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Call 2018 Noise and Nuisance:

SOPRANOISE Final Report

September 2022

Call 2018 Noise and Nuisance SOPRANOISE Project Final Report

CEDR Contractor Report 2022-09

SOPRANOISE - Securing & Optimizing Performance of Road trAffic noise barriers with New methOds and In-Situ Evaluation

by

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Executive Summary

The SOPRANOISE research addresses new tools to assess the acoustic performances of noise barriers as they are effectively used along road and railway networks, and at any time of their entire lifetime (i.e.: before its installation – product certification; at the installation – product approval, during its use / whole lifetime – product maintenance or repairing; and at their "end of life" (decision about product decommissioning).

One of the main outcomes of the research is **the SOPRANOISE 3 step approach** (see Figure ES1). It allows to place the right effort and money to the right level of assessment: from the easiest (but less accurate) way, up to the most accurate one (i.e.: the standardised methods EN 1793-5 [3] and EN 1793-6 [4]), following an "engineering progressive approach".
SOPRANOISE successfully delivers relevant methods for the "missing" levels 1 and 2 with: the "In-situ inspections" and the "quick method", named the "SOPRA method".

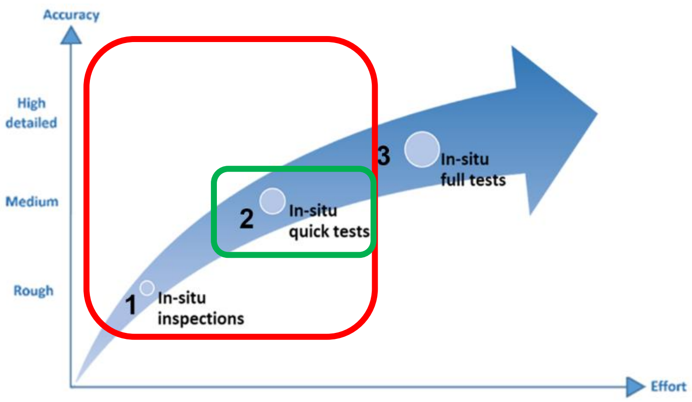

Figure ES1: SOPRANOISE 3 step approach

The principles of the SOPRANOISE 3 step approach are very simple: at the end of each step, relevant decisions can be taken whether fair conclusions could be drawn, or not yet; otherwise, further tests are still necessary (see main principles in Figure ES2).

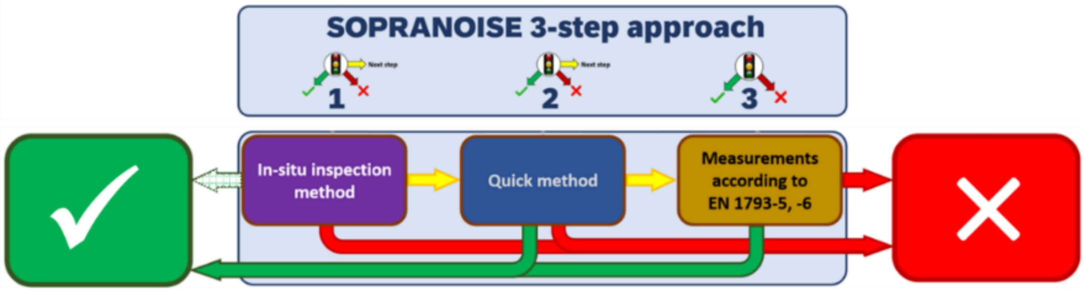

Figure ES2: Main principles of the SOPRANOISE successive 3 step approach

Thanks to this SOPRANOISE 3 step approach it is now possible to choose the most relevant method to assess the acoustic performances at any stage of the whole lifetime of a noise barrier.

However, SOPRANOISE has also many other relevant outcomes, e.g.: two important databases have been built and analysed, one database about the acoustic performances of more than 1.000 noise barrier elements, and another one about how noise barriers are used in different EU countries. The outcomes of those two databases allow to better understand the performances one can expect from the majority of the products placed on the market, and how authorities are considering / using noise barriers along their own network.
It is thus advised to consider *all* the deliverables of the research, as listed hereafter.

Important note:

For detailed information, it is proposed to the reader of this report to refer to all the deliverables available on the SOPRANOISE website[1] (https://www.enbf.org/sopranoise/outcome/) and CEDR website (https://www.cedr.eu/peb-research-programme-2018-noise-and-nuisance), the most relevant being:

Deliverable 2.2: this deliverable presents the results and outcomes of WP2 as follows:

- Review of the physical significance of the EN1793-1, -2, -5 and -6 standards;
- Update and analysis of the noise barrier database[2] ;
- Influence of acoustic degradation of noise barriers on the total noise reduction[3].

Deliverable 3.1: this deliverable presents the results and outcomes of WP3 as follows:

- Review of existing in-situ inspection tools;
- Development and testing of methods based on in-situ inspection;
- Description of the in-situ inspection tools and reporting.

