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THIS COMMUNICATION IS CANCELLED (PAPER IS AVAILABLE). Analysis of in situ acoustical performance of concrete noise barriers

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The need to enhance the people's mobility has produced a significant increase in the environmental pollution, including transportation noise. In order to reduce transportation noise it is possible to act directly on transport media or on the urban environment, by protecting sensitive receptors with techniques for noise reduction. The noise barriers are one of the most common examples of noise reduction devices. In this paper the authors show and discuss the results of an *in situ* analysis of the acoustical performance of concrete noise barriers, installed in an important highway infrastructure of the Central Italy. The structure of examined barriers is composed of 8 overlapping panels made by autoclaved aerated concrete. The faces of the panels, facing the noise source, can be smooth or machined with high pressure water jets (rough surface with irregular horizontal chamfering) to increase the sound absorption properties. In order to increase the sound absorption of the barriers, till to the higher quality class (A4) indicated in EN 1793-5, semi-cylindrical acoustical absorbers have been designed. They are made by metallic micro-holed envelope with the cavity partially filled by suitably shaped polyester fiber and they can be installed at variable distances from the face of the panel.

1 Introduction

The problem of human exposure to noise has increased, particularly over the last fifteen years, by the development of infrastructure and transport systems, resulting in higher public attention to the problem of noise pollution and damage caused by noise [1-4].

As regards the noise due to the transport infrastructures, it has been greatly increased by the current traffic characteristics, with the considerable increase of the flows, the traveling speed and the amount of vehicles in circulation. This effect is particularly significant for the national motorway system and more specifically for those roads considered as highways that cross the national territory and that very usually run near the towns.

The extreme variability of the types of vehicles that travel on the roads and their average speed make complex the analysis of the transportation noise and the problems related to its propagation.

By considering the road as a continuous vehicular flow, it is possible to observe that the main factors of influence to the noise of a given infrastructure (both in terms of equivalent continuous and statistical distribution of sound pressure level) are: the number of vehicles, the presence percentage of heavy vehicles, the average speed of vehicular flow.

More easier is the analysis of a single vehicle considered as a multi noise source, in particular noise sources can be identified in [5]:
- engine, transmission, moving parts, air intake and exhaust system, cooling system;
- contact between tire and ground (rolling noise);
- aerodynamic effect.

With average speeds permitted by law and the composition of traffic flows typical of roads and highways, the aerodynamic effects on the propagation of noise can be reasonably neglected [5].

The noise emitted by the engine is the main component for heavy vehicles, it increases with increasing speed. For light vehicles the more relevant component is the rolling noise, which also increases with increasing speed.

Unlike of the noise emitted from the engine, the rolling noise is characterized by strong directivity, which allows to draw diagrams of emission that can be found in the technical literature.

With regard to the spectral distribution of the emitted sound energy it is possible to observe the presence of components at low and medium frequencies [5], with trends that are more influenced by the vehicles speed that by the composition of the vehicular flows.

In order to reduce the noise pollution due to a road infrastructure, the more effective actions can be summarized in the following three types:
- actions carried out directly on the noisy source (in particular the use of sound-absorbing flooring);
- actions carried out along the sound propagation from source to receptor (in particular installation of noise barriers);
- actions carried out directly on the receptor (in particular use of building structures with high sound insulation).

The first type of actions require frequent maintenance to ensure that the effect of sound absorption, essentially due to the porosity of the flooring, is not reduced quickly in time. On the other hand the actions carried out directly on the receptor have problems of both technical and legal nature, usually not easy to solve.

The actions carried out along the sound propagation from source to receptor, in particular with the use of adequate noise barriers (see Fig 1), are those most commonly taken to reduce the phenomena of noise pollution caused by to road infrastructure.

Figure 1: examples of noise barriers installed on the sides of highway infrastructures.

In this paper the results of the analysis of *in situ* acoustical performance of concrete noise barriers are reported and discussed. The barriers are installed in an important highway infrastructure of the Central Italy.

