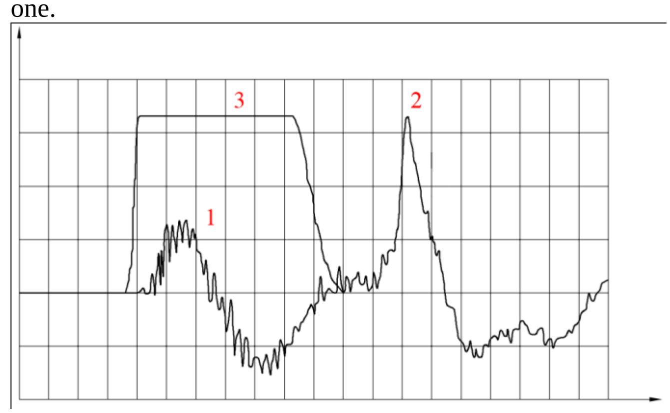

Figure 6. Sketch of an impulse response during S_I measurements. Source: (CEN/TS 1793-5 standard).

Figure 6 shows a sketch of an impulse response of a SI measurement. 1 represents the transmitted component, 2 the diffracted component, 3 is the Adrienne window needed to isolate 1. The delay of the component 2 (diffracted component) is related with the height of the barrier. Of course, the distance between component 1 and 2 decreases when the barrier become smaller (2 moves left). The amplitude of 2 behaves oppositely: decreasing the barrier height causes an increase in the amplitude. This behavior generates two troublesome scenarios:

- The height of the barrier provides components partially overlapping, with the diffracted component having amplitude higher than the transmitted one: the operator could cut away completely the diffracted component by shortening the Adrienne window, thus removing also the "tail" of the transmitted one which is overlapped with the subsequent diffracted component. This results in an overestimation of the Sound Insulation Index, as part of the sound passing through the barrier has been cut away.

- The operator maintains a standard length of the Adrienne window, which will include also the strong peak of the diffracted sound, which will be improperly considered as being part of the transmitted component. This results in an underestimation of the Sound Insulation Index, as part of the sound diffracted by the upper edge of the barrier has been erroneously included in the transmitted component.

The CEN/TS 1793-5 standard mandates for a minimum height of the barrier equal to 4.0 m. However this minimum height can be insufficient for avoiding overlapping between transmitted and diffracted components, particularly with those barriers having a “resonating” structure (cavities, etc.); they often cause a transmitted impulse response “ringing” for several milliseconds (even 20-30 ms), which means that a complete separation of the diffracted components would require a minimum height of 7 or more meters.

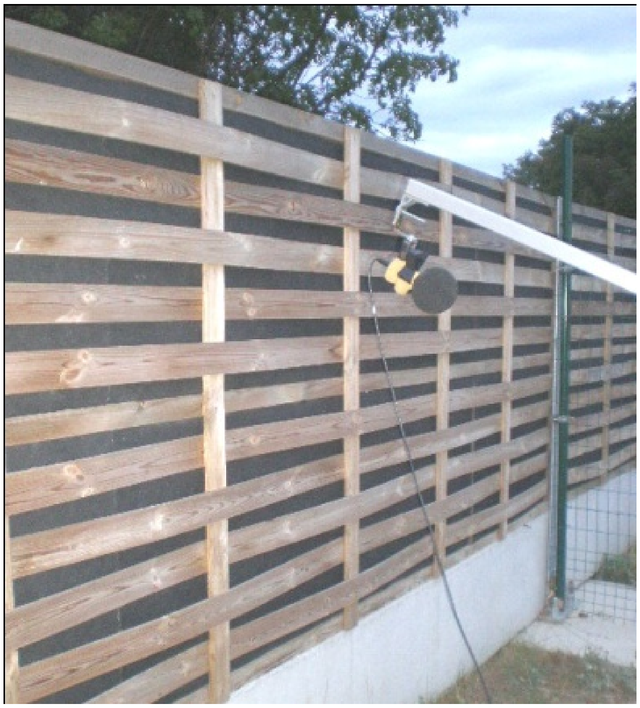

Figure 6. Barrier that doesn’t meet minimum dimension requirements.

Again, when this overlapping problem occurs, the standard does not provide clear indications about the real minimum height of the barrier (as the length of the transmitted component is always assumed to be shorter than the standard Adrienne Window, which only accommodates a length of approximately 5.0 ms).

Furthermore, the standard does not define how to proceed when the operator is asked to qualify a noise barrier of limited height, as it often occurs in practice, as shown in Figure 7.

This gap in the standard can create wrong classifications, which, with reference to the Sound Insulation Index, can either result is significant underestimation or overestimation of the real values.

