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# IN SITU STUDIES OF SOUND INSULATION INDEX OF NOISE BARRIERS

*SUMMARY*

*Outdoor noise barrier is roadside noise reducing device, the primary task of which is the protection of a predetermined sound protection area against road traffic noise. The examinations of acoustic properties of the elements used for construction of noise barriers are usually carried out in laboratory conditions according to the PN-EN 1793-1,2 standard. These examination procedures cannot be applied to existing installations. Therefore problems that are usually neglected are the problems related to the acoustic properties that essentially depend on a series of factors unrelated to the building elements themselves, namely: barrier dimensions, quality of workmanship, barrier location and the type and topography of the ground foundation. In the European Research Project "Adrienne" a methodology has been elaborated for in-situ determination of acoustic parameters of noise barriers. The examination, in which analysis of the system's impulse response after MLS signal actuation and a proper numerical algorithm are applied, leads to determination of airborne sound insulation of the existing constructions as well as the single number sound reflection factors and differences of diffraction properties at the top-edge elements of the barriers. The present paper describes the possibilities of determination of the intrinsic characteristics of airborne sound insulation index for the road traffic noise reducing devices in free field conditions and the determination of single number rating of airborne sound insulation to indicate the performance of the noise barrier.*

***Keywords***: *airborne sound insulation. noise barrier, test methods, in situ measurement*

*BADANIA IZOLACYJNOŚCI AKUSTYCZNEJ EKRANÓW W WARUNKACH TERENOWYCH*

*Ekran akustyczny jest drogowym urządzeniem przeciwhałasowym, którego zasadniczym zadaniem jest ochrona przed hałasem komunikacyjnym terenów chronionych akustycznie. W warunkach laboratoryjnych badania właściwości akustycznych elementów do budowy ekranów akustycznych prowadzone są według wymagań norm PN-EN 1793-1,2. Tych procedur badawczych nie można zastosować do instalacji już wybudowanych. Zatem pomijany jest problem dotyczący właściwości akustycznych, które zależą od wielu czynników, niezwiązanych tylko z wyrobem budowlanym, takich jak: wymiary ekranu, jakość wykonania, usytuowanie i związane z tym rodzaj oraz geometria podłoża. W ramach europejskiego projektu „Adrienne" opracowano metodykę wyznaczania parametrów akustycznych ekranów w warunkach in situ. Pomiary, w których wykorzystuje się analizę odpowiedzi impulsowej układu przy pobudzeniu sygnałem MLS i odpowiedni algorytm obliczeniowy, prowadzą do wyznaczenia izolacyjności akustycznej rzeczywistych konstrukcji oraz jednoliczbowych wskaźników odbicia dźwięku i różnicy dyfrakcji dla krawędziowych elementów ekranów. W pracy przedstawione są możliwości wyznaczania charakterystyk rzeczywistych izolacyjności akustycznej od dźwięków powietrznych dla drogowych urządzeń przeciwhałasowych w warunkach terenowych i wyznaczenia jednoliczbowego wskaźnika oceny izolacyjności akustycznej.*

***Słowa kluczowe***: *izolacyjność akustyczna, ekrany akustyczne, metody badań, pomiary akustyczne in situ*

## 1. INTRODUCTION

Outdoor noise barrier is a natural or artificial obstacle on the propagation path of the acoustic wave, occurring between sound source (a transportation road) and the reception location, situated in the sound protected area. The primary task of the noise barrier is the formation of an acoustic shadow, or a zone that cannot be reached directly by the acoustic wave. The noise barriers are included to the roadside protection group – exactly to the roadside traffic noise reduction devices. From the application point of view the important characteristics of sound barriers are the acoustic parameters of its construction elements. They are specified as:

– the intrinsic sound-reflection characteristics;
– the intrinsic airborne sound insulation index.

