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MEASUREMENT OF SOUND REFLECTION USING THE SOPRA METHOD

Monica Waaranperä[1*] **Jens Forssén**[1] **Wolfgang Kropp** [1]
[1] Division of Applied Acoustics, Department of Architecture and Civil Engineering,
Chalmers University of Technology, Sweden

ABSTRACT

Within the Industrial PhD project Acoustical Planning of Complex Traffic Environments, it is studied whether it would be possible to change the materials or the design of the surfaces of the infrastructure to reduce the sound reflections and decrease the noise levels from road traffic.

Of critical significance for the possibility of taking such potentially noise reducing measures, is the ability to calculate the acoustic effects of the surfaces reliably. This requires sound absorption/reflection data of surfaces and materials.

Existing data are usually acquired under diffuse sound field conditions in laboratories, but measurements of road noise barriers have shown that absorbing materials often function differently under direct sound field conditions. The required data must thus be obtained by measurements in-situ.

Several measurement methods have been considered, e.g. the European standard method for measuring sound reflection of road noise barriers in direct sound field, the EN 1793-5. However, when a quicker version of the EN 1793-5, the SOPRA method, was presented in June 2022 it was decided to try it for measuring the sound reflection of various surfaces in the road infrastructure (road pavements excluded).

This paper presents the preparation, execution and results from the test measurements with the SOPRA method.

Keywords: *sopra method, sound reflection, EN 1793-5, road traffic noise*

1. INTRODUCTION

Traffic noise is the second largest environmental cause of health problems in Europe, after the impact of air pollution At least 20% of the EU population, more than 100 million people, lives in areas that are exposed to traffic noise levels that are harmful to health [1]. Since traffic noise is a particular public health problem in many urban areas, the problem is expected to grow with the continuing urbanisation.

The Industrial PhD project (*Tools for) Acoustical Planning of Complex Traffic Environments* focuses on large scale infrastructure which often are situated in the outskirts of bigger cities - where thousands of people live and work. Some people spend their entire days and nights in these areas, especially children and others without the means to visit a quieter place. The environment in urban areas near such infrastructure landscapes can be challenging even without the traffic impact. High levels of noise and air pollution, enormous barriers of concrete and asphalt and a constant flow of traffic, will add to the conditions.

As a part of the PhD project, it is studied whether it would be possible to change the materials, surfaces (except road pavements[2]) and the design of the infrastructure to reduce the sound reflections and decrease the noise levels from road traffic.

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[*] ***Corresponding author***: monicaw@chalmers.se.

[2] Road pavement is not included in this study since it is already a big area for research and development, with known effects on noise reduction.

Of critical significance for the possibility of taking such potentially noise reducing measures, is the ability to predict or calculate the acoustic effects of the surfaces reliably, which requires sound absorption or reflection data. If *any* acoustic data for infrastructure building materials exist, they are usually acquired under diffuse sound field conditions in laboratories, but measurements of road noise barriers have shown that sound absorbing materials often function differently in direct sound fields, i.e. the open outdoor conditions along the roads [2]. Absorption/reflection data for direct sound field conditions must thus be obtained by measurements in-situ.

Various measurement methods have been considered, among them the European standard method for measuring sound reflection of road noise barriers under direct sound field conditions, the EN 1793-5 [3]. But in June 2022, an interesting alternative was presented: the SOPRA method – a quicker and in some parts simplified version of the EN 1793-5 (and also of the EN 1793-6 for sound insulation measurements of road noise barriers under direct sound field conditions [4]).

It was then decided to investigate if the new SOPRA method could be useful for measuring the sound reflection of various surfaces in the road infrastructure, i.e. not only noise barriers. Since the SOPRA method is new, it was necessary to test and assess it before starting measurement campaigns along the roads. This paper presents the preparation, execution and results from the test measurements, together with parts of the requirements and procedures of the SOPRA method which are relevant for the understanding of the performed test measurements. However, for a complete description of the method it is necessary to read both the SOPRA report and the EN 1793-5.

2. THE SOPRA METHOD

2.1 Background

The SOPRA method, also called the “quick method”, was developed within the SOPRANOISE research project financed by CEDR, the Conference of European Directors of Roads [5]. The work started in December 2019 and was finalized in June 2022. The method is described in the SOPRANOISE deliverable “D4.2 Report on the validation of the new quick methods in-situ with recommendations for proper use” [6], from now on called the SOPRA report.