Deliverable 4.2: this deliverable presents the results and outcomes of WP4 as follows:

- Description of the measuring equipment for the quick method;
- The SOPRA measurement procedure;
- Validation of the method in laboratories and along highways;
- Recommendations for proper use.

Deliverable 5.1: this deliverable presents the following results and outcomes of WP5:

- Physical behaviour of noise barriers / acoustic intrinsic performances[4];
- State of art on the today's noise barriers use within the EU Market[5].

Deliverable 5.2: this deliverable presents the SOPRANOISE final report, that includes:

- How to assess the NB acoustic performances;
- The SOPRANOISE Scientific report;
- Guidelines for noise barriers use.

[1] Available for download
[2] This huge database contains of more than 1.000 tests results on 448 different European noise barrier products, tested by 39 laboratories in 9 different EU countries…
[3] This corresponds to the base of the « in-situ inspections » method developed in WP3.
[4] This report details the main factors influencing the noise barriers acoustic performances and the role of the intrinsic performances in the Insertion Loss (IL: difference in sound level at a receiver location with and without a noise barrier).
[5] To establish this SOA, a questionnaire of has replied by 18 countries, 21 NRA, 6 railway authorities, 3 associations of manufacturers / contractors, and 2 manufacturers.

1. Table of Contents

2. Definition of the Issue

Noise barriers are extensively used by NRAs as effective devices to reduce road noise; railways companies are doing the same for their networks. In order to optimize and secure the performance of noise barriers, one has to understand that their overall acoustic performance to reduce road noise towards the environment is a complex process that includes not only the noise barriers implementation and the geometrical dimensions, but also their "intrinsic quality" (i.e.: the acoustic quality directly pertaining to the products themselves). NRAs logically draft relevant specifications that contractors and manufacturers of noise barriers products have to respect, in order to: not only to correspond to the design hypotheses, but also to guarantee the overall acoustic performances all along their lifetime cycle.

In order to verify if installed noise barriers are effectively respecting the tender requirements, one has to test those in a fair way: as they are installed (involving the quality of the products and how they are installed), which means under real conditions alongside roads (and railways), and following their intended use (i.e.: under direct sound field conditions).

Since 1990, CEN/TC226/WG6[6] drafted standards on the acoustic and non-acoustic intrinsic performances of Noise Reducing Devices, a broader family of road equipment products that also includes noise barriers. CEN/TC226/WG6/TG1 is specially dedicated to the acoustic characteristics and drafted a relevant framework of supporting standards: EN1793-1[1] (sound absorption under diffuse sound field conditions - can only be done in laboratory), -2 [2] (airborne sound insulation under diffuse sound field conditions - can only be done in laboratory), -5 [3] (sound reflection under direct sound field conditions) and -6 [4] (airborne sound insulation under direct sound field conditions). Those last two standardised methods are the only relevant to the intended use of "free standing noise barriers"; they also have the advantage to allow measurements almost everywhere, what is here very relevant while approving and / or monitoring installed noise barriers.

This is already and increasingly done by NRAs to characterize installed noise barriers[7]. However, EN1793-5 [3] and -6 [4] methods require quite lengthy tests that could also be affected by practical conditions (weather conditions, safety, accessibility…), as well as the need of expert users: this can limit their use alongside roads.

While always keeping the possibility to use EN1793-5 [3] and -6 [4] on site, there is a need for new methods that could be easier, faster and safer.

Some NRAs already undertake in-situ inspections in order to monitor the integrity of the different parts of their road/railway equipment. Those inspections are the easiest and cheapest tools to investigate installed noise barriers: implementing such in-situ inspections in a more systematic way, integrating the acoustic characteristics is a real plus that can save time and money.

For quantitative assessments (by measurements), new "quick methods" had to be designed in order to be applicable in a much more systematic and affordable way than the one allowed by the "full" EN1793-5 [3] and -6 [4]: this has been done successfully and led to the brand new and validated quick "SOPRA" method.

As noise barrier performances can decrease over time, while infrastructure administrators need to control and maintain the noise reduction at all stages of their lifetime, there was a clear need to better understand how noise barriers could reduce noise and keep their original acoustic performances along their whole lifetime.

SOPRANOISE successfully replied to all those needs.

[6] Comité Européen de Normalisation / Technical Committee 226: road equipment / Working Group 6: Noise Reducing Devices
[7] In recent years, many NRAs apply EN1793-5 and -6 as noise barriers acceptance and check after installation, as well as to investigate the evolution of the acoustic performances all along their lifecycle.

3. Assessment of the intrinsic performances of installed Noise Barriers

Noise barriers (NB) are obstacles to *sound propagation* purposely built to shield receivers from excessive noise generated by road or railway traffic (Figure 1). Today, NB are considered the most effective noise mitigation measures available when targeting *high noise reductions*. For this reason, the more stringent the noise legislation across Europe becomes, the more NB are installed or refurbished along many road and railway corridors.

