EXPERIMENTAL EVALUATION AND OPTIMIZATION OF THE ACOUSTIC PROPERTIES OF A NOISE BARRIER

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ABSTRACT

The latest Italian laws and U.E. Directives on noise pollution have prompt attention on the acoustic performances of materials; in this field noise barriers are among the most commonly used systems to reduce noise from roads or railways, also in urban areas.
The paper illustrates the measurement results obtained at the Acoustics Laboratory of the University of Perugia on a new noise barrier sample. The barrier is made of perforated metal panels, filled with rockwool; there is also the possibility to insert in the barrier transparent panels, made of PMMA (Polimetylmetacrylate).
Sound insulation properties have been measured in two coupled reverberating rooms, according to ISO 140-1[1], 140-3 [2], 717-1 [3], EN 1793-1 [4] and 1793-2 [5]; measurements have been carried out for two different barriers, one all made of metal panels, the other one with an insertion of PMMA panels. Sound absorption properties of the metal panels have been measured in a reverberating room, according to ISO/DIS 354/2000 [6].
The results show good sound insulation properties (class B3 of ISO), but not completely satisfactory sound absorption properties, especially at low frequencies. So, thanks to Helmholtz resonators theory, an optimization to improve sound absorption properties of the metal panels has been proposed, taking into account all the different parameters affecting the phenomenon.

INTRODUCTION

Noise pollution in urban areas has become more and more serious in these last years. More than 140 millions of people in Europe are exposed to noise levels causing annoyance during day time; 20% of them (80 millions) are exposed to levels which may cause serious health damage [7]. Roads and railways are among the most important noise sources; to reduce their impact, noise barriers are among the most commonly used systems. The experimental determination of noise barriers acoustic performances is extremely important for the design of these systems; at the Acoustics Laboratory of the University of Perugia, acoustic measurements were taken on a new noise barrier sample, made of perforated metallic panels with internal rockwool and transparent PMMA modules; both sound insulating and sound absorbing properties of the barrier were investigated.
The barrier performances were then compared with the requirements of EN 1793-1 and EN 1793-2 and of the Italian National Motorway and Railways Companies and Environment Ministry.

In the last part of the paper some indications are given to optimize the acoustic absorption performances of the sample.

DESCRIPTION OF THE EXPERIMENTAL APPARATUS

Measurements were carried out in the coupled reverberating rooms at the Acoustic Laboratory of the University of Perugia. The rooms are made up of two box–shaped concrete structures, divided from each other and from the surroundings, in compliance with UNI EN ISO 140-1.
The geometrical features of the rooms are the following:
- Emitting room: internal dimensions: 4.6 m x 4 m x 2.9 m; net internal volume: V = 53.36 m^3 ;
- Receiving room: internal dimensions: 4.6 m x 3.9 m x 3.5 m; net internal volume: V = 62.79 m^3

The roofing is made up of a 0,4 m thick concrete floor; the two reverberating rooms are connected by an opening with the following dimensions: 4.16 mx 2.47 m, Area = 10.28 m^2.
During the sound-absorption tests in the emitting room, the opening was closed with a 0.4 m thick brick wall.
The phonometrical equipment used for the measurements has the following characteristics:
- OROS 2 acquisition card for elaborating and analysing acoustic measurements;
- omnidirectional noise source, made up of a dodecahedron the sides of which have been equipped with twelve circular loudspeakers (ϕ=16cm), set up on a 1.5 m pole;
- 200 W bichannel amplifier to supply the noise source (model SU A 900 Technics);
- white noise generator: DAT digital recorder to reproduce tapes with white noise (model TCD-D7 Sony);
- condensator microphones: half inched, omnidirectional and precision (model WC53A);
- calibrator: 250 Hz, LPS = 124 dB to calibrate the microphones (model 4228, Bruel &Kjaer).

There is also a thermoigrometer to measure the environmental conditions during testing.

