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EXPERIMENTAL VERIFICATION OF THE EUROPEAN METHODOLOGY FOR TESTING NOISE BARRIERS IN SITU: SOUND REFLECTION

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ABSTRACT
The European project *Adrienne* (1995-97) produced innovative methods for testing the intrinsic characteristics of noise barriers in situ. These methods are now under consideration at CEN to become European standards. This paper reports the verification of the *Adrienne* test method for sound reflection over a selection of seventeen noise barriers, tested both outdoors, using the new method, and in laboratory, following the EN 1793-1 standard. The *Adrienne* method has been found sensitive to the shape and the acoustic impedance of the barriers under test. The comparison between outdoor and laboratory results shows an acceptable correlation, while differences can be explained with the different sound fields and averaging techniques between the outdoor and laboratory tests. It is concluded that the *Adrienne* method is the most promising one for its intended use.

1 - INTRODUCTION
The sound reflection/absorption of seventeen noise barriers, representative of the Italian and European market, was tested both outdoors, using the new *Adrienne* method [1,2,3], and in laboratory, following the EN 1793-1 standard [4]. In both cases different single number ratings for sound reflection/absorption were calculated [4,5,7]. The work permitted:

- to test the practicability and the reliability of the new method for different kinds of barriers;
- to test the sensitivity of the new method to the shape and the acoustic impedance of the barriers under test;
- to compare the outdoor and laboratory values obtained on the same set of barrier samples and to investigate their correlation, which can be useful for predicting the expected field performance from laboratory data.

2 - THE SAMPLES
All samples had the same global size: about 3.0x3.5 m for the laboratory test and 18.0x4.0 m for the outdoor test. In Table 1, the barrier samples are presented with conventional names in order to not disclose the producer names. The barriers submitted to the test can be grouped in six classes:

- concrete barriers (5 samples): barrier elements are made of a heavy concrete back panels supporting front panels made with lighter concrete and with a non flat shape; the posts are large and strong to support the considerable weight of the structure;
- metallic barriers (7 samples): barrier elements are metallic boxes, perforated on one face and partially filled with a high density rock wool; in two cases a high density synthetic damper was added; in two cases the elements were simple, not perforated, metallic sheets; the posts are metallic beams with a "H" section;

- resin barriers (1 sample): the barrier elements are boxes made with polyether resin sheets reinforced using glass fibres; the boxes are perforated on one face and partially filled with a glass fibre blanket; the posts are made using the same polyether resin;
- acrylic barriers (1 sample): the barrier elements are transparent polymethylmethacrylate (PMMA) sheets, 20 mm thick, supported by a light metallic frame;
- mixed barriers (1 sample): the half barrier close to the ground is made of metallic panels, like those described above (point 2); the upper half is made of transparent polymethylmethacrylate (PMMA) sheets, 15 mm thick, supported by a light metallic frame; the posts are metallic beams with a "H" section;
- wood barriers (1 sample): the barrier is made of four layers i.e., from front to back: wood tiles made of spaced laths; rock wool blanket; fibre-concrete aggregate board; wood board; the posts are metallic beams with a "H" section.

3 - LABORATORY MEASUREMENTS

The laboratory test method specified in EN 1793-1 [4] was applied. It fully conforms to the well-known ISO 354 [6], with some additions relevant for noise barriers. The specimens were mounted in the test opening and assembled in the same manner as the manufactured devices used in practice, with the same connections and seals between component parts. All the reflecting parts exposed on the traffic side (posts, brackets, and other parts) were present on the specimens. Where posts are employed in construction, at least one post was included in the specimen, with panels attached on both sides. The samples were placed directly on the floor of the reverberation room, with the side that would face the traffic noise source facing the inner part of the room. The values of the sound absorption coefficient α_s were measured in the one-third octave bands from 100 Hz to 5 kHz [4], [6]. Two kinds of single number rating of sound absorption were calculated: the rating α_w used in building acoustics, as defined in ISO 11654 [7]; the traffic noise rating DL_α, as defined in EN 1793-1 [4], using the normalized A-weighted sound pressure level of traffic noise defined in EN 1793-3 [5]. All values of the ratings α_w and DL_α are reported in Table 1. The DL_α values were calculated both on the full frequency range 100 Hz to 5 kHz, in one-third octave frequency bands, and in the "restricted" frequency range 250 Hz to 5 kHz; the latter calculation was made in view of the comparison with the single number rating values resulting from the outdoor measurements (see Section 4).