The acoustic properties of the noise barrier elements are determined in a specialized laboratory and they are expressed as single number rating of sound insulation index $DL_R$ and a single number rating of sound-absorption $DL_\alpha$. The acoustic parameters of the noise barriers can be also determined *in situ*, i.e. in their actual locations. The reference methods for determination of these parameters *in situ* are presented in papers (Clairbois *et al*. 1998; Garai 1993; Garai and Guidorzi 2000; Mommertz 1995). In the *in situ* conditions one can also determine the differential diffraction factor for the edge elements located at the top-edge of the sound barrier (EN 1793-4). The methods for determination of acoustic characteristics of noise barriers *in situ* have been elaborated during a series of studies by research institutions, implemented during the European Research Project "Adrienne", the results of which have been presented in (Garai and Guidorzi 2000). The evaluation of the sound barrier application effect is characterized by acoustic performance measured *in situ* (EN 1793-1). The acoustic

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performance is expressed in decibels and is calculated as the difference between the sound levels measured in the reception location before and after the application of the noise barrier. The acoustic performance is determined by the direct or indirect method, depending on the development stage of the construction. In further sections of the paper a method is presented for determination of the airborne sound insulation for noise barriers in post-development conditions.

## 2. ACOUSTIC PROPERTIES OF THE ROADSIDE SOUND BARRIERS

The noise barrier should, according to (EN 1793-1), exhibit a proper airborne sound insulation index value, i.e. such that the level of the sound penetrating directly through the barrier should be considerably lower than the level of the sound diffracted at the top-edge of the screen. The building elements applied in construction of the sound barriers are tested in laboratory conditions, according to procedures specified in the standards (EN 1793-1, EN 1793-2, EN 1793-5). Results of these tests provide the acoustic parameters of these elements. The obtained values are the sound-absorption coefficients $\alpha_{Si}$ for each 1/3 octave wide frequency band in the frequency range from 100 Hz to 5 kHz and the characteristics of the intrinsic sound insulation index $R_i$ in 1/3 octave frequency bands in the frequency range from 100 Hz to 5 KHz. For determination of the element's properties the respective averaged values are used, taking into account the normalized sound spectrum of the traffic noise (EN 1793-3), being single number evaluation coefficients, calculated in dB:

- single number rating of sound absorption evaluation $DL_\alpha$;
- single number rating of the airborne sound insulation index $DL_R$.

### 2.1. Airborne sound insulation index

The single number rating $DL_R$ characterizes the airborne acoustic insulation power of the sound barrier elements in a situation when the sound generated by the stream of vehicles (traffic noise) reaches the sound barrier plane without any reflections from additional surfaces and the effects of sound diffraction on the barrier edges are not taken into account. In cases when there are additional, often multiple reflections in the vicinity of the barrier or when the diffraction effects on the barrier edges have to be taken into account it is necessary to characterize the barrier element properties as a function of frequency, in particular for the lower frequency band.

This single number rating is also used for classification of the airborne insulation performance for construction elements according to the introduced single number rating system from B0 to B3 (see Tab. 1).

**Table 1**

Airborne sound insulation $DL_R$ is categorized using a single number rating system

| Category | $DL_R$, dB |
|---|---|
| B0 | Not determined |
| B1 | < 15 |
| B2 | 15 do 24 |
| B3 | > 24 |

Determination of the sound insulation power *in situ* is a non-invasive method, which allows testing of the supplied quality of the barrier elements, according to specification, as well as the preservation of acoustic properties in the progress of exploitation period. The measurement results in the laboratory and *in situ* conditions are not fully comparable, because in the laboratory conditions the scattered field measurement methods are applied, while the in situ measurements are carried out using the direct incident sound in free field conditions. However multiple experiments indicate a very good correlation between the results obtained from studies carried out according to procedures described in (EN 1793-2) and (EN 1793-5).

### 2.2. *In situ* examinations of the acoustic barriers

In the measurements the applied method makes use of the digital pseudo-random MLS (*maximum length sequence*) signal. After executing proper mathematical calculations, using the primary MLS signal and the response of the analyzed system to the signal as input data, one can determine the impulse response of the analyzed system, and consecutively its frequency response. An essential advantage of the MLS signal measurements is its high resistance to external noise (noise background level), what is especially important when the measurements are carried out in a near vicinity of active transportation roads.