Figure 1: To reduce traffic noise, NB are placed as obstacles to the sound propagation [1]

Many factors need to be considered in the detailed design of NB. About their acoustic performance (which is the main reason for using them), the noise reduction achieved by NB in their environment is characterized by the “Insertion Loss” (IL: difference in sound level at a receiver location with and without the presence of the NB): this is an *extrinsic* characteristic that involves a lot of factors, all influencing the final NB effective performances. Specifically attached to *the product itself*, the *intrinsic* acoustic characteristics are: *sound absorption / reflection*, *airborne sound insulation* and *intrinsic sound diffraction*. To understand their roles, Figure 2 shows how physics rules the IL of a NB:

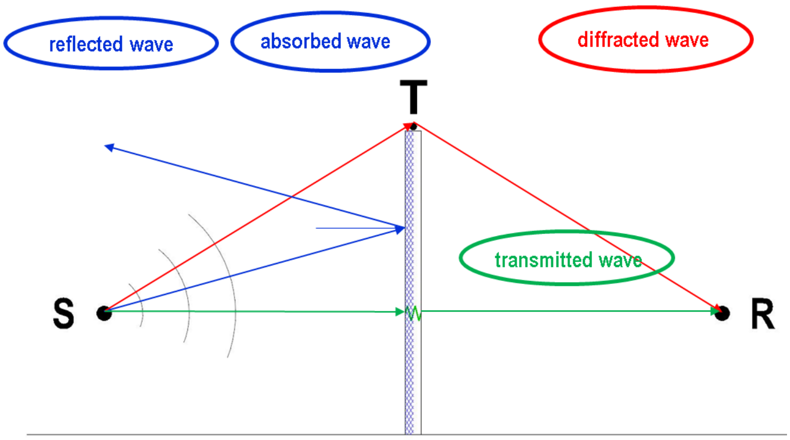

Figure 2: Sound reflection / absorption, sound transmission, sound diffraction [2]
S: *sound source* (e.g.: the vehicles); **T**: top of the NB, **R**: receiver (e.g.: a dwelling)

Reflections occur when a *sound wave* hits the exposed side of the NB : it partly reflects on it and this *reflected sound (wave)* can affect the facing areas; the (intrinsic) *sound absorption* performance of the barrier can usefully reduce reflections. **Transmission** occurs when a *sound wave* hits the exposed side of the NB: it partly transmits through the NB itself. As the main role of the NB is to play as an obstacle to the sound propagation, this transmitted energy must be negligible compared to that one diffracted at the top edge of the NB.

A NB should act as an obstacle to the sound propagation; however, a part of the *sound wave* still passes over it: this is called **diffraction**. The *sound wave* diffracts on the top edge of the NB (where it is partly attenuated), and then propagates to the protected side of the device.

This report relates to the assessment of the *intrinsic* performances of installed NB, whatever along roads or railways, with different methods: from the simplest up to the most detailed ones, each replying to relevant different uses.

3.1. The SOPRANOISE 3-step approach

To assess the *intrinsic* acoustic performances of installed noise barriers from the easiest (but less accurate) way up to the most accurate one (but obviously related to more effort and money), SOPRANOISE established an "engineering progressive approach" with the following 3 successive steps (see Figure 3) :

(1) in-situ inspections,

(2) in-situ "quick" tests[1],

(3) in-situ "full" tests[2],

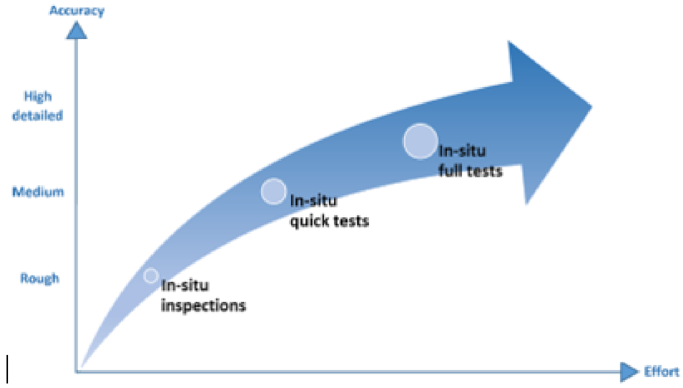

Figure 3: SOPRANOISE 3-steps approach to characterize the *intrinsic* acoustic characteristics of installed noise barriers: from less accurate but easy methods up to the more accurate full in-situ tests.

At the end of each step, relevant decisions should be taken whether fair conclusions could be drawn: "**acceptance**[3]" or "**rejection**", otherwise further tests are still necessary (see successive steps in Figure 4).