Above all, the SOPRA method is a simplification of the *measurement* methods in two European test standards for determining the intrinsic, acoustic characteristics of road noise barriers under direct sound field conditions: the EN 1793-5 for sound reflection and the EN 1793-6 for airborne sound insulation. The method is designed to be a fast and relatively simple way to test installed noise barriers along the roads, giving a reasonable estimate of the noise barrier´s performance, but it cannot replace the full standard methods for declaring the acoustics characteristics of a certain product.

To separate the values obtained from performing the standard tests and those from the SOPRA method, the word “quick” is added to the name of the resulting quantities. The reflection index, RI, according to the EN 1793-5, is thus called the quick reflection index, RI_Q. And the sound insulation index, SI, according to the EN 1793-6, is named the quick sound insulation index, SI_Q.

2.2 Quick sound reflection index measurements.

The principle behind both the SOPRA method and the EN 1793-5 for reflection measurements is to use the signal subtraction technique[3] to capture the sound reflective properties of a noise barrier (or device under test).

The set-up, with the loudspeaker and the microphone antenna in front of a noise barrier, see Fig.1, means that the sound wave emitted by the loudspeaker first reaches the microphones, then the noise barrier on which it is reflected and goes back towards the microphones again. The impulse response of the reflected signal in relation to the emitted test signal depends on the reflective properties of the noise barrier. By performing a free field measurement without the noise barrier but with the same geometrical set-up and equipment as for the reflection measurement, the impulse response of the free field measurement can be used for subtracting the direct component from the impulse response of the reflection measurement. This results in an estimate of the wanted impulse response of the sound reflection from the noise barrier.

The location for the reflection measurements must be carefully chosen to avoid sound reflections from objects closer to the microphones than the studied noise barrier. Reflections from further away, arriving after a certain time delay, can be excluded from the calculation of the quick reflection index, RI_Q, by time windowing operations[4] to extract the relevant parts of the free field and the reflected impulse responses, of each microphone.

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[3] The signal subtraction technique is described in EN 1793-5.

[4] The windowing operations in the time domain shall be performed with the Adrienne temporal window, described in EN 1793-5.

The RI_Q can then be calculated according to Eqn. (1) below.

$$RI_{Q,j} = \frac{1}{n_j} \cdot \sum_{k=1}^{n_j} \left[\frac{\int_{\Delta f_j} |F\,[h_{r,k}(t) \cdot w_{r,k}(t)]|^2 df}{\int_{\Delta f_j} |F\,\,[h_{i,k}(t) \cdot w_{i,k}(t)]|^2 df} \cdot C_{geo,k} \right] \tag{1}$$

$h_{i,k}(t)$	incident reference component of the free field impulse response at the k-th measurement point;
$h_{r,k}(t)$	reflected component of the impulse response taken in front of the sample under test at the k-th measurement point;
$w_{i,k}(t)$	time window (Adrienne temporal window) for the incident reference component of the free field impulse response at the k-th measurement point;
$w_{r,k}(t)$	time window (Adrienne temporal window) for the reflected component at the k-th measurement point;
F	symbol of the Fourier transform;
j	index of the one-third octave frequency bands;
Δf_j	width of the j-th one-third octave frequency band;
k	microphone number according to Fig. 1;
n_j	number of microphone positions on which to average;
$C_{geo,k}$	correction factor for geometrical divergence between the loudspeaker and the microphone position at the k-th measurement point,

Note that Eqn. (1) is a simplified version of the expression to compute the reflection index RI according to the EN 1793-5, which also includes the correction factors $C_{dir,k}$ and $C_{gain,k}$.

2.3 The measurement system

The system for the SOPRA reflection measurement must include a signal generator and input channels for 3 - 6 microphones. The measurements shall be made in one-third octave bands between 200 and 5000 Hz with a minimum sample rate of 44,1 kHz.

A sound level meter is also necessary for checking the signal-to-noise ratio, S/N, concerning the strength of the output sound signal in relation to the background noise. The S/N shall be greater than 10 dB over the whole frequency range of the measurements.

Further and more detailed requirements for the measurement system and equipment are described in the SOPRA report and in EN 1793-5.