2 General characteristics of the analyzed noise barriers

The analyzed noise barriers are built with a concrete structure that is composed of 8 overlapping panels made by autoclaved aerated concrete (porenbeton) and assembled *in situ* (see Fig. 2). The geometrical dimensions of each panel are: length L=7.5 m, height h=0.625 m and thickness S=0.2 m, consequently each analyzed barrier has an overall height above the ground (given by the sum of the 8 panels) H = 5.0 m (Fig. 3).

The face of the panels, facing the noise source, can be smooth or machined with high pressure water jets, in order to obtain a rough surface with irregular horizontal chamfering and enhanced sound absorption properties.

Figure 2: some pictures of analyzed noise barriers: panels made by autoclaved aerated concrete before the assembly (upper left side), operations of *in situ* assembly of the panels (upper right side), noise barrier with semi-cylindrical acoustical absorbers (bottom left side), detail of acoustical absorbers (bottom right side).

The analyzed noise barriers can be composed completely of panels with smooth faces, completely of panels with machined faces or of a combination of smooth and machined faces.

In order to further increase the sound absorption properties, special semi-cylindrical acoustical absorbers can be applied on the faces of the panels facing the noise source. The semi-cylindrical acoustical absorbers have been specifically designed during this research activity, they are made by metallic micro-holed envelope with the cavity partially filled by suitably shaped polyester fiber and they can be installed at variable distances from the face of the panel.

The semi-cylindrical acoustical absorbers can be applied on the faces of the panels by using hooking mechanical systems (nailed directly to the panels in predefined positions) and they can be fixed with bolts, resulting in different percentages of coverage of the surface of the panels, in function of the acoustical performance to be obtained. As can be seen from the schematic representation of Fig. 3, each acoustic absorber has a length of 200 cm and a height of about 25 cm (maximum radius of the section of the absorber is 11.5 cm).

The designed acoustical absorber contributes significantly to improve the absorption properties of the noise barrier on which it is installed, in particular acting through the phenomena of absorption (for porosity and cavity resonance) and diffraction of the sound perturbation.

Overall the set of design characteristics give to the analyzed noise barriers high acoustical performance, promoting good behavior of the barriers on a wide portion of the frequency range of interest (standardized) between 100 Hz and 5 kHz. In addition to this, it should be considered the contribution, to the mitigation of noise from the transport infrastructures, given by the high sound insulation of the barriers in cementitious materials (for example in concrete or porenbeton).