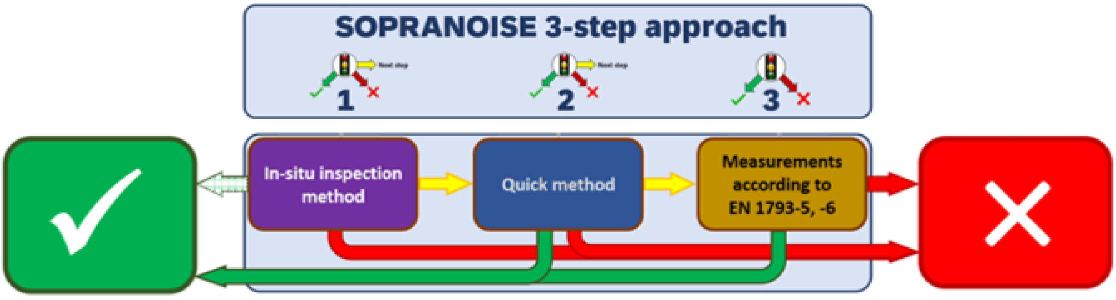

Figure 4: SOPRANOISE 3 successive steps approach to characterize the *intrinsic* acoustic characteristics of installed noise barriers: *main* principles (adapted in Figure 5 and Figure 6).

However, the validity of the conclusions may vary depending on what we want to do with the test results. In facts, we can have 2 main different kinds of assessment:

- **monitoring** the evolution of performances of already installed noise barriers (e.g.: along time, in regular intervals and/or before decommissioning stage) as an objective tool to take decisions on NB replacement);
- **approval** of *newly installed* noise barriers (to compare results with specific quantified requirements).

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[1] the quick method is now called the « SOPRA » method

[2] the full methods are those described within EN-1793-5 [3] and -6 [4] , based on the QUIESST research [2]

[3] for inspection tests, one must be very careful: those tests being done by visual inspection, they cannot give relevant results about the *airborne sound insulation* if defects are hidden (e.g.: degraded interior acoustic materials)

3.1.1 Monitoring of already installed noise barriers

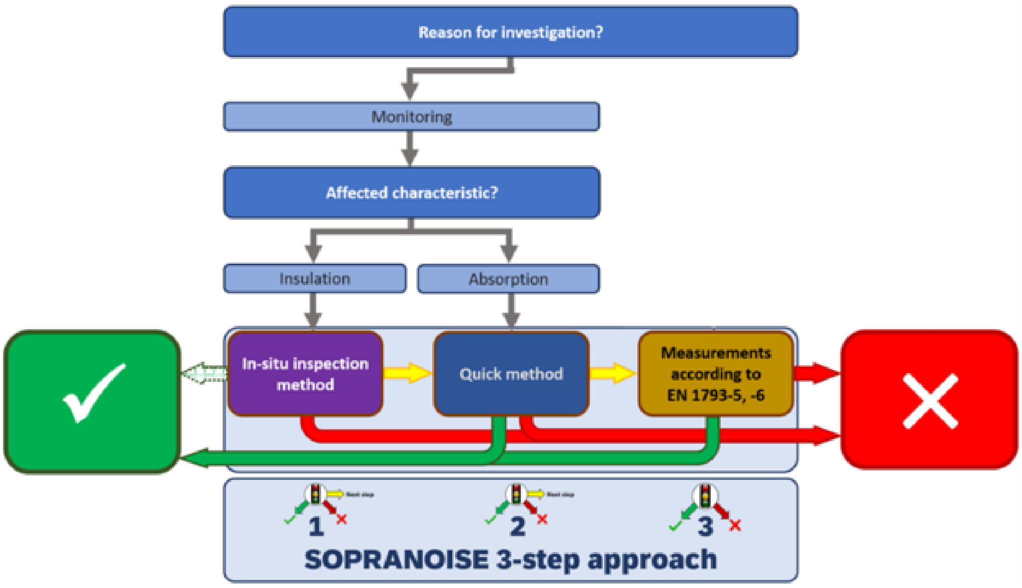

Figure 5: SOPRANOISE 3 successive steps when monitoring the performance of installed NB.

If the reason for investigation is to monitor the noise barrier, Figure 5 shows how to use the SOPRANOISE 3-Step approach. The process is the following:

Airborne sound insulation

"In-situ inspections" are useful to check if installed noise barriers have defects that can affect its global IL performance (not exactly *intrinsic* but *extrinsic*): they could be used to monitor *up to what extent* a NB can be considered as efficient to reduce noise in the environment it has to protect. However, "In-situ inspections" cannot give any quantified value of the *intrinsic airborne sound insulation*. The SOPRANOISE 3-Step approach applies as follow:

- **Step 1**: "In-situ inspections"; then, if results of the inspections are clear and fair, then "acceptance" or "rejection" can be decided[4]; otherwise further investigations have to be done;
- **Step 2**: (tests with) the Quick / SOPRA method; then, if the results of the test carried out are clear and fair, "acceptance" or "rejection" can be decided; otherwise further investigations have to be done;
- **Step 3**: (test with) standard '"full" methods.