2.4 The set-up

Two different set-ups are needed, one for measuring the impulse response of the reflected signal from the studied surface (e.g. noise barrier) and one free field measurement. Fig. 1 below shows the set-up for the reflection measurement, with the following measures:

- Height of loudspeaker, h_s = 2,0 m above the ground, measured from the center of the speaker membrane.
- Distance between the loudspeaker front panel and the studied surface[5], d_s = 1,5 m
- Distance between the loudspeaker front panel and the microphone antenna, d_{SM} = 1,25 m
- Distance between the microphones and studied surface, d_M = 0,25 m (not marked in Fig. 1).

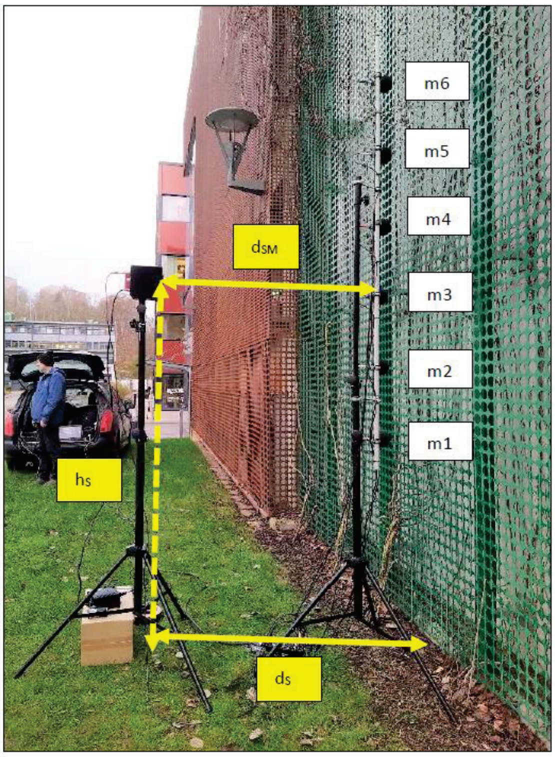

Figure 1. The set-up for measuring the impulse response of the sound reflection.

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[5] If the studied surface is uneven, the horizontal measures shall be between the loudspeaker/microphones and a reference plane formed by the most protruding parts of the surface.

The microphones, M1 - M6, shall be mounted on a linear antenna with the following microphone heights, h_M, above the ground:

h_{M1} = 1,2 m
h_{M2} = 1,6 m
h_{M3} = 2,0 m
h_{M4} = 2,4 m
h_{M5} = 2,8 m
h_{M6} = 3,2 m

Three microphones are essential for the SOPRA method: M2, M3 and M4. The relevance of adding the two top microphones, M5 and M6, is depending on the height of the measured surface, see Tab. 1.

The bottom microphone, M1, will be affected by the ground reflection and data from it are therefore not included in the calculation of the quick reflection index. RI_Q.

Table 1. Microphones to be considered in the calculation of the quick reflection index, RI_Q, depending on the height of the measured noise barrier, h_B[6].

Barrier height, h_B [m]	Microphones	Lowest reliable 1/3-octaveband
$h_B \leq 3$	M2 – M4	315 Hz
$3 < h_B \leq 5$	M2 – M5	250 Hz
$h_B > 5$	M2 – M6	200 Hz

The distance between each microphone and the studied surface shall be 0,25 m whether the surface is vertical or inclined, i.e. it should be possible to incline the microphone antenna so it becomes parallel to the studied surface. However, if the surface is concave or convex, the antenna shall be positioned vertically.

The free field measurement shall take place in the same area as the reflection measurements, under essentially the same conditions. It has the same loudspeaker and microphone set-up as the reflection measurement, but they are placed in a position so far from other surfaces and objects that the sound reflection from those will be late and can easily be identified and excluded when the impulse response signals are windowed, as mentioned in 2.2 above.

3. TEST MEASUREMENTS

The test measurements of sound reflection, according to the SOPRA method, have been performed outdoors during two occasions, in November 2022 and in April 2023. The first measurements took place on the Chalmers campus area in Gothenburg, with the main objective to test the equipment, the handling of it and the signal processing. The test surfaces were walls on buildings. The second set of measurements, which is described below, was performed on the backside (non-roadside) of two types of installed noise barriers in the northeastern part of Gothenburg.

3.1 The test measurement equipment

Available equipment at the Applied Acoustics division was used for the test measurements, including a SQuadriga III from HEAD acoustics, a compact mobile 24-bit recording and playback system with a signal generator and sound level meter function [7]. The SQuadriga in question has an additional module which can analyze the transfer function, coherence and impulse response. The resulting data is delivered as WAV files and in HEAD acoustics hdf format. The hdf files can be transformed into MATLAB data via the Artemis Suite software from HEAD acoustics.