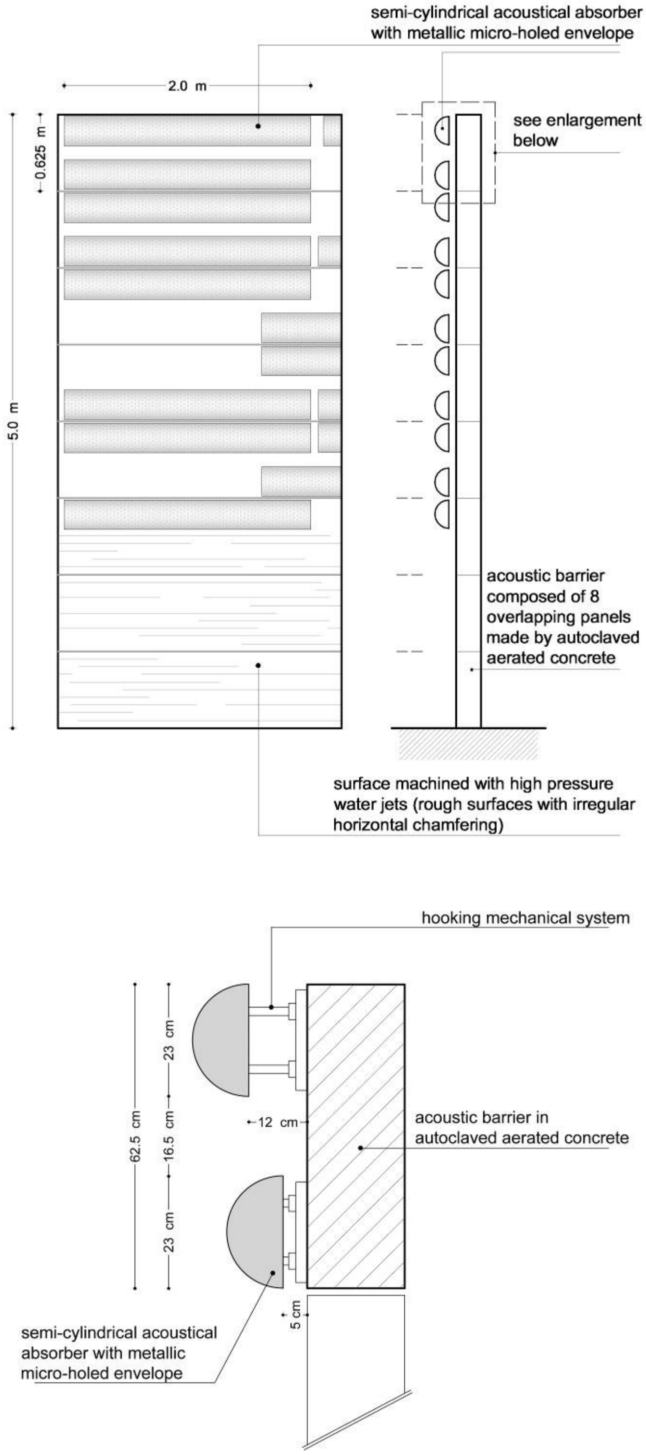

Figure 3: schematic representation of the analyzed noise barriers (top) with details of the main dimensions of the semi-cylindrical acoustical absorbers (bottom).

It important to note that the common noise barriers, made with sandwich panels (typically thin and light), do not possess all the characteristics which are proper instead of the analyzed barriers independently of the type of installation and of the geometry of particular application. Furthermore, the thin barriers can produce diffraction effects of the upper edge only in the case in which are installed suitable systems on the edge of the barrier itself.

3 Configurations of analyzed noise barriers and measurement setup

As described above, the analyzed noise barriers can be realized in different configurations. They can be obtained by varying the number of panels with surface treatment with respect to the total number of panels that make up the barrier and applying a different number of semi-cylindrical acoustic absorbers so as to cover different percentages of the total area of the barrier.

In Table 1 the characteristics of the configurations of barriers whose performance have been measured *in situ* are shown. In particular in Tab. 1 with N_L is indicated the number of panels with the face exposed to the noise machined with high pressure water jets (rough surface), with N_I the number of the panels with the face completely smooth, with N_T the total number of panels that make up the barrier and with A_S the percentage of the total surface exposed to the noise of the barrier that is covered by sound absorbers. (e.g. see Fig. 3).

Table 1: parameters characterizing the configurations of the analyzed barriers.

Configuration	N_L	N_I	N_T	A_S (%)
LAAS/20	0	8	8	20
LAAS/26				26
LAAS/35				35
IAAS/0	3	5		0
IAAS/18				18
IAAS/25				25

With regard to the configurations in which there are some panels with machined surfaces (configurations identified with IAAS) should be specified that these panels are installed in succession starting from the ground and therefore they represent the 3 panels closer to the ground level, since they have higher sound absorption performance with respect to the smooth panels.

For all the configurations shown in Table 1, *in situ* measurements of sound reflection performance have been carried out. For some significant configurations, *in situ* measurements of airborne sound insulation performance (configuration IAAS/25) and of sound diffraction performance (LAAS/35 configuration) have been also performed, these measurements are not discussed in this paper.

The measurements have been carried out on a series of barriers installed near the link road R14 Casalecchio di Reno (Bologna, Italy) of the motorway A1, which is one of the largest motorways of the central-northern Italy.

The activity of the *in situ* measurements has been conducted in accordance with the procedures outlined in the technical regulations, particularly in the technical specification CEN / TS 1793-5 [6] regarding the performance of sound reflection and airborne sound insulation and in the technical specification CEN / TS 1793-4 [6] regarding the performance of sound diffraction.

The positioning of the instrumentation used for all measurements has been in compliance with the indications reported in the technical specifications. In particular for the measurements of sound reflection performance, the complex loudspeaker-microphone has been positioned in such a way that the microphone is placed in front of the most protruding part of the surface of the analyzed barrier, as close as possible to center of the barrier.