Sound absorption/reflection

Based on visual inspections, the "In-situ inspections" can only characterize the *airborne sound insulation*: in that way, for *sound absorption/reflection*, one has to go directly to Step 2: Quick / SOPRA method and/or to Step 3: standard '"full" methods.

Whatever for *airborne sound insulation* or for *sound absorption/reflection* authorities should fix their own *rejection criteria* for Step 2; however, an *official approval* of the NB performances can only be done by Step 3. In other words, the acceptance criterion for a newly built NB should refer to measurement results according to the full EN standards, namely EN 1793-5 and EN 1793-6 (Step 3) and cannot be done only based on Step 1 or Step 2.

[4] for inspection tests, one must be very careful : those tests being done by visual inspection, they cannot give relevant results about the *airborne sound insulation* if defects are hidden (e.g. : degraded interior acoustic materials)

3.1.2 Approval of y installed noise barriers

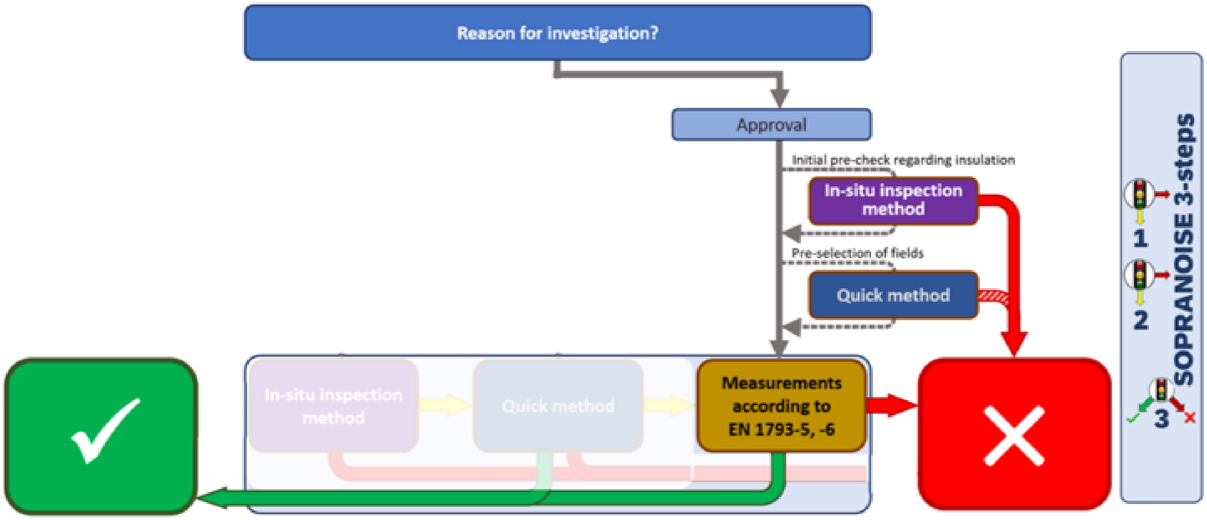

Figure 6: SOPRANOISE 3 successive steps to official approval of installed NB.

If the reason for investigation is the approval of noise barriers, Figure 6 shows how to use the SOPRANOISE 3-Step approach. The process is the following:

If authorities are willing to officially approve the intrinsic acoustic performance of installed NB, the only methods certifying that the measured values are those ones described in the standard '"full" methods EN 1793-5 (for *sound absorption / reflection*) and EN 1793-6 (for *airborne sound insulation*). In the SOPRANOISE 3-Step approach, this is the **Step 3**.

However,

- **Step 1**: "In-situ inspections" *could be very useful* before any other ones.
  Those inspections could usefully detect if defects are already existing that could degrade the IL performance: in such cases, the defective items have to be directly rejected before carrying out any further tests[5].
- **Step 2**: the Quick / SOPRA method *could be very useful* before applying the standard '"full" methods: as this method is much quicker, safer and less expensive that the standard '"full" methods, it is the best method for having a relevant overview on the whole length of NB, with possibility to establish relevant statistics and justify relevant sampling of *where to limit* the tests to be carried out with the standard '"full" methods.
  Additionally, authorities could also fix criteria of rejection at this level[6].

The next chapters will shortly introduce the Step 1 and Step 2 methods: for more details, the reader could refer to the SOPRANOISE deliverables D3.1 *Final report on the main results of WP3 (including M3.1, M3.2 and M3.3) – In-situ inspection tools* [5] and D4.2 *Report on the validation of the new quick methods in-situ with recommendations for proper use* [6] , while for Step 3, the references are directly the corresponding EN 1793-5 [3] and EN 1793-6 [4] (CEN) standards.