DESCRIPTION OF THE SAMPLE

The road barrier can be assembled with two types of modular elements with different characteristics and dimensions.
The first type of panel with both sound absorption and sound insulation properties is made up of an aluminum box-shaped structure with porous material inside with the following dimensions: m 1.00x3.00x0.10 or m 1.00x1.16x0.10. The boxed structure is 2 mm thick zinc plated and on the side facing the road there is a bore of Φ = 8 mm at 60° and 12 mm inter-axis. On the other side, a weighting sheet has been applied, the density of which is 5 kg/m^2. The area of the single bore is equal to 50mm^2 and the empty/full ratio of the bored panel is 60%. The porous material inside the metallic structure is mineral rock wool in rigid panels, with a density of 100 kg/m^3 and a thickness of 0,08 m; in order to avoid damage due to the exposure to atmospheric agents, the rock wool is coated with a glass veil to prevent putrefaction. The panel has an overall mass per area unit of 21.6 kg/m^2.
The second type of panel is made up of a transparent sheet in PMMA with 150 mm thickness with only sound insulating properties, inserted in a metal frame with m 0,43x3x0,1or m 0,43x1,16x0,1 dimensions. The two modular elements can be assembled in several ways according to need.

MEASUREMENTS METHODOLOGIES

Sound-absorption

Sound-absorption measurements were carried out in the emitting room. The first test was performed on the metal panel with dimensions m 1x3x0,1 (sample I), the second one on the same metal panel along with the transparent one of m 0,43x3x0,1dimensions (sampel II); in both cases the sample was placed in direct contact with the floor.
Measurements were carried out using the method of reverberation time specified in ISO 354/85 [8] and in ISO/DIS 354/2000. The room where the measurements were taken complies with ISO 140-1/1990 regulations as far as reverberation times (less than 2 seconds in the frequency range 100-5000Hz), and with ISO 354-1985 as far as the equivalent absorption surfaces.

To qualify the room the best positions were found for sources and microphones so that noise diffusion was the most uniform. To this aim, various different configurations were considered; the best positioning was chosen as the one that allowed the least differences among the reverberation times.
The procedure requires two series of measurements, one in the empty room, one with the sample inside of it. Before measuring, the temperature and relative air humidity values are measured and the microphones are calibrated. A sound field is then generated inside the room (white noise) and kept for at least 15 seconds to produce a constant pressure level inside the room itself.The signal is then interrupted; the decline curve is measured and the reverberation time for each frequency is calculated. Five measurements were taken for each source and microphone position, for a total of 60 measurements for each sample. The mean reverberation times were calculated; the absorption coefficient was calculated from the comparison between the reverberation time when the room was empty and when the testing sample was inside the room. The calculations contain corrections to take account of the sample volume and the surface of the floor covered by the sample.
In compliance with ISO 354 testing repeatability was also verified. Repeatability is defined as the value below which the absolute difference can be found with 95% probability between two testing results obtained using the same method on identical samples under the same conditions (same operator, same equipment), in a brief time interval. The repeatability test of the room, carried out in a previous work [9] is equal to 0.01.

Sound-insulation

The measurement of the sound insulation properties of the barrier were taken in compliance with ISO 141, ISO 717 and EN 1793. Figure 1 shows the measurement sequence followed. Each sample a) is installed in the reverberating chamber 24 hours before the measuring. Source *b)* and microphone *c)* are set up in the positions chosen according to ISO 140/3; for each position of the source, five microphone positions are chosen. The sound is generated by a digital recorder *d)* amplified and spread in the room by an omnidirectional source
The test consists in determining the average sound pressure level inside the emitting chamber and the receiving one; from these values sound insulating properties are calculated [10].
The determination of the sound insulation performance was carried out for two different sample configurations: in the first (fig. 2, sample I), only bored metallic panels were used; in the second (fig. 3, sample II) even PMMA transparent modular elements were inserted. In both cases, the area of the samples is 10,28 m^2.

RESULTS

The sound-absorption coefficient for frequency bands of one third of octave is presented in figure 4, for the two different samples. The single number rating of sound absorption DL_α defined in 1793-1 was also calculated (Table 1). The values of the acoustic absorption coefficient at the different frequencies, although classifying the barrier in the second best category, can be improved especially at lower frequencies.
The sound insulation properties of the two samples are reported in figures 5 and 6. The values of the single-number quantities R_w and DL_R were calculated in compliance with ISO 717 and EN 1793 (table 1). Both samples belong to class B3 of EN 1793-1 (highest class for airborne sound insulation properties).