The flat spectrum pseudo noise signal, which was selected for the test measurements, was emitted through an Active Mix Cube loudspeaker with integrated amplifier from Avantone. Four G.R.A.S. (46 AE and 146 AE) free field microphones with integrated amplifiers were placed in the positions M2, M3, M4 and M5. The measurements were made in one-third octave bands between 200 and 5000 Hz with a sample rate of 51,2 kHz.

3.2 Test object 1 - timber noise barrier in Sävenäs

The first test object was a timber noise barrier situated along the south side of the E20 at Sävenäs, an area with single homes northeast of the Gothenburg center. The barrier is at least 15 years old and consists of wooden panels on the roadside, and on the backside 20 mm thick porous sheets with diagonal wooden slats, fixed with horizontal, 180 mm wide parts of slats with c/c 800 mm, leaving 620 mm porous surface in between, Fig. 2. The 60 mm space between the wooden panels and the porous sheets is filled with mineral wool. The sections of the noise barrier elements are installed in 100 mm steel posts with a c/c distance of 3 m. The height of the barrier elements is generally 3,5 m, with a fiber cement board

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[6] Shortened version of Tab.5 in the SOPRA report.

between the bottom of the barrier elements and the ground. A metal cap is mounted on top of the barrier.

Figure 2. The Sävenäs timber noise barrier on the non-roadside.

Between the noise barrier and the houses is a quite busy bike and pedestrian road. The stands with the microphones and loudspeaker were therefore placed in a section with bushes where the fiber cement board was completely below the ground surface, Fig. 3. Four microphones (M2 – M5) were used for the Sävenäs measurement. (Due to quite dense shrubbery, it was only possible to perform the measurement on one section of the noise barrier). The free field measurement was performed in an open area on the opposite side of the bike and pedestrian road.

Figure 3. The Sävenäs measurement position.

3.3 Test object 2 - noise barrier by the Torpa school

The second test object was a 3,5 m high noise barrier situated along the southwest side of the road Östra Torpavägen, near the Torpa school in Gothenburg. The barrier was installed about 3 years ago (2019-2020) with sound absorbing panels[7] on the roadside, Fig. 4.

Figure 4. The noise barrier by the Torpa school.

The test measurement was performed on the reflective backside of the noise barrier, Fig. 5, since the roadside was not accessible due to heavy traffic and a narrow road shoulder. The free field measurement was made a few meters away from the noise barrier, in the direction of the school yard.

Figure 5. The measurement site of the Torpa school barrier. The school area is to the right in the picture.

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[7] In the product description of the noise barrier the single-number rating of the sound absorption is declared to 11 dB in diffuse sound field, tested according to EN 1793-1 [8].

3.4 Post-processing

The acquired impulse response data from the sound reflection measurements of the two noise barriers were post-processed in MATLAB. The lowest one-third octave band to consider in the calculations was 250 Hz since both noise barriers were 3,5 m high, see Tab.1.

The resulting quick sound reflection indices, RI_Q, was calculated according to Eqn. (1) and are presented in Fig. 6 (timber noise barrier) and Fig. 7 (Torpa school barrier). The single-number ratings for sound absorption, $DL_{RIQ,}$ was calculated according to Eqn. (3) in the SOPRA report.

3.5 Results

The results from the test measurements are presented and discussed below.

Starting with test object 1, the resulting single-number rating of the sound absorption, DL_{RIQ}, for the **timber noise barrier** was 3,3 dBA, averaged over all four microphones (M2 – M5). The DL_{RIQ} result is quite low, but the plot in Fig. 6 reveals substantial variations in the RI_Q spectra of the different microphones. The reasons are not clear. It could be due to the evaluation method itself, or due to the properties of the measurement object. The variation might also partly be explained by the design of the noise barrier, where the relatively large parts of wooden slats in front of the sound absorptive panels could cause both sound reflection and scattering. Furthermore, the extremely high RI_Q at 2000 Hz of microphone M5 could be due to reflections from both the wooden slats and the metal cap at the top of the noise barrier. Since all four microphones show fluctuations in the RI_Q spectrum it could imply that the sound absorbing *material* is efficient but the overall *design* of the noise barrier impairs the sound absorbing performance. However, this needs further clarification.