The measurement system (Fig. 1) has been actuated using the MLS signal (signal parameters: order $N$ = 16, length $L$ = 65535 samples, sampling frequency $f_p$ = 48 kHz, signal duration $T_s$ = 1,37 s, anti-aliasing filter limit frequency $f_{co}$ = 10 kHz), send from a two-channel Bruel&Kjaer sound-card, through Elmuz 2258M amplifier to a MONACOR SPH-176 loudspeaker. In the reception point the signal has been registered by a ½" free-field microphone GRAS 40AF type. After signal registration the cross correlation between generated and received signals has been determined. After signal separation the isolated impulse responses have been subject to spectral analysis using the FFT algorithm, taking into account the geometrical differences of the propagation paths for various locations of the loudspeaker and the microphone. In order to obtain information about the spectral characteristic the spectral data obtained from FFT are converted to 1/3 octave and 1/1 octave frequency bands. From the values obtained for the 1/3 octave frequency bands in the range from 100 Hz to 5000 Hz the barrier's sound insulation index $SI_j$ is calculated.

For determination of the sound insulation index $SI_j$. the measurements are carried out for 9 measurement points distributed as shown in Figure 2. The distances of individual points in the measurement mesh are equal to $s$ = 0.4 m. The center line of the system of measurement points is located at half value of the barrier height (H/2).

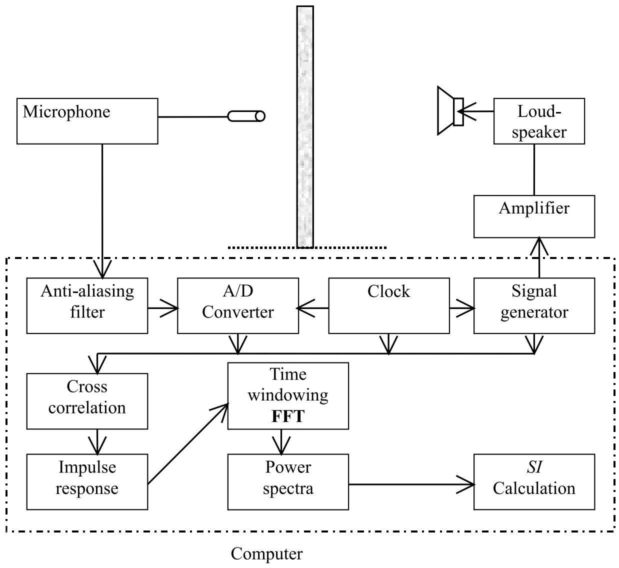


**Fig. 1.** Block scheme of the measuring system

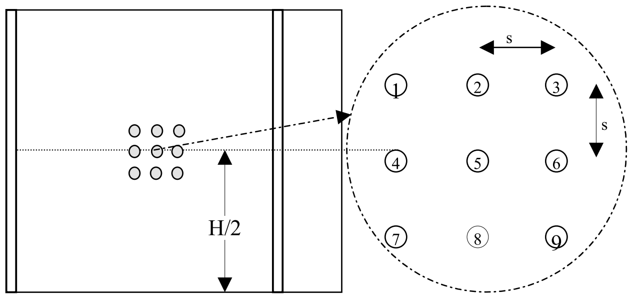


**Fig. 2.** Distribution of the measuring points at the barrier plane

Numerical value of the coefficient for individual 1/3 octave frequency bands are calculated from the following formula [9]:

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

where:

$h_i(t)$ – the incident reference component of the free field impulse response,

$h_{ik}(t)$ – the transmitted component of the impulse response at the $k$-th measuring point ($k$ = 1, 2, …, 9),

$d_i$ – the geometrical spreading correction factor for the reference free field component,

$d_k$ – the geometrical spreading correction factor for the transmitted component at the $k$-th measuring point,

$w_i(t)$ – the reference free field component time window (*Adrienne window*),

$w_{i,k}(t)$ – the time window for the transmitted component at the $k$-th measuring point,

$\Im$ – the symbol of the Fourier transform,

$j$ – 1/3 octave frequency band index (between 100 Hz and 5 kHz),

$\Delta f_i$ – the width of the 1/3 octave frequency band.