Table 1: Measurements results

	R_W	DL_R	Cat.*	DL_a	Cat.**
Sample I	34	28	B3	8	A3
Sample II	35	29	B3	4	A2

* EN 1793-1 ** EN 1793-2

OPTIMIZATION OF THE SOUND ABSORPTION PROPERTIES

The sound-absortion properties of sample I of the barrier is in agreement with the typical trend of bored sound panels.
The requirements of the Italian National Motorway and Railways Companies and Environment Ministry Commitee report the minimum values of the sound absorption coefficient for noise barriers (table 2).

Table 2: requirements for sound absorption coefficient for noise barriers [11], compared with tets results, sample I

	Sound absorption coefficient					
Frequency (Hz)	Test 1	Test 2	Test 3	Test 4	Test 5	Requirement
125	0,49	0,51	0,58	0,61	0,48	**> 0,35**
250	0,57	0,57	0,53	0,57	0,55	**> 0,70**
500	0,86	0,87	0,91	0,87	0,88	**> 0,80**
1000	0,93	0,92	0,96	0,91	0,94	**> 0,80**
2000	0,86	0,82	0,83	0,84	0,81	**> 0,80**
4000	0,80	0,76	0,77	0,83	0,87	**> 0,75**

Except for the frequency band at 250 Hz, all the other values measured for sample I (bored metal panel) satisfy the Committee's requirements.
The theory of Helmholtz acoustic resonators, applied onto the panels, supplies with a good approximation, an equation from which the value of the frequency can be taken at which the maximum absorption is obtained. The relation is as follows [12]:

$$f_{max} = \frac{c}{2\Pi}\sqrt{\frac{P}{HL_e}}$$

Where c is sound speed in air (340 m/s), p is the percentage of bores in the panels (empty area/total area = 40%; H is the thickness of the rock wool (0,08m), L_e is the equivalent length of the resonating neck and is expressed as:

$$L_e = 0{,}8d + L$$

with d diameter of the bore (8mm) and L is the length of the bore equal to the thickness of the sheet (2mm).
Replacing the numerical values, f_{max} = 1320 Hz.
The trend of the sound-absorption coefficient found experimentally places the maximum in the 1000-1250 Hz range, just below the theoretical value. Since the unsatisfactory value is placed at 250 Hz, it can be assumed that, by lowering the value of the absorption maximum, an improvement of the properties is possible at lower frequencies.
The following parameters are suggested for the optimization of sound absorption properties of the panel:
- bore diameter = 6mm;
- bore inter-axis from 12 mm to 11 mm, always at 60°;
- thickness of the bored sheet = 2mm;
- thickness of the rock wool from 8 cm to 10 cm.

In this way, the empty/full ratio is equal to 37% and the frequency of maximum absorption is shifted from 1320 Hz to 1130 Hz, with potential improvements at lower frequencies.

CONCLUSIONS

The paper presents the experimental results obtained for the acoustic performances of a new noise barrier sample. Both sound absorption and insulation properties were investigated, according to UNI EN ISO 140-1, 717-1, UNI EN 1793-1, 1793-2, ISO/DIS 354/2000; two different barrier samples were considered, one with bored metal panels only (sample I), the other with the insertion of a PMMA transparent panel (sample II).
The results show that the sample has good sound-absorption characteristics, belonging to A3 class (the best class being A4) of UNI-EN 1793. As far as sound insulation, the single sumber quantity Rw resulted to be greater than 34 dB for both samples, which therefore belong to the best category B3 of UNI-EN 1793.
Finally, thanks to Helmholtz acoustic resonators theory, an optimization of sound absorption properties of the bored metal panel has been proposed.

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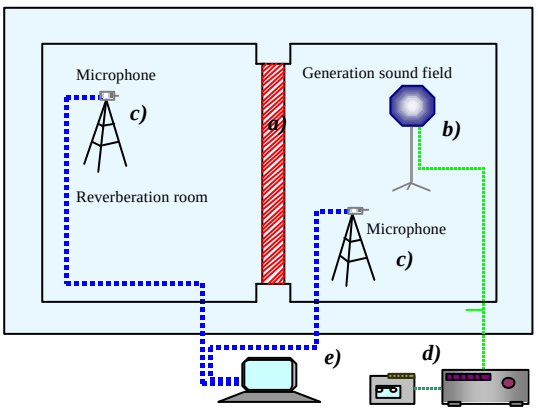

Fig. 1 : measurement equipment

Fig. 2: sample I of the noise barrier (only bored metal panels)

Fig. 3: sample II of the noise barrier (PMMA and bored metal panels)

