Austrian investigation on the influence of sound leakage in noise reducing devices

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Noise barriers are the most widely used means for road traffic noise abatement. Sound absorption and sound insulation are the key properties for noise barrier elements. The standard method of determining these properties by reverberation room measurements has recently been complemented by an in-situ method following CEN/TS 1793-5, also known as Adrienne method. This method allows flexible assessment of the acoustic performance of noise barriers in almost arbitrary places by means of mobile measurement equipment. Using the possibility to perform in-situ measurements the authors have investigated the presence of sound leakage due to structural imperfections which limit the sound insulation performance of noise barriers. This paper summarizes the results of Austrian research on different kinds of barriers regarding the difference in sound insulation between measurements carried out in front of the supporting post (where leakage is likely to occur) and in the middle of the barrier. A statistical correlation of the data was also performed.

1   Introduction

The most widespread technical solution for reducing the noise exposure of people living alongside roads, highways and railways is the installation of traffic noise reducing devices. Noise barriers generally consist of acoustically active elements made of aluminum, wood or concrete combined with absorptive rock wool or other porous materials and supporting parts which hold the active elements in place.

Airborne sound insulation is surely the most relevant property of a noise barrier, which indicates its ability to block the transmission of sound through the barrier. If the sound insulation of a barrier is sufficient, the sound waves have to travel around the edges of the barrier to reach the receiver behind it, which leads to a considerably longer propagation path and therefore attenuation of the noise. In cases where the sound energy that is reflected back from the surface of the noise barrier would cause problems, it sufficient sound absorption is essential. Absorbing surfaces reduce the reflected amount of sound energy by transforming it into heat energy through friction effects.

For this reason the problem of vertical and horizontal leakage due to the presence of gaps or construction faults represents a very important issue by characterizing the in-situ acoustic performance of noise barriers.

The most frequently type of leakage is maybe the vertical one, due to the presence of the post. In this region it is easier to have gaps in the continuity of the construction and the sound energy can be transmitted more easily than in front of the principal element of the noise barriers. The main topic of this paper is the investigation of different types of noise barriers concerning the vertical leakage due to the presence of the post.

2   The laboratory method

Noise barriers are currently classified following the standards EN 1793-1 [1], „Road traffic noise reducing devices – Test method for determining the acoustic performance – Part 1: Intrinsic characteristics of sound absorption" and EN 1793-2 [2], „Road traffic noise reducing devices – Test method for determining the acoustic performance – Part 2: Intrinsic characteristics of airborne sound insulation". These methods use reverberation chambers and diffuse sound fields, which is quite a different setup compared to the in-situ method. Therefore different results may be expected.

The classification of noise barriers is also economically very relevant, because noise barriers with low sound insulation and sound absorption are barred from certain applications. The required insulation and absorption classification is stated in tenders of road and rail administrations, which in practice fixes a minimum of required performance.

3   The in-situ method

The so called Adrienne method is a very flexible in-situ method to measure the acoustic properties of a noise barrier. This measurement method is described in the technical specification CEN/TS 1793-5 [3], "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". This standard examines two different properties of noise barriers: sound absorption and sound insulation.

The topic of the paper is the investigation of the vertical leakage due to the presence of the post for sound insulation; therefore we will not take into account sound absorption and we will only present a short summary regarding the measurements method of airborne sound insulation.

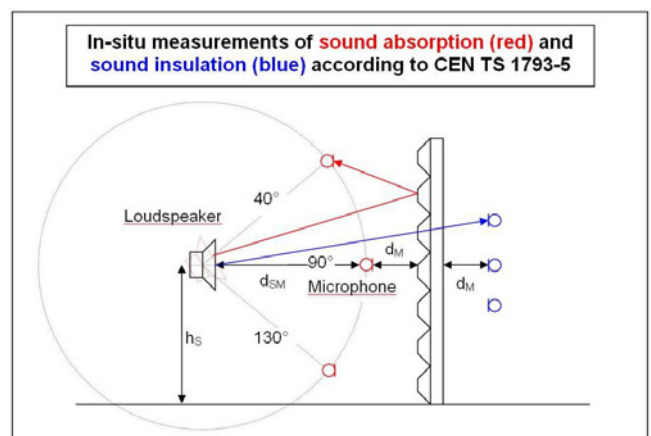In Fig.1 the standard setup for the measurement according to CEN/TS 1793-5 is shortly delineated.

.Fig.1 Setup for the measurements for airborne sound absorption (red line) and airborne sound insulation (blue line) according to the CEN/TS 1793-5.