[5] warning: no acceptance can be given at this stage.
[6] warning: no acceptance can be given at this stage.

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3.2 Step 1: In-situ inspections

Carefully done, *inspections* are the simplest and cost effective tools to monitor any equipment all along its lifetime, this can be usefully applied to Noise Barriers: monitoring NB is the best way to maintain those to stay functional, safe and effective over years.

The *in-situ inspections* procedure developed in WP3 corresponds to the first step of the SOPRANOISE 3-steps approach.

This *in-situ inspection* procedure targets *simplified acoustic assessments*[7] of possible degradations of *airborne sound insulation*. It is mainly based on *visual* inspections and *characterization of defects* in NB, focusing on their possible effect on *sound transmission* and on the *insertion loss*. It is based on inputs which can be made by visually inspecting a noise barrier and protocol, among other describing information, the size and position of identified defects.

If degradations of the *sound absorption* performance are suspected, inspections are not sufficient to conclude on their effect on the *global acoustic performance* of the NB: assessing *sound absorption* the requires to pass to Step 2 and Step 3[8]. However, during inspections, some evident degradations could directly be reported as: destroyed hard porous materials or evident degradation of mineral wool inside cassettes. In such cases, inspections could be used to directly conclude that the absorptive materials have to be replaced, but their real effect on the IL has not been studied in this research.

The reader can usefully refer to the SOPRANOISE deliverables D3.1 *Final report on the main results of WP3 (including M3.1, M3.2 and M3.3) – In-situ inspection tools* [5] for more details about how inspection tools have been designed and just ified, while the following presentation aims to quickly show with an example how simple and useful those *inspection tools* are.

3.2.1 Short description of the in-situ inspection procedure

The acoustic inspection protocol is set up as an Excel file consisting of five different sheets, as shown in Figure 7: the *inspector* can use this Excel document to obtain a first assessment of the acoustic condition of the noise barrier. This can be partly prepared in advance and finalised in an interactive manner during the general inspection routines on a portable device.

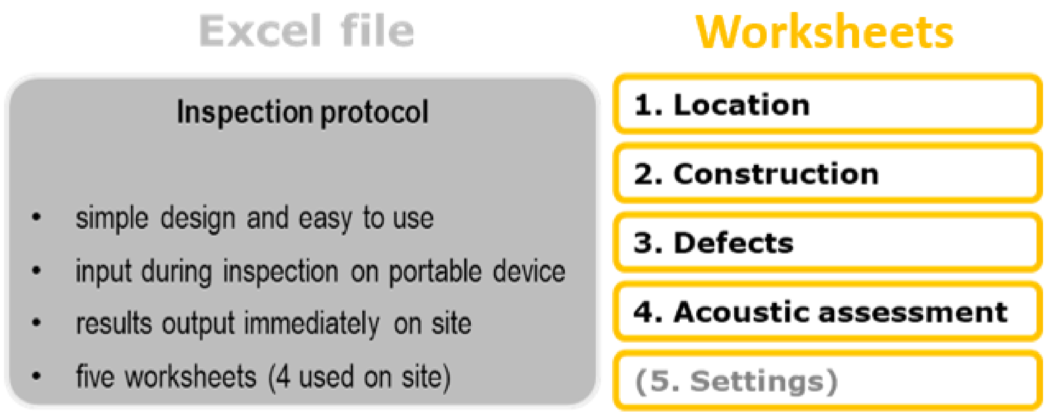

Figure 7: principles of the in-situ inspection protocol for assessing airborne sound insulation performance of already installed NB.

As shown in Figure 7, main features are:

[7] important reminder: *inspection tools* are not intended to be used for *approvals* of newly built noise barriers, that can only be done by *quantitative* measurements. The intended purpose of the inspections is to *qualitatively assess installed noise barriers and prioritize their maintenance*.

[8] of course, *qualitative* assessment of the *sound absorptive materials*, if visible, could always *be done* by inspections (mostly to monitor *degradations*), but *fair conclusions* on the *global acoustic performance* cannot be given from those.

- the procedure can easily be implemented in a general inspection routine of any existing road / railway inspection routines;
- few inputs are required and, thanks to dropdown lists and check boxes, the data entry process is quick and easy;
- the global settings are adjustable via a worksheet that can be protected;
- the results of the acoustic *qualitative assessment* are directly available in a self-explanatory “traffic-light” rating and a critical radius (see 3.2.3) .

The purpose and content of the five worksheets is the following :

1. **Location (inputs):**
   General information about the location of the noise barrier is entered on this sheet, mainly as free text.

2. **Construction (inputs):**
   The maximum of information on the materials used in the design of the noise barrier has to be entered in order to document the actual condition of the NB (while the calculation itself is independent from the inputs made in this sheet, records on the noise barrier construction are always useful for further investigations).