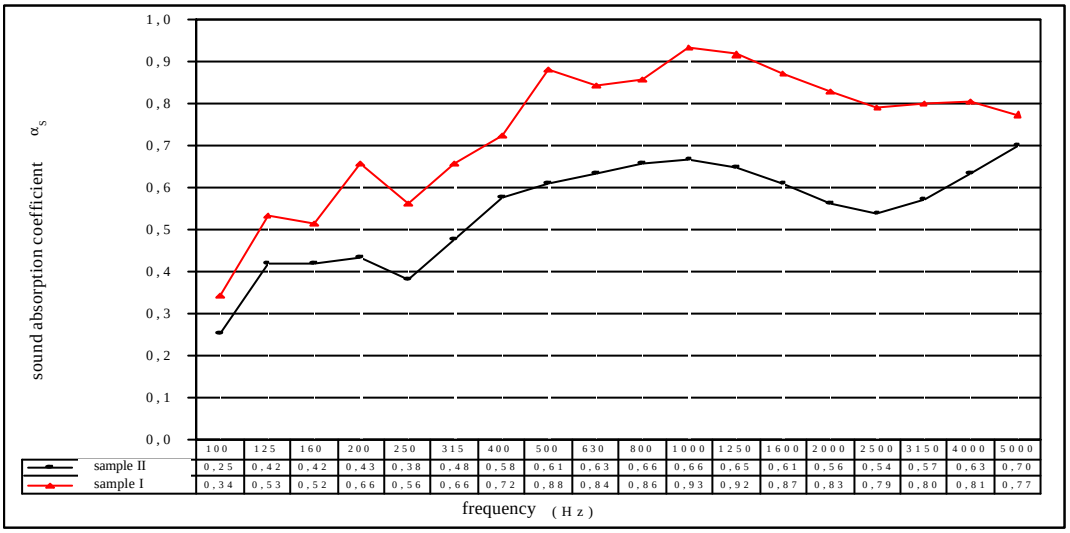

Fig. 4: sound absorption coefficient vs frequency of the two noise barrier samples

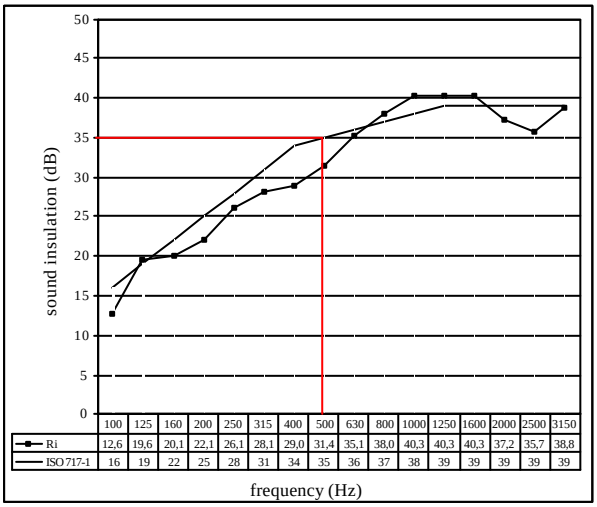

Fig. 6: sound insulation vs frequency of the noise barrier, sample II

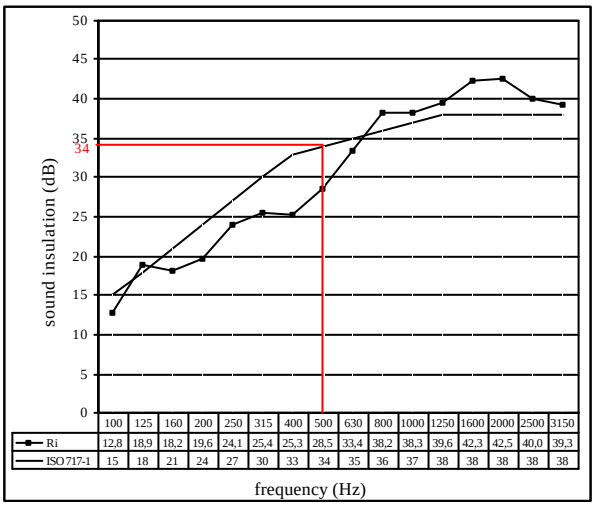

Fig.5: sound insulation vs frequency of the noise barrier, sample I