In-situ testing of acoustical properties of noise barriers

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ABSTRACT

The acoustic performance of noise barriers is mainly determined by the insulation and the absorption of the noise barrier. To assure proper working of the noise barrier, contracts demand minimum values for the insulation and absorption. These minimum requirements are determined on test samples in the laboratory. Determination of the insulation and absorption in situ is hardly ever required.
However, in the past years we noticed an increasing interest for in-situ measurements to determine the insulation and absorption of noise barriers. Comparison between the results of laboratory and in-situ measurements is not straight-forward because of the diffuse, omnidirectional sound field in the laboratory and the limited angles of incidence in the field.
We conducted an extensive measurement program to compare the results of laboratory and in-situ measurements. The goal of this research is to enable validation of the requirements for lab-based acoustic requirements for insulation and absorption with in-situ measurement results. This will allow the manufacturers to optimize their designs for the best performance in the field. Also, this allows for COP testing and monitoring of the acoustic durability over time.

Keywords: Noise barrier, Insulation, Reflection
I-INCE Classification of Subjects Number(s): 51.4

1. Introduction

Noise barriers are commonly used as a noise mitigation measure. They can effectively prevent the propagation of the noise from the sound to the receiver as they function as obstacles between the noise source and the receiver. When a sound wave reaches the noise barrier three phenomena occur:

- **Reflection**: the sound wave reaching the exposed side of the noise barrier partly reflects. The amount of reflection is determined by the acoustical absorption of the noise barrier
- **Transmission**: The sound wave reaches the exposed side of the noise barrier and partly transmits through the noise barrier. This transmitted energy has to be as low as possible because the noise barrier should act an obstacle to the sound propagation. The transmission can be influenced by changing the insulation of the noise barrier
- **Diffraction**: part of the sound wave passes over the noise barrier. It diffracts on top of the edge and then propagates to the receiver.

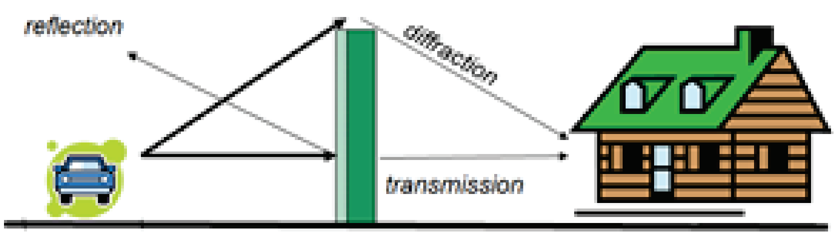

Figure 1 – Reflection, Transmission and diffraction at a noise barrier

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The amount of reflection, transmission and diffraction depends on the dimensions and the intrinsic acoustical properties of the noise barrier. Other influence factors are the position of the noise barrier, the transfer path itself and the meteorological conditions.

2. Quantification

The acoustic performance of noise barriers is thus mainly determined by the insulation and the absorption of the noise barrier. Therefore, contracts often specify minimum values for the insulation and absorption to assure proper working of the noise reducing device. These minimum requirements are determined on test samples in the laboratory. Determination of the insulation and absorption *in situ* is hardly ever required.

Still, in the past years we noticed an increasing interest for in situ measurements to determine the insulation and absorption of noise barriers, mainly because national road and railway authorities are increasingly looking for a test method for the conformity of production of noise barriers that are realized along a road or railway. Measurement methods to do so exist. It is not straight-forward, however, to compare the results of laboratory and in situ measurements. Differences between the results of these methods arise because of the diffuse, omnidirectional sound field in the laboratory versus the limited angles of incidence in the field.

Currently, we are conducting an extensive measurement program in which we perform insulation and absorption measurements both in the laboratory and in situ, so we can compare the results of laboratory and in-situ measurements. The goal of this research is to enable validation of the requirements for lab-based acoustic requirements, for both insulation and absorption, with in situ measurement results. This will allow the manufacturers to optimize their designs for the best performance in the field. Also, this allows for COP (Conformity of Production) testing and monitoring of the acoustic durability over time.

3. Measurement methods

The European standard EN-1793 describes the methods to determine the insulation and absorption of noise reducing devices, in the laboratory as well as in-situ.

3.1 Acoustic insulation

3.1.1 Laboratory measurement

EN 1793-2 (2) specifies the laboratory method to determine the acoustic insulation of road traffic noise reducing devices. The measurements are performed in reverberant conditions. The EN 1793-2 standard covers the assessment of the intrinsic performance of barriers that can reasonably be assembled inside the testing facility described in EN ISO 10140-2 (5) and EN ISO 10140-4 (6). The sound reduction indices R_i for each third octave band between 100 and 5 kHz are determined. In addition, the single number rating is DLR_i is derived from these values and is used to indicate the performance of the noise barrier.