3. **Defects (inputs):**
   This sheet is the main input sheet of the inspection protocol: all information on the detected defects are filled in there. Except for the field number and additional notes, all inputs can be selected from a dropdown list or via check boxes. This makes the actual inspection process fast and easy to handle on site. Entry fields in the ‘Defects’ sheet are:

   - field number,
   - noise barrier side,
   - field height,
   - defect location,
   - type/cause of defect (view through, position (vertical and horizontal), size (vertical and horizontal),
   - additional notes.

4. **Acoustic assessment (outputs):**
   This sheet presents the results of the acoustic *inspection* and is a *pure output sheet*, where each considered noise barrier field is listed with the assessed acoustic condition and a critical radius of influence. Two different types of acoustic assessment are included: the result of the calculation *for each noise barrier field individually*: from this, the severity (in the acoustic sense) of a single leak becomes evident. However, in general more than one leak can occur in the same noise barrier field or in neighbouring noise barrier fields. Thus, for a comprehensive *overall acoustic assessment* of the whole NB, the superposition of leaks close to each other is also considered. The calculated “Critical radius” is the radius of influence behind the noise barrier up to which the leak has a non-negligible effect on the acoustic performance of the noise barrier.

5. **(Settings):**
   It is possible to tune few global parameters. In general, those modifications are not necessary since the default values serve as a good approximation within the accuracy of the method. However, to prevent incorrect use of this sheet, it can be also locked.

3.2.2 Example: inspection of an acrylic glass NB in Germany

Figure 8: View of the noise barrier used for this demo example

Preparation before inspection

Before starting the actual inspection, the first two sheets of the inspection protocol ('1. Location' and '2.Construction') should be filled in with the location data and the information on the material composition of the noise barrier: this should be preferably done before going on site, in order to ease the process on site.

Sheet 1: Location (inputs to be preferably filled before inspection)

SOPRANOISE in-situ inspection protocol for noise barriers

Sheet 1 - Location

road name	1	B42	
near	2	Oberwalluf	
emergency lane	3	no	
from/to km	4 (a,b)	45,7	52,9
direction	5	Frankfurt	
from/to coordinates	6 (a-d)	50,044433	8,137693
		50,044482	8,137751

Figure 9: Screenshot of *Sheet 1: Location* with demo entries

The corresponding successive entries of the example are (Figure 9):

1. The first entry is the abbreviation and corresponding number of the motorway/road. In the example, it is the federal highway with the designation "**B42**".
2. The second entry describes which city or municipality is nearby. At the given location of the example, the noise barrier is located near "**Oberwalluf**".
3. The third field asks whether the road has an emergency lane between the first traffic lane and the noise barrier at the inspected location. In the example there is none, consequently "**no**" is chosen.
4. In fields 4a and 4b, the beginning and end of the inspected section is entered on the basis of the kilometres of the motorway. In the example, the noise barrier was inspected from the kilometre marker "**45.7**" to "**52.9**". This means that 7.2 km were inspected.
5. Field five represents the direction of travel to define the side of the road on which the inspected noise barrier is located. For the example of the federal highway B42 used here, this leads in the direction of "**Frankfurt**".
6. The last four fields indicate the GPS coordinates of the beginning (from) and end (to) of the inspected section as taken from any navigational system. In the example, the GPS coordinates of the inspected noise barrier section are "**50.044433 | 8.137693**" and "**50.044482 | 8.137751**".

4 and 6 are in principle interchangeable and describe the same facts. However, the fields 4a and 4b give greater attention to the inspected length of the noise barrier, whereas the coordinates in the fields 6a - d give more attention to the position of the inspected noise barrier section on the map. Thus, of course, both entries can be made, but one of the two is also sufficient.

Sheet 2: Construction (inputs to be preferably filled before inspection)