To adopt this method we have to use a loudspeaker emitting a spherical sound wave, which impinges on the noise barrier surface. Either the reflected or the transmitted (and diffracted) sound is measured at the microphone positions.

Each type of measurement requires a free-field measurement without the noise barrier as a reference.

The used signal is a Maximum Length Sequence (MLS) signal which allows the determination of the impulse response with a very high signal-to-noise ratio. The height of the loudspeaker has to be half of the height of the measured barrier.

A time window, also called "Adrienne" window, is then applied to the impulse responses to filter out unwanted reflections from the ground or other nearby objects in the time domain. Fig.2 shows the Adrienne window and an example of the transmitted impulse response.
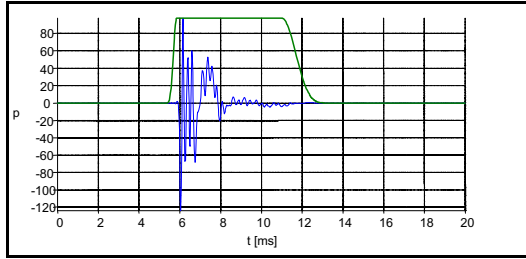

,Fig.2 Impulse response of the transmitted sound wave (blue line) and Adrienne window (green line).

The sound source emits a signal that travels towards the device under test and is partly reflected, partly transmitted and partly diffracted by it. The microphone placed on the other side of the device receives the transmitted sound and the diffracted sound.

The impinging sound energy is determined by measuring the impulse response at the microphone position without the noise barrier in free field. Both impulse responses are corrected for geometrical attenuation, assuming spherical sound wave propagation. The sound insulation measurement setup shows 9 microphones forming a square grid with a side of 0.8 m close behind the sound barrier.

In this setup the impulse response received at the microphone positions is compared to the impinging sound energy. The power spectra of the direct wave and the transmitted wave corrected to take into account the path length difference of the two waves, gives the basis for calculating the sound insulation index.

The lowest frequency that can be measured with this method depends on the height of the barrier.

The results undergo a Fast-Fourier-transform and are presented as reflection coefficients in third-octave bands. Equation (1) shows the definition of the sound insulation index SI:

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

$h_i(t)$ is the incident reference component of the free-field impulse response;

$h_{t,k}(t)$ is the transmitted component of the impulse response at the k-th angle;

$d_i(t)$ is the geometrical spreading correction factor for the reference free-field component;

$d_k(t)$ is the geometrical spreading correction factor for the transmitted component at the k-th scanning point (k=1,… , n);

$w_i(t)$ is the reference free-field component time window (Adrienne window);

$w_{tk}(t)$ is the time window for the transmitted component at the k-th scanning point (Adrienne window);

t is the time from the beginning of the impulse response;

Δf_j j-th 1/3 octave frequency band (from 100 Hz to 5000 Hz);

n is the number of scanning points;

F is the symbol of the Fourier transform.

The final sound insulation index SI is the logarithmic average of the sound insulation indices measured at the nine positions of the grid. The results shall be converted into the single number rating DL_{SI}, in decibels, using the spectrum from EN 1793-3 [4]. This index describes the insulation properties of the barrier. The definition of the single number rating of the sound insulation index DL_{SI} is described in equation (2).

$$DL_{SI} = -10 \cdot \lg \left(\frac{\sum_{i=m}^{18} 10^{0,1 \cdot L_i} \cdot 10^{-0,1 \cdot SI_i}}{\sum_{i=m}^{18} 10^{0,1 \cdot L_i}} \right) \quad (2)$$

$m = 4$ number of the 200 Hz- third octave frequency band;

L_i dB (A)-value of the i-th 1/3 octave band of the normalized traffic noise spectrum according to EN 1793-3.

In this paper the single number rating of measurements carried out in front of the post will be denoted with $DL_{SI,P}$ and the single number rating of measurements carried out in front of the element with $DL_{SI,E}$.

The Adrienne method has been designed to overcome the disadvantages of the laboratory method using a reverberation chamber (see paragraph 2). The biggest advantage of the Adrienne method is the possibility to test the acoustic performance with mobile equipment in-situ and that no special test rooms are needed. It is also possible to test the acoustical long-term performance of the barrier in order to test its durability and to investigate construction errors like in the case of the present research.

4   Measured samples

The measurements were carried out by arsenal research with the Adrienne method for airborne sound insulation in the years 2001-2003 on noise barriers in use at the roadside as well as on sample constructions on the manufacturer's premises [5].