3.1.2 In situ measurement

The in situ measurement to determine the acoustic isolation is specified in EN 1793-6 (4). An artificial sound source emits a transient sound wave that travels towards the noise barrier under test. The sound wave is partly reflected, partly transmitted and partly diffracted. A square array with nine microphones is placed behind the noise barrier. The microphones register both the transmitted and the diffracted noise. The direct free field sound wave can be obtained by performing the same measurement on a similar location, without the noise barrier. The sound insulation index, *SI*, can be calculated from the ratio of the acoustic power of the direct and the transmitted components. *SI* is a dimensionless quantity in dB expressed in third octave bands. It can be used to derive the single value indicator, DL_{SI}. A picture of the microphone array is given in the figure below.

Figure 2 – Microphone array to determine the sound insulation

3.1.3 Comparison of both measurement methods

The results of the in situ measurement are comparable but not identical to the results of the laboratory measurement (see 4.1). The main reason for the results not being identical is that the laboratory method uses a diffuse sound field while for the in a directional sound field is used. However, research studies suggest that a good correlation exists between the results of the two measurement methods (8).

3.2 Acoustic absorption

3.2.1 Laboratory measurement

The standard EN 1793-1 (1) specifies a test method to qualify the sound absorption performance of noise reducing devices. The test is designed to allow the intrinsic sound absorption of the device to be measured. The result can be used as aid to select a suited noise barrier for a particular road side application. The test method is derived from the method described in ISO 354 (6). The test sample is placed in a reverberation room. The absorbing properties are determined by comparing the reverberation time of the empty room with the reverberation time of the room with the test sample.

3.2.2 In situ measurement

The measurement to determine the acoustic reflection of noise reducing devices is described in part 5 of EN 1793 (3). An artificial sound source and a square nine microphone array are used. The array is placed between the sound source and the object under test. The sound source emits sound waves that travel through the microphone array to the object under testing, on which the waves reflect. The microphones receive the direct sound wave from sound source to object under test and the indirect sound wave. A free field measurement with the same source and microphone setup is subtracted from the previous measurement to isolate the reflected component. To subtract both measurements from each other the signal converted into impulse responses. An example of an impulse response is given in. One can clearly distinguish the direct peak and the reflected component. The ratio of acoustic power of the direct and reflected components is used to calculate the sound reflection index *RI*.

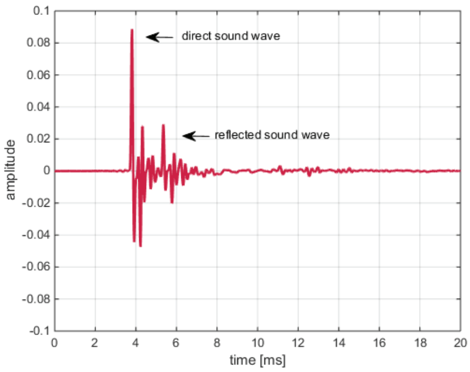

Figure 3 – Impulse response when measuring a noise reducing device.

3.2.3 Comparison of the measurement methods

The results of the laboratory and in situ measurement methods are not directly comparable as both methods yield different quantities. The laboratory measurement yields an absorption coefficient while the result of the in situ measurement is a specific quantity, the reflection index. Absorption coefficients, obtained in the laboratory, can be converted to conventional reflection coefficients by taking the complement to one. Secondly, similar as for the isolation method the sound field used in situ differs from the sound field in the laboratory. The latter is a diffuse sound field where the first one is a directional sound field.

4. Measurement program

We carried out an extensive measurement program to test the in situ measurement methods and compare them with the results from the laboratory measurements. Part of this research has been published in an earlier stage (9).

4.1 Acoustic insulation

4.1.1 Experimental setup

We developed a test setup to compare the results of the laboratory and in-situ results for measuring the acoustical insulation. The setup was realized in six different variants ranging from low to high insulation values. An overview of these six variants is given in Table 1.

Table 1 – overview of the different variants to determine the acoustic isolation

variant	material	remarks
1	6mm MDF	~4.5 km/m^2
2	12mm MDF	~9 km/m^2
3	24mm MDF	~18 km/m^2
4	36mm MDF	~27 km/m^2
5	54mm MDF	~41 km/m^2
6	6mm MDF – 44mm Rockwool sheet – 6mm MDF	construction with a cavity

The insulation of all six variants was measured in the laboratory under reverberation conditions and in situ. A picture of the experimental setup during the in situ measurements is shown in Figure 4.