The obtained values of sound insulation index in 1/3 octave frequency bands allow the determination of a single number rating of airborne sound insulation $DL_{SI}$. Such a coefficient is calculated for two cases characterizing the barrier construction: one for the construction element filling the space between the barrier supports, and the other for the barrier support element itself. The single number rating of airborne sound insulation for both measurement cases is determined from the formula (2).

$$DL_{SI} = -10\log\left[\frac{\sum_{i=m}^{18}10^{0.1L_i}10^{-0.1SI_i}}{\sum_{i=m}^{18}10^{0.1L_i}}\right] \quad (2)$$

where:

$m$ = 4 (the number attributed to $f$ = 200 Hz for 1/3 octave frequency band,

$L_i$ – relative A-weighted sound pressure levels of the normalized traffic noise spectrum in the $i$-th frequency band, 1/3 octave wide, defined as in (EN 1793-3).

## 3. EXPERIMENTAL STUDIES OF ROADSIDE BARRIERS

The studies of airborne sound insulation power have been carried out on real objects (see Fig. 3). All in situ measurements have been carried out according to the methodology described above. Figure 4 presents the results for the "green wall" sound barrier of 10 cm thickness and 4m height. Figure 4a presents the values of sound insulation index in 1/3 octave frequency bands for measurements carried out at the front of the sound barrier panel, while Figure 4b presents the results of measurement in front of the post between the panels. For both cases single number sound insulation index have been calculated and the plots also show the respective curves of reference values for the airborne sound insulating power (according to EN ISO 717-1).