Austrian noise barrier elements can be divided into three main categories based on the materials used for the acoustically active elements. All standard noise barriers alongside roads are mounted using steel posts to hold the active elements and a concrete pedestal of 0.5 m height.

For the present study 14 different barriers have been used: 4 are made of aluminium, 6 of timber and 4 of cement-bound wood chipping.

Elements of the first type are aluminium cassettes containing absorbing and insulation components. The second type of barriers uses timber constructions to hold the absorbing material in place. The third variety uses bricks or sheets of cement-bound wooden chippings, sometimes in combination with concrete to create a porous sound-absorbing surface.

Figure 3 shows some examples of which noise barriers measured within this investigation.

.Fig.3 Test equipment during the measurements on the most common Austrian noise barriers (made of aluminums, timber and cement-bound wood chipping).

Figure 4 represents the grid of the 9 microphone positions for the measurements of airborne sound insulation. The position 5 is in the middle of the barrier, the grid is a square with 80 cm side length.
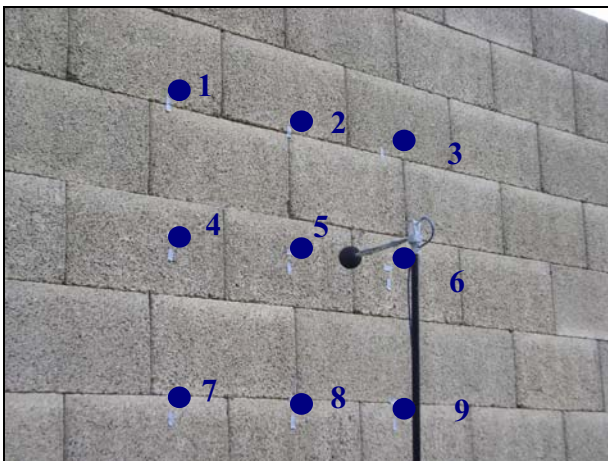

.Fig.4 The 9 microphone positions for the measurements of airborne sound insulation according to CEN/TS 1793-5 (the point 5 is in the middle of the noise barriers element and the distance between all the points is 40 cm).

5   Results and correlations

The goal of this paper is the correlation between acoustic performance of the element and performance of the post. In order to improve this relationship a first comparison between the measurements in front of the posts and the measurements in front of the elements will be necessary.

The correlation will also be examined separately for each tested material and then a general correlation will be carried out.

5.1   Post-element comparison

Figure 5 represents clearly the effect of the vertical leakage due to the presence of the post. All measurements in front of the post yield a single number rating DL_{SI} lower than in front of the element (for all the 14 measured barriers $DL_{SI,E}$ is higher than $DL_{SI,P}$).
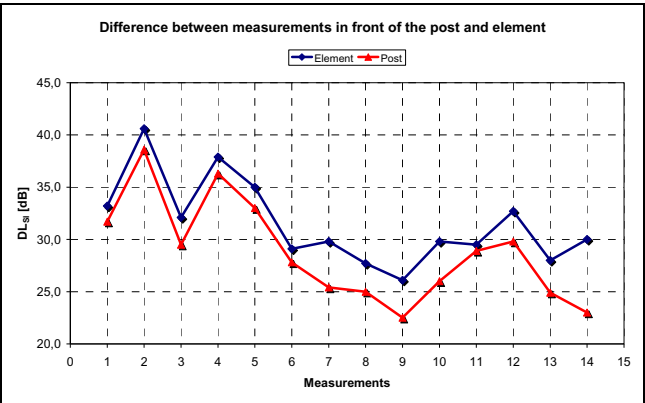

.Fig.5 Comparison of measurements of the sound insulation index DL_{SI} in front of the post (red line) and measurements in front of the element (blue line).

Figure 6 shows the difference between measurements of the post and of the elements, divided into the three materials. For the majority of the tested barriers this difference is between 1 and 4 dB. Only for the measurement Nr. 14 this difference is about 7 dB.
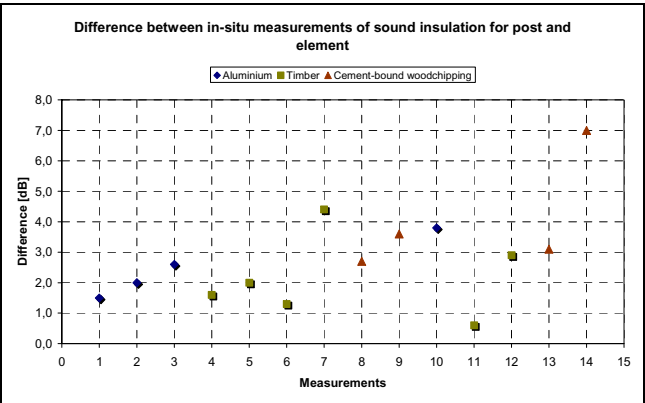

.Fig.6 Difference of the sound insulation index DL_{SI} between measurements in front of the post and measurements in front of the element, for three different materials.