Figure 4 – Experimental setup used for the isolation measurements

4.1.2 Measurement results

The results of the measurements are shown in Figure 5. The figure depicts the overall insulation level of the test setup. The x-axis shows the results for the laboratory measurements, the y-axis shows the results for the in-situ measurements. We observe a good correlation between the results of the both measurement methods. Both measurement methods are able to distinguish the insulating properties of the different variants, but we do notice differences in overall levels.

Based upon the available results we established a linear relation between the results of both measurement methods. This relation is depicted in the same figure (blue line). The figure also depicts the relation that was established within the QUIESST-project (red line). We notice that both relations show a great similarity. We conclude that the results of the current research fit well in the results of the QUIESST-project.

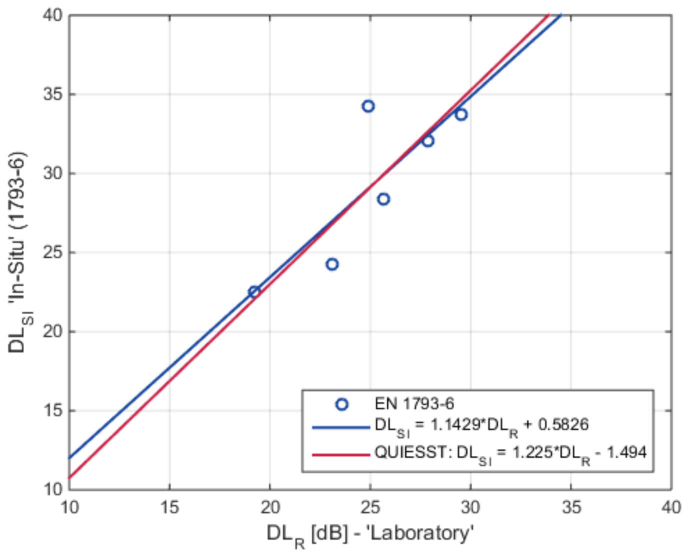

Figure 5 – Comparison between laboratory and in situ determination for the acoustic insulation of noise reducing devices.

Additionally, we analyzed and compared the sound insulation values in one-third octave bands. Two typical results are presented below. Figure 6 shows the results for the variants 2 and 5 with a thickness of 12 and 54 mm respectively. The blue line represents the results measured in situ, the black dashed line is the result measured in the laboratory. In general we notice a good agreement between the two results for both methods. In the high frequency range there is an offset. We also notice differences in the lower frequency range, where the in situ measurement yields lower insulation values. However in the frequencies that dominate the tyre/road-noise (around 1000 Hz) the results for both measurement methods fit quite well.

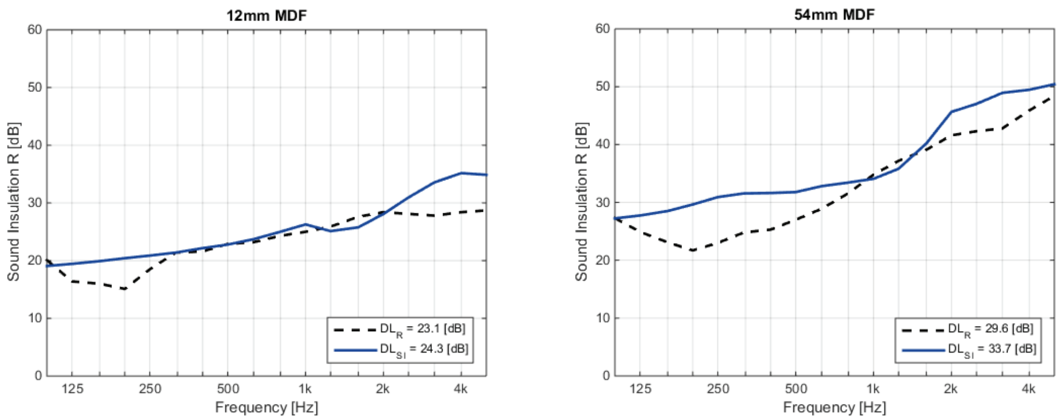

Figure 6 – Comparison of sound insulation in each third octave band measured in the laboratory (black dotted line) and in situ (blue solid line). The left diagram shows the results for the variant with a thickness of 12mm, the diagram on the right hand side depicts the result for the variant with a thickness of 54 mm.