Before proceeding to the measurements it has been verified that the maximum sampled area (MSA as defined in [6]) for each configuration was representative of the percentage distribution of semi-cylindrical acoustic absorbers applied to the analyzed barrier.

The measuring equipment used during the tests (supplied by the Lighting and Acoustics Laboratory, Dept. of Energy and Systems Engineering, University of Pisa) complies with the specification CEN/TS 1793-5. The instrumentation used during the activity consists of:

- Brüel and Kjaer integrating-averaging sound level meter, model 2250, single-channel, class 1;
- Brüel and Kjaer prepolarized free-field ½" microphone, model 4189, nominal Open-circuit Sensitivity 50 mV/Pa, equipped by windscreen;
- Brüel and Kjaer sound calibrator, model 4231;
- Brüel and Kjaer 2 channels power amplifier, model 2716, with maximum output power 400 W (measured at 230 V AC);
- 01 dB 6” full range sound source (loudloudspeaker), model “Rotone” maximum power 200 W;
- workstation laptop complete with software Dirac (developed by Brüel and Kjaer) for generating the sound signal Maximum Length Sequence (MLS).

For the validity of the measurements it is required [6] that these are carried out in the absence of rain or other precipitations, the wind speed in the positions of measurements is less than 5 $m \cdot s^{-1}$ and the air temperature is between 0 and 40 °C. In order to verify these conditions and in order to use the correct values of the sound speed in post-processing, some measurements of wind speed have been performed during the activity using an anemometer connected to a data logger. Moreover measurements of air temperature and relative humidity of the air have been performed with a frequency acquisition of $1.7 \cdot 10^{-3}$ Hz using two probes equipped with internal memory, each arranged on one side of the barrier. All the measurements of sound reflection performance have been carried out in wheatear conditions in which all the limit values fixed for the meteorological parameters in the technical specifications were satisfied.

4 Results of *in situ* measurements

The impulse responses for all the analyzed configurations have been obtained using MLS sound signals (MLS order N=15, MLS signal length T=0.68 s) and subsequently post-processed, in accordance with what is indicated in [6]. The post processing of impulse responses has been performed using a sample rate f_s=48 kHz ($f_s > f_{s,min}$=43 Hz, minimum value indicated in [6]).

Before proceeding to the determination of the performance indexes, all the recorded signals have been filtered by anti-aliasing Butterworth filter of order 20, with the cut-off frequency of the filter f_{co}=10 kHz, f_{co} is smaller than the upper limit value $f_{co,max}=k \cdot f_s$=12 kHz indicated in [6] (with k=0.25 for the Butterworth filters).

With reference to the *in situ* measurements of sound reflection, for all analyzed configurations the sound reflection index RI as a function of frequency has been calculated, using the signal subtraction technique [6] to obtain the reflected component from the overall impulse response, and performing the windowing operations with Adrienne temporal window [6], in order to amplify the signal portions most useful for the study of the phenomenon investigated.

In the graphs of Fig. 4 and Fig. 5 the RI values at the central frequencies of the one-third octave bands (from 100 Hz to 5 kHz) are reported. The RI values are obtained respectively for the configurations consisting of panels completely smooth (LAAS configurations, see Tab. 1) and for the configurations with machined surfaces (IAAS configurations, see Tab. 1).

From the analysis of Fig. 4 and Fig. 5 it is possible to highlight, in a quantitative way, such as the increase of the surface covered by semi-cylindrical acoustical absorbers produces a reduction of the RI at all the frequencies in the range from 100 Hz to 5 kHz. This effect is particularly evident from a comparison between the RI values obtained for the configuration without acoustical absorbers (IAAS/0) and for the configurations, realized starting from the same barrier, with the addition of acoustical absorbers (IAAS/18 and IAAS/25).