V. Experimental measurements

The techniques described by the CEN/TS standard was utilized to determine the reflection characteristics of two road barriers located in Trieste, Italy. The first two barriers under test are installed in “Grande Viabilità Triestina” between Cattinara and Patriciano (Italy).

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 figure 7 and 8 reports the in-situ measurement of SI.

Figure 7. Measurements of SI on barrier “A”

The results of the measurements by the CEN/TS 1793-5, both for Reflection Index (RI) and Sound Insulation Index (SI) for each element and post, are reported in Table 2.

Table 2. Measurement results

	DL_R	$DL_{SI\ element}$	$DL_{SI\ post}$
Barrier “A”	26 [dB]	25.6 [dB]	23.1 [dB]
Barrier “B”	29 [dB]	18.5 [dB]	19.3 [dB]

Figure 8. Measurements of SI on barrier “B”

A. Comparison between laboratory and CEN/TS 1793-5 measurements

The results obtained following the aforementioned standard are reported in Table 2, which compares the single-rating numbers DL_R and DL_{SI}. Looking at the data, DL_R represents the result in laboratory, whilst the “in situ” behavior is represented by DL_{SI}. The two coefficients deviate each other, as was demonstrated by other previous experiments [17].
Nevertheless, in barrier “A” this difference can be safely considered null: a gap of 0.4 dB is physically insignificant. On the other hand, barrier “B” manifests a too wide gap between values. As described before, this effect is due to the short delay between transmitted and diffracted components: Figure 13 shows how the diffracted component falls inside the Adrienne window, because of the limited height of barrier “B”. For this reason the whole result is compromised.

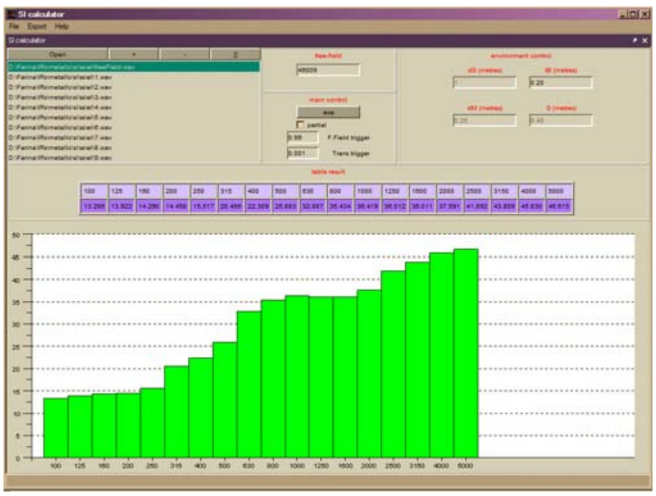

Figure 9 – Metallic and PMMA - Sound Insulation Index – Element - $DL_{SI} = 25.6 \quad [dB]$

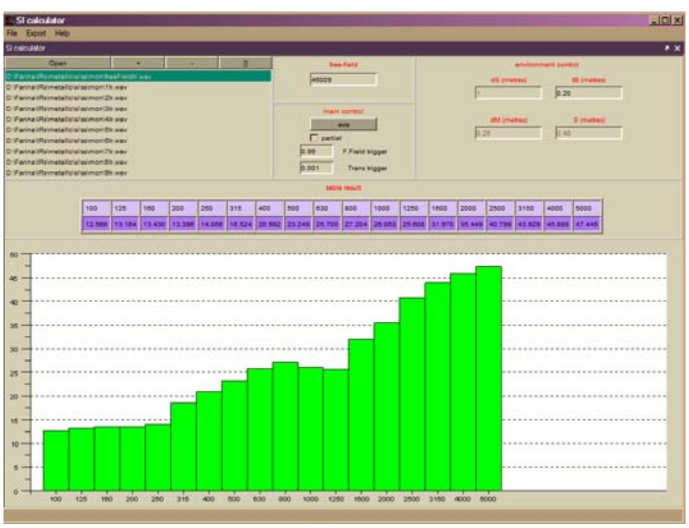

Figure 10 – Metallic and PMMA - Sound Insulation Index – Post - $DL_{SI} = 23.1 \quad [dB]$

Figure 11 – Wooden barrier- Sound Insulation Index – Element - $DL_{SI} = 18.5 \quad [dB]$

Comparing the two different road barriers, it is evident that Barrier “A” resulted more performing than Barrier “B”. However, this result could be depending both on the height of the barriers (barrier “A” is taller than barrier “B”) or on the material (barrier “A” is made on steel and PMMA and therefore should be more insulating than barrier “B” that is made of wood).
However, the different height could provoke this difference, much more than the different material.