4.2 Acoustic absorption

4.2.1 Test setup

We designed an experiment to test the setup for the absorption measurement. A first step in this setup was to measure the acoustical absorption of absorbing foam to prove correct working of the measurement setup. This experiment consisted of two parts:

- Measuring the reflection index with the setup as described in EN 1793-5 so by using a square array with nine microphones;
- Measure the reflection index with the Extended Surface method (10). This method is commonly used to measure the acoustical absorption of porous road surfaces in situ.

Both methods can determine the reflection index and hence the absorption under direct incidence and should in principle yield similar results.

A second step in this process is to compare the results of these measurements with the results of the measurements of the absorbing material in the reverberation room.

4.2.2 Results

As explained in section 0 the data analysis subtracts the impulse response from a free field measurement from the impulse response from the subject under testing. The goal of the signal subtraction technique is to remove the incident component of the impulse response (the direct sound), leaving only the impulse response of the reflected wave. This is depicted in the figure below. The upper diagram shows the results of the free field measurement, the middle diagram the impulse response of the subject under test. The resulting signal after subtraction is shown in the lower diagram. It is clear that the direct component is almost completely removed from the signal.

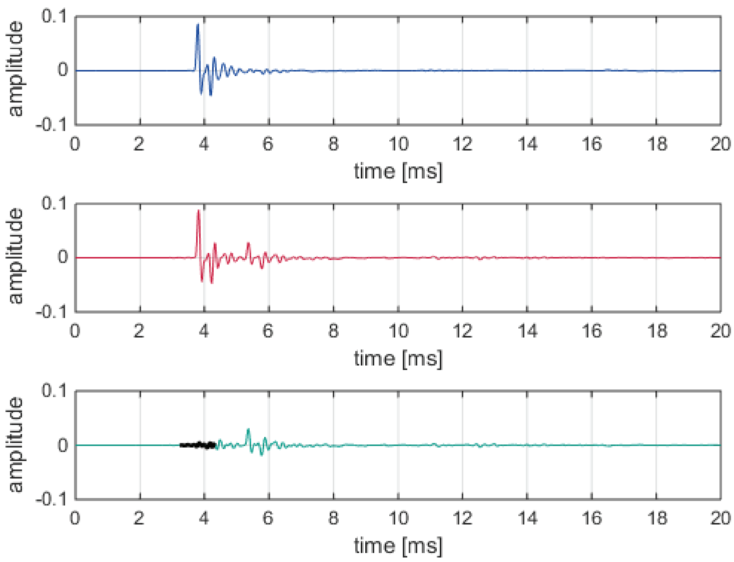

Figure 7 – Example of signal subtraction technique. The upper diagram shows the impulse response of the free field measurement, the middle diagram shows the impulse response when measuring the object under testing. The lower diagram shows the resulting signal.

The effectiveness of the subtraction can be quantified by the decibel level reduction in the direct sound from the measurement to the result. More specific, the sum of the energy within 0.5ms of either side of the main peak in the impulse response of the direct sound can be compared before and the after the subtraction to find the effective reduction. EN1793-5 prescribes the reduction factor R_{sub} for this purpose. If the reduction factor R_{sub} equals the peak to noise ratio of the measurement it can be considered as complete subtraction as this would leave no energy in the area of the direct sound except the background noise. A value of R_{sub} is below 10 dB indicates that the subtraction is not perfect. The example shown in Figure 7 has a high value for R_{sub}. An example where the value of R_{sub} is below 10dB is shown in Figure 8. The part of the signal marked with black in the lower diagram still has energy remaining from the direct sound wave.

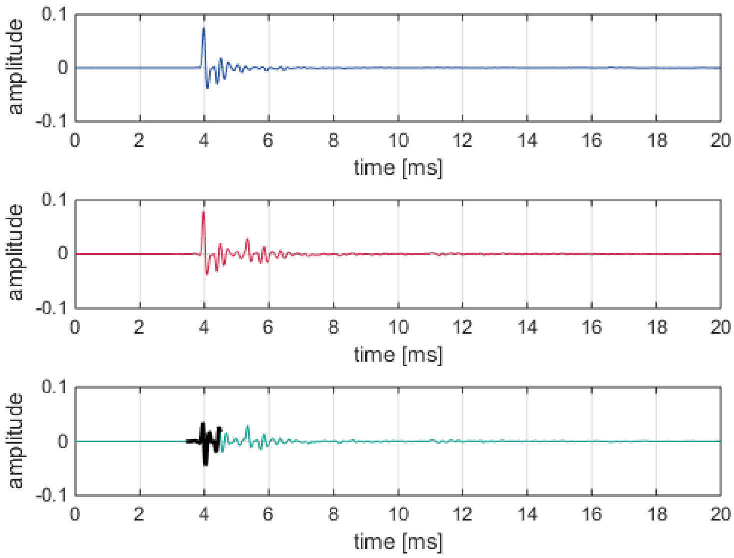

Figure 8 – Impulse responses where the results subtraction method was not perfect. The upper diagam shows the free field impulse response, the diagram in the middle shows the impulse response for the object under test. The remaining signal after subtraction is depicted in the lower diagram. It is clear from the lower figure that energy from the direct sound wave is still present in the subtracted signal