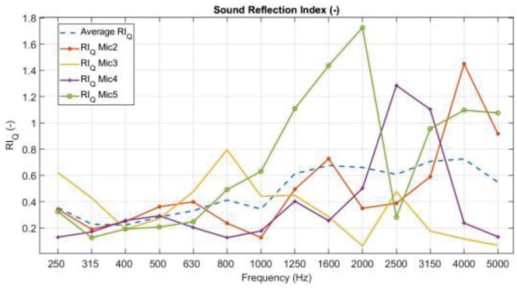

Figure 6. RI_Q spectra of the timber noise barrier.

The reflection measurement of the second test object, the **Torpa school noise barrier,** resulted in a negative single-number rating for the sound absorption, DL_{RIQ}, of -0,6 dBA, which was not too surprising since the measurement was performed on a hard and presumably sound reflecting surface. Still, it might be useful to study RI_Q spectra from measurements of non sound absorbing surfaces like this. In Fig. 7 it can be noticed that the RI_Q of the top microphone, M5, generally lies higher than the other microphones' RI_Q. This could be a sign that M5 is affected by diffracted traffic noise from the roadside of the noise barrier and M5 should thus not be included in an evaluation of the noise barrier element, even though it matters for the resulting sound levels and sound qualities in the area behind the barrier.

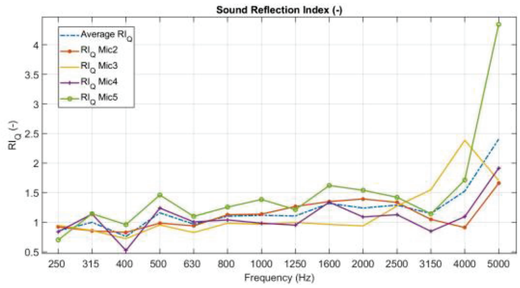

Figure 7. RI_Q spectra of the noise barrier at the Torpa school.

Specifications and results of the measurements for both noise barriers are summarized in Table 2.

Table 2. Specifications and results of sound reflection measurements of the timber noise barrier (NB1) and the Torpa school noise barrier (NB2*)*.

Object	**NB1**	**NB2**
Height	3,5 m	3,55 m
Frequency range, one-third octave bands	250 - 5000 Hz	250 - 5000 Hz
Microphones	M2 - M5	M2 – M5
Type of surface	Absorptive/ reflective	Reflective
Background noise level	58 – 61 dBA	57 – 59 dBA
Single-number rating, $DL_{RIQ,\ 250\text{-}5000\ Hz}$	3,3 dBA	-0,6 dBA

When measuring on the backside of a noise barrier, one must consider the risk of transmission of road traffic noise from the other side of the barrier. This should normally not be a problem when the measurements are performed on the roadside, i.e. as intended in the SOPRA method for sound reflection measurements.

4. CONCLUSIONS

The purpose of this study was to test the SOPRA method for sound reflection measurements before deciding whether to use it or not for measuring roadside surfaces, i.e. in-situ. The drawn conclusions of the test are above all concerning the preparation and the execution, and not so much the analysis of the obtained results of the test objects.

The preparation before a measurement is often the most time consuming part of a test, and this was undoubtedly the case here. The SOPRA report cannot be directly used as an instruction manual to perform the reflection measurements since it refers to the EN 1793-5 for parts that have not been simplified or changed. It takes quite some time to extract and merge the essential information that is needed from the two documents, and also to gather and assemble the appropriate measurement equipment, prepare the software and the signal processing.

After the preparation though, the execution of the sound absorption measurements was indeed quick. However, it is strongly advised to practice the set-up and measurement procedure before heading out on actual field measurements roadside.

The results of the test measurements were promising. Even though the purpose of the test measurements was to assess the SOPRA method and not to evaluate the test objects, the resulting quick sound reflection indices of the two different types of noise barriers were not unexpected, which could be an indication that the preparation, measurements and the post-processing were successful. However, the results contained substantial variations, which calls for further studies.

Further, it should be investigated how the SOPRA methods could be useful for the road authorities. Tests according to EN standards, like the EN 1793-5, are usually carried out by authorized technical test institutes and not by acoustic consultant companies. If the SOPRA method to measure the acoustic qualities of both new and older installed noise barriers is to be put into a more widespread use, a concise description of the method would be necessary, e.g. for the road authorities' calls for tender.

5. FUTURE WORK

Based on the experiences from the test measurements, it has been decided to use the SOPRA method for the planned collection of sound reflection data of road infrastructure surfaces and materials, including installed noise barriers.

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