5.2   Separate post-element correlations

The correlation between measurements in front of the post and in front of the element has first been carried out separately for each kind of noise barrier.

The level of correlation for the 4 tested noise barriers made of cement-bound wood chippings is very poor (R^2=0.01). The difference between $DL_{SI,P}$ and $DL_{SI,E}$ is between 2.7 and 7 dB.

A possible explanation of this result is that the height of two of these barriers was only 3 m, instead of the 4 m as written in the standard. A second important reason is represented by the small number of tested samples, not enough for statistical statements.

In Figure 7 the linear correlation for the barriers made of cement-bound wood chipping is shown.

Post-element correlation for in-situ measurements of sound insulation

◆ Cement-bound woodchipping — Linear (Cement-bound woodchipping)
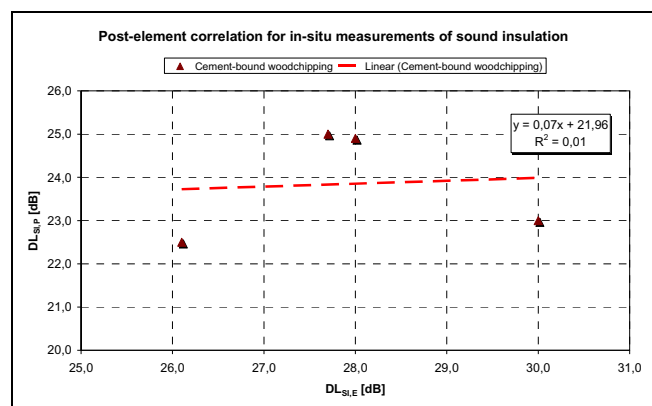
y = 0,07x + 21,96
R^2 = 0,01

Fig.7 Linear correlation between measurements in front of the post and in front of the element for 4 noise barriers made of cement-bound wood chipping.

The level of correlation for the 6 tested noise barriers made of timber is very high (R^2=0.88). The difference between $DL_{SI,P}$ and $DL_{SI,E}$ is between 0.6 and 4.4 dB.

Figure 8 shows the linear correlation for the barriers made of timber.

Post-element correlation for in-situ measurements of sound insulation

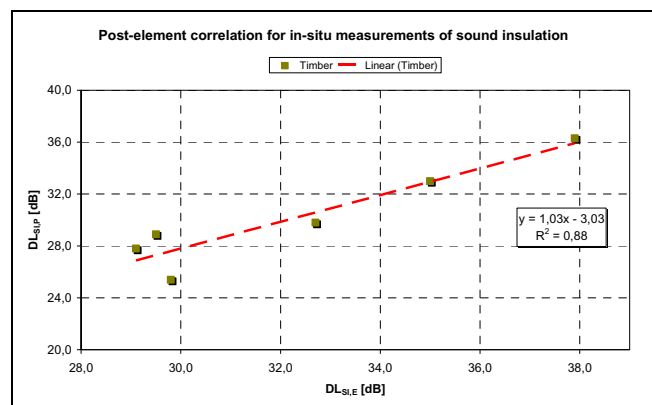■ Timber — Linear (Timber)

y = 1,03x - 3,03
R^2 = 0,88

Fig.8 Linear correlation between measurements in front of the post and in front of the element for 6 noise barriers made of timber.

The level of correlation for the 6 tested noise barriers made of aluminum is very good (R^2=0.98). The difference between $DL_{SI,P}$ and $DL_{SI,E}$ is between 1.5 and 3.8 dB.