A bad S/N-ratio is obtained at several microphone positions. This is illustrated in Figure 9, which shows the value for R_{sub}. Around the center microphone position, the R_{sub}-values are typically higher than 10 dB. For other positions, the signal-to-noise ratio is too low.

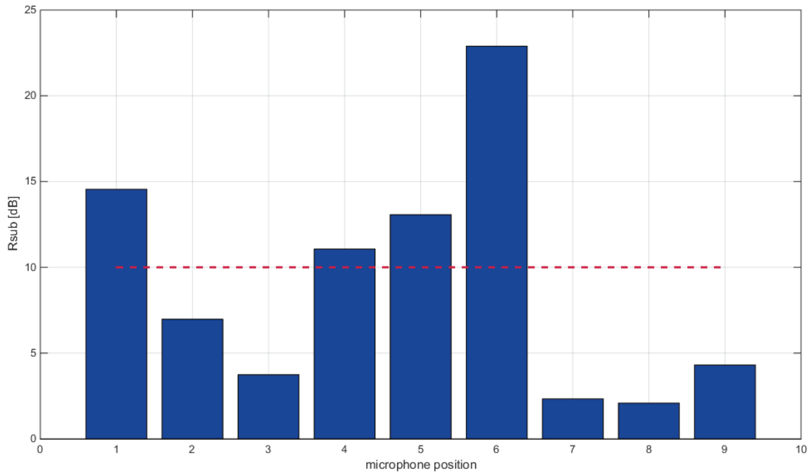

Figure 9 – Value for R_{sub} at each microphone position, indicating the S/N-ratio at each measurement position

Most likely this is caused by the construction of the microphone array and the position with respect the sound source. We think that the microphone array was a bit deformed during the free field measurement resulting that the position of some microphones was a bit altered which may have caused the bad S/N-ratio at these positions. We plan to continue working on this measurement setup. A first step to improve S/N-ratio is to redesign the test set-up.

5. CONCLUSIONS

The current research aimed at in situ testing of noise reducing devices. We have been working on the determination of the insulation and reflection of noise reducing barriers. The research confirms that differences exist between the overall insulation values measured in the reverberation room and measured in situ. However, we established a linear relation between the results of both measurements. This relation matches the relation that was previously established in the research project QUIESST. The insulation spectra obtained by both measurement methods exhibit differences as well but they match very well in the frequencies around 1000 Hz which is the frequency at which tyre/road noise is dominant.

The measurement of the acoustic absorption is hampered at the time by a bad S/N-ratio. We developed a test setup to verify correct working of the measurement setup. In the coming months we will continue working on this topic. We will also further develop our setup for measuring the reflection in situ.

REFERENCES

1. EN 1793-1, Road traffic noise reducing devices - Test method for determining the acoustic performance - Part 1: intrinsic characteristics of sound absorption, 2012
2. EN 1793-2, Road traffic noise reducing devices - Test method for determining the acoustic performance - Part2: intrinsic characteristics of airborne sound insulation under diffuse sound field conditions, 2012;
3. EN 1793-5, Road traffic noise reducing devices - Test method for determining the acoustic performance - Part 5: In situ values of sound reflection under direct sound field conditions, 2016
4. EN 1793-6, Road traffic noise reducing devices - Test method for determining the acoustic performance - Part 6: Intrinsic characteristics of airborne sound insulation under direct sound conditions, 2012;
5. ISO 10140-2, Acoustics -Laboratory measurement of sound insulation of building elements - Part 2: Measurement of airborne sound insulation, 2010
6. ISO 10140-4, Acoustics -Laboratory measurement of sound insulation of building elements - Part 4: Measurement procedures and requirements, 2010
7. ISO 354, Acoustics- Measurement of sound absorption in a reverberation room, 2003
8. QUIESST, Guidebook to Noise Reducing Devices optimisation
9. Peeters F, Peeters B, Wijnant Y, Determination of acoustic properties of noise barriers, Proceedings DAGA 2016
10. ISO 13472-1: Acoustics - Measurement of sound absorption properties of road surfaces in situ - Part 1: The Extended Surface Method