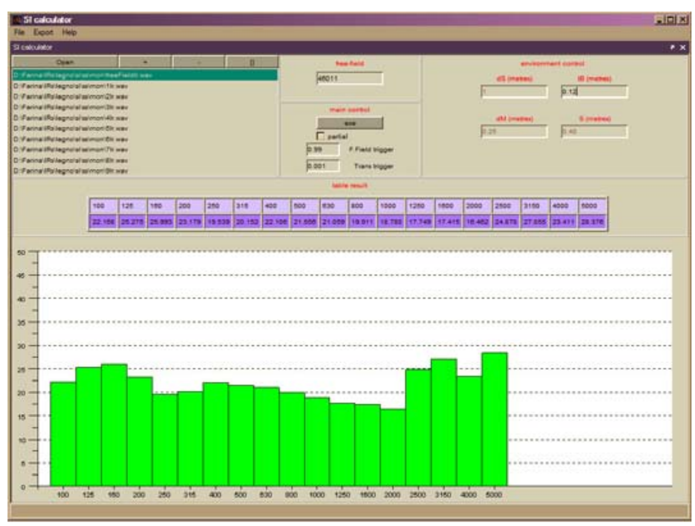

Figure 12 – Wooden barrier- Sound Insulation Index –Post - $DL_{SI} = 19.3 \quad [dB]$

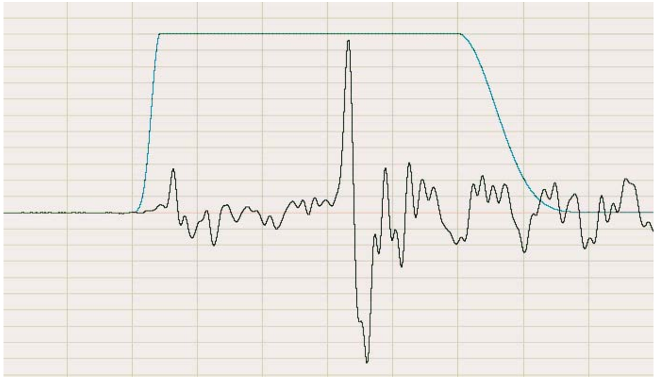

Figure 13. Barrier "B": transmitted and diffracted components both fall inside the Adrienne window.

One more important component is the difference between the Element and the Post. Barrier "A" resulted much more similar at low frequencies than barrier "B", On the other hand, at middle frequencies barrier "A" shows a gap between Post and Element, whereas barrier "B" resulted having much more similar performance. This result should be considered during the choice of the typology of the barrier, since it could provoke an important effect in the general extrinsic performance of the barriers.

The results from both the barriers (Element and Posts) are summarized in figure 14.

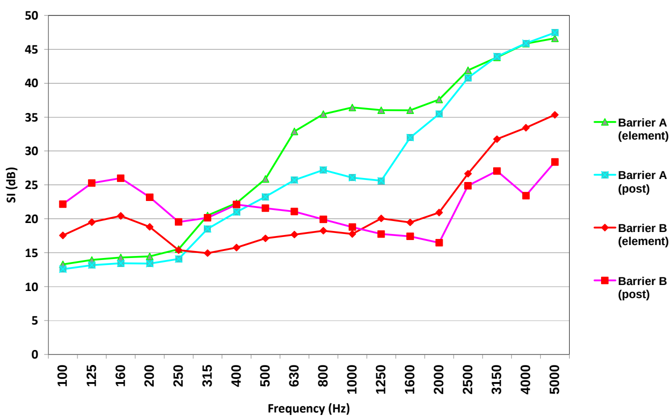

Figure 14. SI comparison between the 2 barriers

VI. Conclusions

The experimental measurements that were done in two different typologies of road barriers were compared with the laboratory measurements. The use on CEN/TS 1793-5 to classify the effectiveness of barrier has been shown to provide results that fairly agree with the laboratory only in sound insulation test and only when the barrier is very tall and without resonant cavities: for example, the deviation between laboratory and "in situ" results for barrier "A" is negligible. When these geometrical and structural requirements are not met, the result deviates significantly (as it happened for barrier "B").

In this case, it has been shown how $\boldsymbol{DL_{SI}}$ can be strongly affected by the diffracted component of the impulse response, if it falls within the Adrienne window. Depending on how the operator deals with this problem, the final result of the Sound Insulation rating can either be underestimated or overestimated.

In practice, the CEN-TS 1793/5 method revealed to be completely unusable for measuring reflection index, as demonstrated in other articles.

It is also important to note that these barriers could also act as a sound source, since the noise emission of cars and trucks could provoke a vibration of some components that could result as a noise source. For these reasons further experimental measurements are planned, in order to determine the value of the Intensity of Acoustic Radiation (IAR) of the barriers [20], and compare RI with IAR.

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