When the RI index has been evaluated as a function of frequency it is possible to characterize the analyzed barrier with a single index that takes into account the behavior of the sound reflection at all the frequencies. This index, named single-number rating of sound reflection DL_{RI} is defined as [6]:

$$DL_{RI} = -10 \cdot \lg \left[\frac{\sum_{i=4}^{18} RI_i \cdot 10^{0.1 \cdot L_i}}{\sum_{i=4}^{18} 10^{0.1 \cdot L_i}} \right] \quad (1)$$

where L_i is the sound pressure level due of the traffic noise as defined in [6] for the i-th central frequency of one-third octave bands.

In Tab. 2 the DL_{RI} values obtained for all the analyzed configurations are reported with the quality class [6] that can be assigned to the different configurations of the barriers.

Lacking laboratory tests relating to the acoustical performance of the analyzed barriers and therefore not having available values for the DLα index as defined in [6], the quality class of each configuration has been assigned by comparing directly the values obtained from *in situ* measurements DL_{RI} with the limit values of quality class given in [6].

The use of the DL_{RI} index for the determination of the quality class, as well described in [7-9], is conservative with respect to the actual performance of the barriers.

Since the distribution of semi-cylinder acoustical absorbers is non-uniform on the surfaces of the barriers exposed to noise (see Figure 2), the *in situ* measurements of sound reflection performance have been repeated for some significant configurations by positioning the complex loudspeaker-microphone in order to obtain different MSAs.

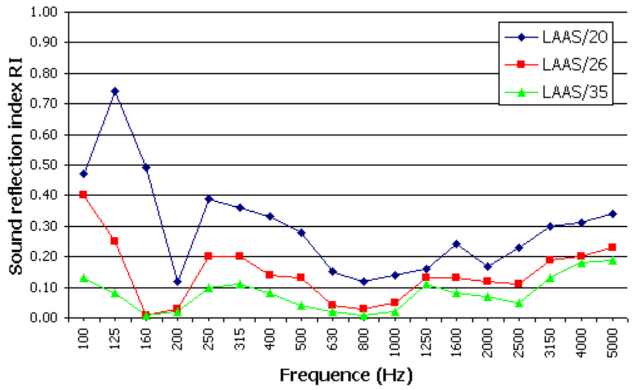

Figure 4: results of *in situ* measurements of sound reflection index as a function of frequency for the LAAS configurations.

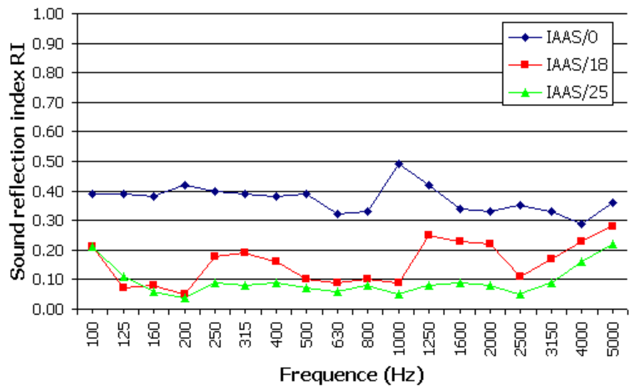

Figure 4: results of *in situ* measurements of sound reflection index as a function of frequency for the IAAS configurations.

Tab. 2: single-number rating DL_{RI} values and quality class for all the analyzed configurations.

Configuration	DL_{RI} (dB)	Quality class [6]
LAAS/20	6.6	A2
LAAS/26	9.6	A3
LAAS/35	12.0	A4
IAAS/0	4.2	A2
IAAS/18	8.1	A3
IAAS/25	11.1	A4

By way of example in Fig 6, for the configuration LAAS/35, 3 different positions of the complex loudspeaker-microphone (vertical planes orthogonal to the surface of the barrier on which the rotations indicated in the measurements procedures have been carried out)and the respective MSAs are shown.

The axis indicated by C in Fig. 6 represents the positioning of the loudspeaker-microphone on the vertical plane passing through the center of the barrier, the axes indicated by Sx and Rx represent positions of the complex loudspeaker-microphone shifted of 1 m respectively towards left and right from the center of the barrier.