4 - OUTDOOR MEASUREMENTS

The *Adrienne* test method was already presented in several publications, e.g. [1,2,3], and will not be detailed here. It is only worth recalling that the final value of the *sound reflection index RI* is the arithmetic average of the values measured at several points in front of the barrier. The analysis window must be the new *Adrienne* window, uniquely defined in shape, length and position [1,2,3]. Valid sound insulation index measurements, for 4 m tall barriers, are acknowledged to start from the 250 Hz one-third octave band [1,2,3]. In the following the outdoor measured values are therefore considered in the frequency range from 250 Hz to 5 kHz, in one-third octave bands.
The measurement system was similar to that described in [2,3]. The test signal was a MLS sequence of order 16; 64 averages were performed for each impulse response acquisition. The test site is a flat, grass covered ground. The grass was cut before the beginning of the tests. All samples were built in the same place and removed after the test, one after the other. Measurements were taken in good meteorological conditions, with no rain or strong wind (wind speed always < 4 m/s). Background noise did not influence the measurements.
The single number rating for the reflection index was computed using a formula analogous to that for DL_α [4] and was named DL_{RI}; due to the above mentioned low frequency limit, the calculations were performed in the one-third frequency bands from 250 Hz to 5 kHz. The results are reported in Table 1.

Sample	Type	α_w [dB] lab.	DL_α [dB] lab.	DL_α [dB] lab.	DL_{RI} [dB] outdoors
		100 to 5k Hz	100 to 5k Hz	250 to 5k Hz	250 to 5k Hz
CON1	Concrete	0.75	9	10	6
CON2	Concrete	0.65	6	7	4
CON3	Concrete	0.90	10	12	4
CON4	Concrete	0.65	5	6	3
CON5	Concrete	0.50	5	5	2
CON6	Concrete	0.20	1	1	0
MET1	Metal	1.00	20	20	5
MET2	Metal	1.00	18	20	5
MET3	Metal	0.95	16	20	5
MET4	Metal	0.15	0	0	0
MET5	Metal	0.95	8	9	4
MET6	Metal	0.95	19	20	6
MET7	Metal	0.95	13	20	5
RES1	Resin	0.80	8	9	4
ACR1	Acrylic	0.10	0	0	0
MIX1	Met./Acr.	0.60	4	4	3
WOOD	Wood	0.65	8	8	4

Table 1: Single number ratings of sound absorption/reflection.

5 - COMPARISON BETWEEN LABORATORY AND OUTDOOR DATA

In the laboratory a conventional sound absorption coefficient is measured (Sabine's coefficient α_S); outdoors the new sound reflection index, *RI*, is measured; in order to compare them on the same graph, the sound absorption coefficient were converted to conventional sound reflection values using the formula:

$$r_S = 1 - \alpha_S \tag{1}$$

It is well-known that the Sabine's coefficient is overestimated and can also get values over 1, outside the range of validity of its own definition; in this case, the value of r_S in Eq. (1) was set to zero. The new sound reflection index *RI* is defined so as it can get values over 1, for reflecting and non flat surfaces [1,2,3]. In any case, differences between the values of r_S and *RI* were expected, because:

- the sound field in front of the test specimen is a diffuse field in laboratory and a frontal free-field outdoors.
- The sampling and averaging of the sound field is very different between the laboratory and outdoor procedures;
- The steady state signal recorded in the laboratory is very different from the impulse response recorded outdoors.

Fig. 1 shows the results for the sample CON4, constituted by back concrete panels supporting light clay aggregate blocks, 120 mm thick. The blocks contain cavities connected to front holes on the exposed face and are intended to act as resonators to improve the sound absorption. The two curves are similar down to 250 Hz, where the outdoor measurements have they low frequency limit. On the other hand, laboratory results seem to overestimate the sound absorption (underestimate the sound reflection). This is confirmed looking at Fig. 2, that shows the results for the sample MET2, a metallic barrier with a curved shape and made of metallic boxes having the side that would face the traffic noise source perforated in order to expose the inner rock wool. For this sample, the α_S values are so overestimated that the reflection coefficient r_S is no more useful from the 500 Hz one-third octave band on.
The application of standard statistical theory to data of Table 1 permitted to obtain various correlation laws between the single number ratings.
The linear correlation between the two single number ratings α_w and DL_α obtained from laboratory measurements, calculated over the frequency range 100 Hz to 5 kHz, is:

$$DL_\alpha = 18.71\alpha_w - 4.10 \;\; (r = 0.875) \tag{2}$$

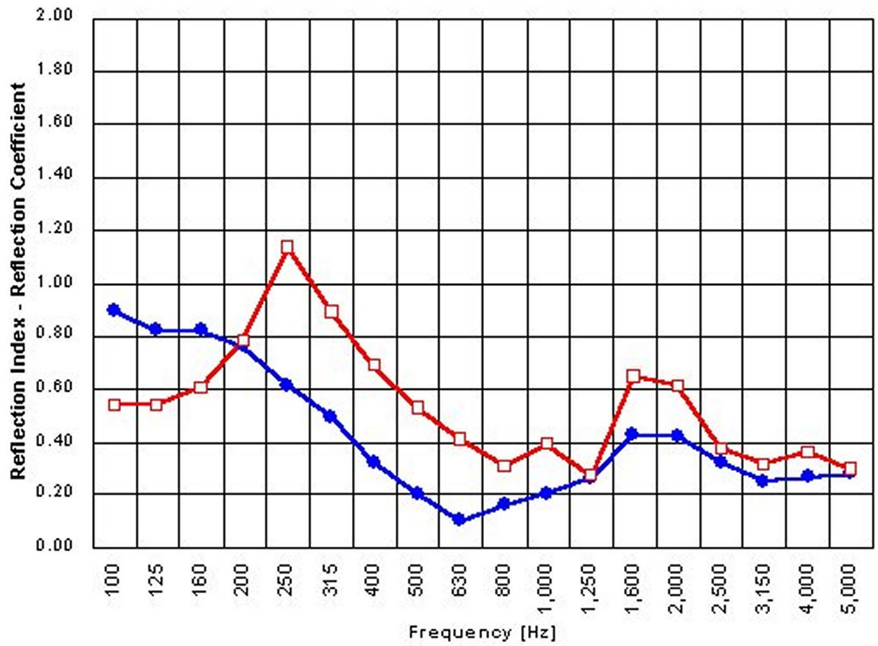

Figure 1: Sound reflection index and sound reflection coefficient values for barrier CON4: (•) laboratory measurements; (□) outdoor measurements.

The value of the correlation coefficient is quite low, considering that the two ratings were calculated on the same data set: it is clear that the two ratings are not fully comparable, being based on different procedures and bounded to conventional maximum values (1 for α_w [7] and 20 dB for DL_α [4]). Therefore, for noise barriers the usage of α_w should be avoided.
The linear correlation law between the single number ratings DL_α, obtained from laboratory data, and DL_{RI}, obtained from outdoor data (all calculated over the frequency range 250 Hz to 5 kHz), is:

$$DL_{RI} = 0.26 DL_\alpha + 1.26 \;\; (r = 0.84) \qquad (3)$$

The value of the correlation coefficient is strongly influenced by the anomalous result of the sample CON1, which got an unusually great value of the outdoor rating; excluding this sample the linear correlation law becomes:

$$DL_{RI} = 0.26 DL_\alpha + 1.11 \;\; (r = 0.89) \qquad (4)$$

Now the value of the correlation coefficient is quite acceptable and its value is high enough to support the conclusion that Eq. (4) can be useful for predicting the expected field performance from laboratory data measured according to EN 1793-1.
Work is in progress to obtain a better value of the lowest reliable frequency for outdoor measurements; it is hoped that this can also improve the strength of the correlation between outdoor and laboratory data.

6 - CONCLUSIONS

The new *Adrienne* method proved to be easy to use and reliable for all kinds of barriers. It has been found sensitive the shape and the acoustic impedance of the barriers under test. The comparison between outdoor and laboratory results shows a quite acceptable correlation, while existing differences can be explained with the different sound fields and averaging techniques between the outdoor and laboratory tests. In other words, results obtained using the *Adrienne* test method [1,2,3] are fairly consistent with laboratory results obtained using EN 1793-1 [4]. While work is in progress to obtain a better value of the lowest reliable frequency for outdoor measurements, the correlation laws resulting from the present work can already be useful for predicting the sound reflection performance of noise barriers in the field from laboratory data. It can be concluded that the *Adrienne* method is the most promising one for its intended use.

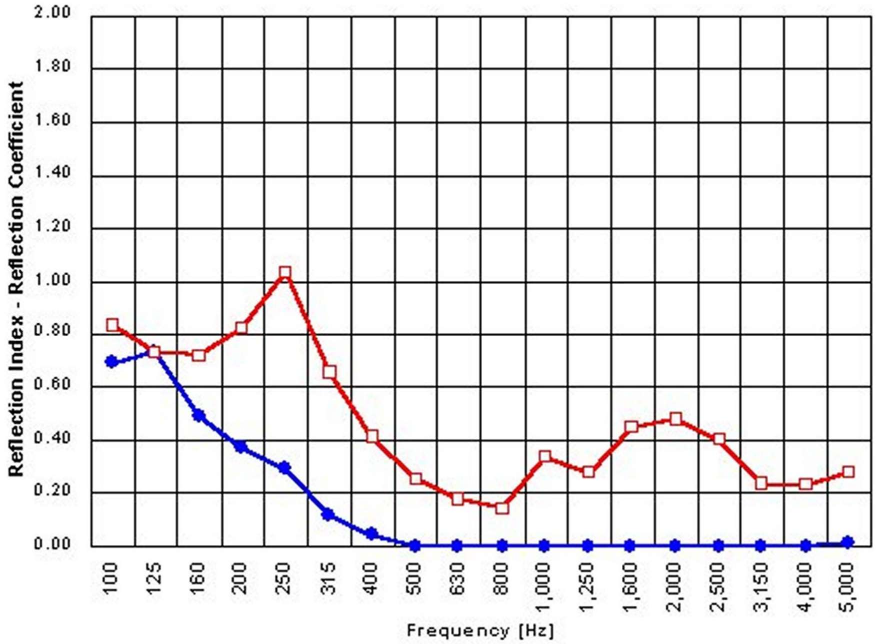

Figure 2: Sound reflection index and sound reflection coefficient values for barrier MET2: (•) laboratory measurements; (□) outdoor measurements.

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