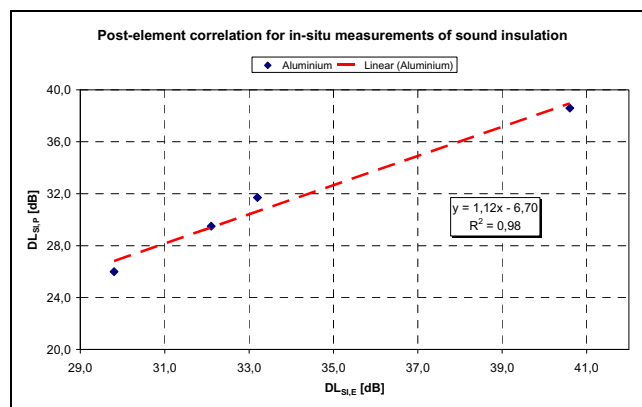In Figure 9 the linear correlation for the barriers made of aluminum is shown.

Post-element correlation for in-situ measurements of sound insulation

◆ Aluminium — Linear (Aluminium)

y = 1,12x - 6,70
R^2 = 0,98

Fig.9 Linear correlation between measurements in front of the post and in front of the element for 4 noise barriers made of aluminum.

5.3 Overall post-element correlation

In order to deduce a general relationship for the influence of the post on the sound insulation of the barrier, an overall linear correlation of the all measured barriers has been performed. The results show that if we consider all the 14 measurements the level of correlation becomes very good (R^2=0.90) despite the presence of two barriers with 3 m height. Figure 10 shows the overall linear correlation between measurements in front of the post and in front of the element for the 3 materials.

Post-element correlation for in-situ measurements of sound insulation

◆ Aluminium ■ Timber ▲ Cement-bound woodchipping
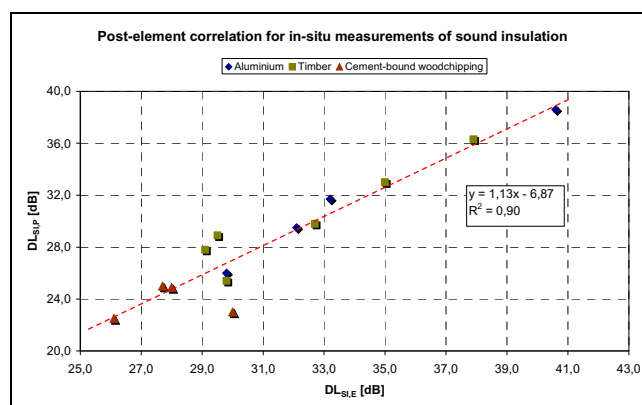
y = 1,13x - 6,87
R^2 = 0,90

Fig.10 Linear correlation between measurements in front of the post and in front of the element for the 3 materials (aluminum, timber and cement-bound wood chipping).

6 Conclusions

The investigation of decreased sound insulation in noise barriers due to gaps and posts is very relevant for the performance of noise barriers. In this paper an investigation of different types of noise barriers concerning the vertical leakage due to the presence of the post has been carried out.

The correlation between performance of noise barriers in front of the posts ($DL_{SI,P}$) and in front of the elements ($DL_{SI,E}$) for in-situ sound insulation was the main topic of this research.

The results show that if we consider all the 14 measurements the level of correlation becomes very good (R^2=0.90)

Concerning the results separated into the different kind of barriers, for barriers made of aluminum and for barriers made of timber the correlation levels are very high (respectively R^2=0.88 for timber and R^2=0.98 for aluminum). For the barriers made of cement-bound wood chipping the correlation level is very poor (only R^2=0.01). The reason for this could be the height of the barriers (3 m instead of minimum 4 m as written in the standard).

In the majority of the investigated cases the decrease of sound insulation in front of the post was found to be between 1 and 3 dB, with a possible tendency to slightly decrease with higher sound insulation values.

The influence of post and in general of the vertical and horizontal leakages on the airborne sound insulation needs anyway more investigations, because the number of the measured barriers is not statistically relevant and because the presence of the post is not the only cause of sound leakage for noise barriers.

References

[1] EN 1793-1 "Road traffic noise reducing devices – Test method for determining the acoustic performance – Part 1: Intrinsic characteristics of sound absorption", 1997, CEN

[2] EN 1793-2 "Road traffic noise reducing devices – Test method for determining the acoustic performance – Part 2: Intrinsic characteristics of airborne sound insulation", 1997, CEN

[3] EN 1793-5 "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", 2003, CEN

[4] EN 1793-3 "Road traffic noise reducing devices – Test method for determining the acoustic performance – Part 3: Normalized traffic noise spectrum", 1997, CEN

[5] Gerhard Rauscher, Manfred Haider, Johanna Bohrn, "Road traffic noise reducing devices – acoustic in-situ measurements", 2003, Road Research Programme of the Austrian Ministry for Transport, Innovation and Technology, Road Research Publication Vol. 547