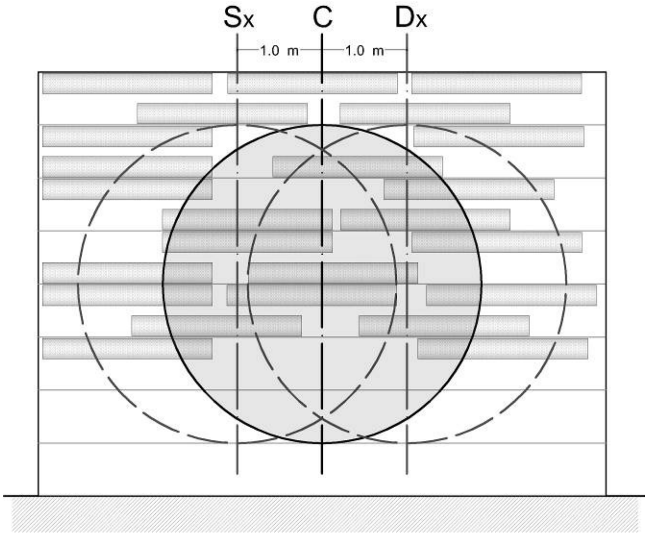

Figure 6: indication of the vertical planes used in the *in situ* measurements for the positioning of the complex loudspeaker-microphone and representation of the relative MSA.

From the analysis of the Fig. 6 it is possible to note that for different MSAs correspond different surfaces that are covered by the semi-cylindrical acoustical absorbers. In Tab. 3 the surfaces covered by the absorbers S_A, the percentages of coverage of the MSA and the DL_{RI} values obtained for different positions are indicated.

From the analysis of the values reported in Tab. 3, it can be observed that the increase of the percentage of absorbers contained in MSA corresponds to a reduction of DL_{RI}. In particular, passing from position Dx to position Sx, an increase of 18% of S_A can be obtained which corresponds to a reduction of DL_{RI} of about 6%.

In Fig. 7 the results of *in situ* measurements of RI as a function of frequency obtained for different MSAs of the LAAS/35 configuration are shown.

Tab. 3: surfaces covered by the absorbers, percentages of coverage of the MSA and DL_{RI} values for LAAS/35 configuration.

Position	**MSA (m^2)**	**S_A (m^2)**	**S_A/MS A(%)**	**DL_{RI} (dB)**
C		4.7	39	12.0
Sx	12.1	5.5	45	12.7
Dx		4.5	37	11.9

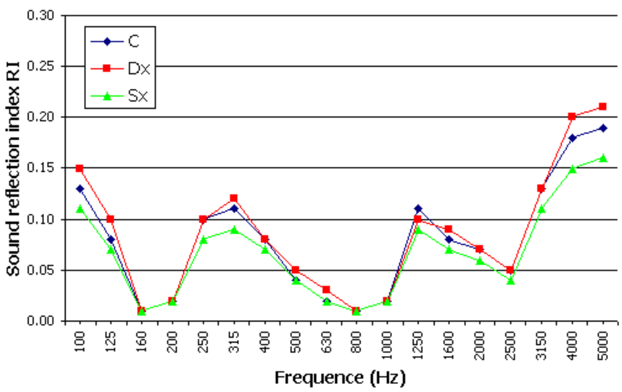

Figure 7: results of *in situ* measurements of sound reflection index as a function of frequency for different MSAs (LAAS/35 configuration).

As can observed from Fig. 7, the most significant differences between the different positions, and consequently between different MSAs, are obtained for frequencies between 250÷400 Hz, and for frequencies above 3150 Hz, the frequencies for which, especially for the LAAS configurations, the effect of the presence of semi-cylindrical acoustical absorbers is more important (see Fig. 4).

5 Conclusions

In this paper the results of the analysis of *in situ* acoustical performance of concrete noise barriers are reported and discussed. The barriers are installed in an important highway infrastructure of the Central Italy. The analyzed noise barriers can be realized in different configurations. The faces of the barriers exposed to the noise source can be smooth or machined with high pressure water jets and on these faces can be applied semi-cylindrical acoustic absorbers specially designed. From the results of the in situ measurements it can be observed that the higher quality class (A4) can be assigned to the analyzed barriers if a sufficient amount of semi-cylindrical acoustical absorbers is applied on their surfaces.

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