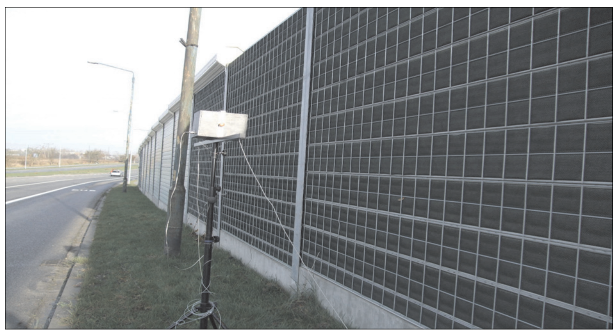

**Fig. 3.** In situ measurements of the sound insulation index

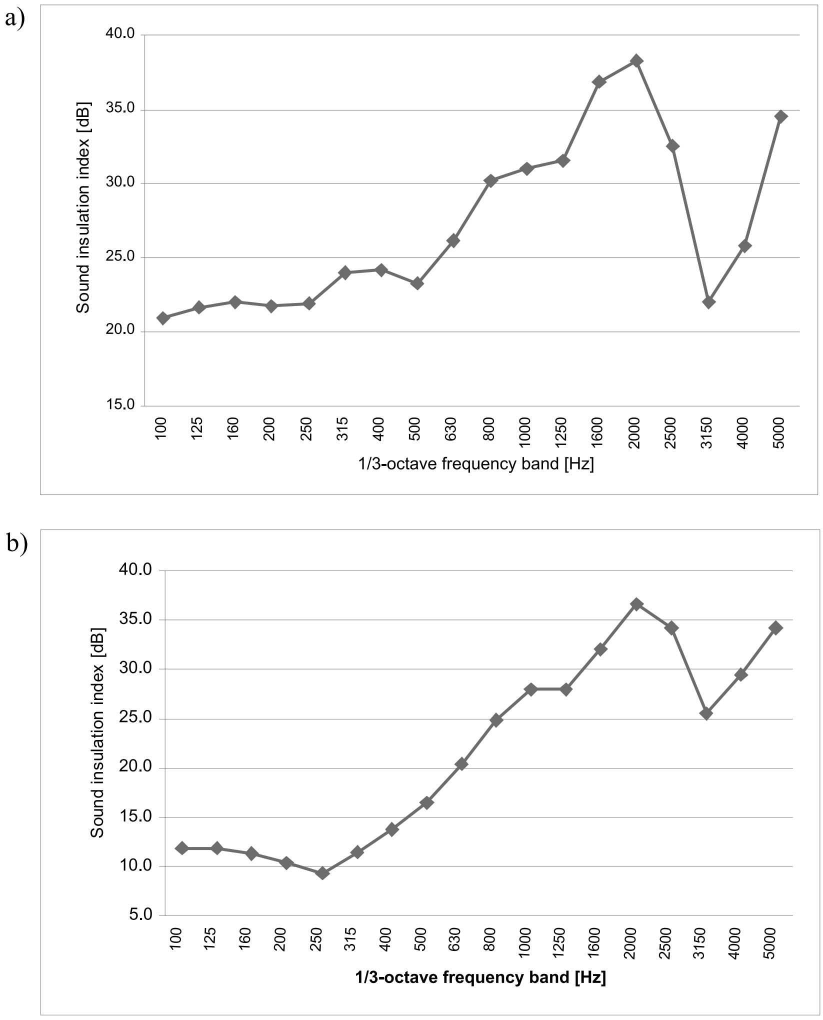


**Fig. 4.** The values of the airborne sound insulation index SI: a) result of measurements in front of an acoustic element; b) result of measurements in front of a post

The results of the in situ measurements have been compared to examinations of a similar type barrier in the reverberation chamber conditions. The results indicate a good convergence of the sound insulation indices for the full panel case in the individual frequency bands. The differences can result from measurements carried out in various acoustic field conditions and various mounting details of the panel elements. On the other hand the measurements carried out on the support poles of the panel elements clearly indicate that some flaws in the mounting of panel elements are present. This is also confirmed by a direct evaluation the workmanship quality of the sound barrier assembly. The MLS technique allows effective measurement execution in situ. Particularly important are the requirements of small differences between the signal sound level and the noise background level, which can be quite high in the vicinity of an active transportation road.

## 4. CONCLUSIONS

The acoustic studies of roadside noise reduction devices executed in situ do not require special laboratory measurement chambers. The new measurement technique enables the determination of airborne sound insulation characteristics for the elements of the sound barrier in their actual location. It offers a tool for verification of the workmanship quality during assembly of these roadside devices (the quality of connections between the panel elements or connections between the panels and posts etc.) as well as quality control of the construction elements supplied to the location by their manufacturer. The applied measurement methodology is fully compliant with the EU standards with respect to determination of acoustic characteristics for the road traffic noise reducing devices.

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## References

Clairbois J.-P., Beaumont J., Garai M., Schupp G. 1998, *A new in situ method for the acoustics performance of road traffic noise reducing devices*. Proc. ICA/ASA 98, Seattle, USA, pp. 471–472.

EN 1793-1 (1997), *Road traffic noise reducing devices — Test method for determining the acoustic performance — Part 1: Intrinsic characteristics of sound absorption*.

EN 1793-2 (1997), *Road traffic noise reducing devices — Test method for determining the acoustic performance — Part 2: Intrinsic characteristics of airborne sound insulation*.

EN 1793-3 (1997), *Road traffic noise reducing devices — Test method for determining the acoustic performance — Part 3: Normalized traffic noise spectrum*.

EN 1793-5 (2002), *Road traffic noise reducing devices — Test method for determining the acoustic performance — Part 5: Intrinsic characteristics – In situ values of sound reflection and airborne sound insulation*.

Garai M. 1993, *Measurement of the sound-absorption coefficient in situ: the reflection method using periodic pseudo-random sequences of maximum length*. Appl. Acoust. 39, pp. 119–39.

Garai M., Guidorzi P. 2000, *European methodology for testing the airborne sound insulation characteristics of noise barriers in situ: experimental verification and comparison with laboratory data*. J. Acoust. Soc. Am., 108(3), pp. 1054–1067.

Garai M., Guidorzi P. 2000, *Experimental verification of the European methodology for testing noise barriers in situ: sound reflection*.

Mommertz E. 1995, *Angle-dependent in-situ measurements of reflection coefficients using a subtraction technique*. Appl. Acoust. 46, pp. 251–263.

EN 1793-4 (2002), *Road traffic noise reducing devices – Test method for determining the acoustic performance – Part 4: Intrinsic characteristics – In situ values of sound diffraction*.