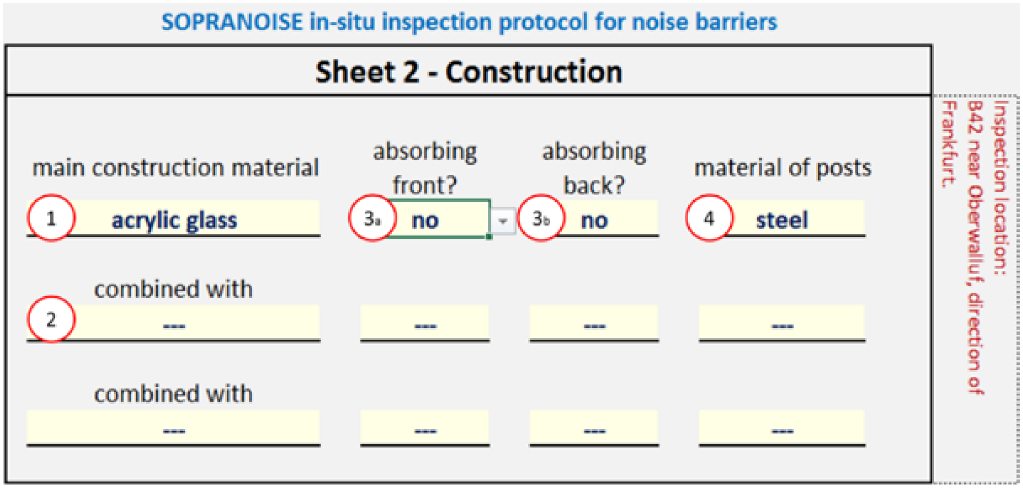

Figure 10: Screenshot of *Sheet 2: Construction* with demo entries

The input options are here divided into three lines, each line representing one material used in the noise barrier construction. If the barrier consists of only one material along its entire inspected length, filling in one line will be sufficient.

A total of three materials can be entered, one main material and two materials with which the main material was combined. Further input fields deal with the absorptive properties of the noise barrier and the material of the posts.

The corresponding successive entries of this example are (Figure 10).

1. In a dropdown menu the user can choose between the most commonly used materials for noise barriers: steel, aluminium, wood, concrete, wood-concrete, stone, gabion, earth, plastics, acrylic glass, polycarbonate and mineral glass.
   In the example, the main construction material of the noise barrier is "**acrylic glass**".
2. If required, for the second and third material the same choices can be made.
   In the example, the concrete elements are not combined with elements made of another material.
3. The front and back side of the acrylic glass elements are fully reflective. Therefore, the selection is "**no** | **no**".
4. For the material of the posts, one can choose between steel and concrete.
   In the example, the posts are made of "**steel**".

Additionally, there is a summary box at the right side of the input block with the most important information of the sheet 'Location'. This side header serves for a better assignment of the sheets in printouts.

In-situ inspections

Sheet 3: Defects (inputs corresponding to the in-situ inspections)

SOPRANOISE in-situ inspection protocol for noise barriers

Sheet 3 - Defects

1	2	3	4	5						6	7	8	9	10	11
				impact	deformation	rust	vegetation	degradation	lacking material		position /m		size /cm		additional notes (e.g. on visual/aural impression, absorption material, environmental conditions, general condition, reference to photographs ...)
field no.	NB side	field height /m	defect location	type/cause of defect						view through	vertical	horizontal	vertical	horizontal	
35	front	2	at element	☐	☐	☐	☐	☐	☑	yes	1.5 - 2.0	middle	15 - 35	65 - 125	Breakouts probably due to expansion stresses and vibrations
57	front	2	at element	☐	☐	☐	☐	☐	☑	yes	1.5 - 2.0	middle	35 - 65	65 - 125	"
83	front	2	at element	☐	☐	☐	☐	☐	☑	yes	1.5 - 2.0	middle	35 - 65	125 - 235	" (Particularly large outbreak)
84	front	2	at element	☐	☐	☐	☐	☐	☑	yes	1.5 - 2.0	middle	15 - 35	125 - 235	Breakouts probably due to expansion stresses and vibrations
86	front	2	at element	☐	☐	☐	☐	☐	☑	yes	1.5 - 2.0	middle	15 - 35	65 - 125	"
87	front	2	at element	☐	☐	☐	☐	☐	☑	yes	1.5 - 2.0	middle	35 - 65	65 - 125	"
98	front	2	at element	☐	☐	☐	☐	☐	☑	yes	1.5 - 2.0	middle	35 - 65	125 - 235	" (Particularly large outbreak)
				☐	☐	☐	☐	☐	☐						
				☐	☐	☐	☐	☐	☐						
				☐	☐	☐	☐	☐	☐						
				☐	☐	☐	☐	☐	☐						
				☐	☐	☐	☐	☐	☐						
				☐	☐	☐	☐	☐	☐						
				☐	☐	☐	☐	☐	☐						

Inspection location: B42 near Oberwalluf, direction of Frankfurt.

Noise barrier material: acrylic glass with — and

Figure 11: Screenshot of *Sheet 3: Defects* with demo entries

This is the main sheet of the in-situ inspection protocol and the only one to has to be filled in on site during the inspection. The information protocolled here is mostly relevant for the *acoustic assessment* calculated on the next sheet. Each row of the table represents a defect that has been identified. All information describing the position, size and type of damage must be entered. The check boxes can be used to indicate how the damage looks like and presumably occurred.

The corresponding successive entries of the example are (Figure 11):

1. **field no:** number of the noise barrier field. Whole-number values can be entered freely in numerical form. The numbers can be simply determined by numbering every field from the beginning to the end of the inspected noise barrier section. *The entry is important for the 'Acoustic assessment' sheet.* The first defect in the example is located at field no. "**35**" of the inspected noise barrier.
2. **NB side:** noise barrier side under inspection. Possible entries are "front" or "back". "front" is the side facing the road, "back" is the side facing the residents. The inspected side of the example is the "**front**" side.

3 **field height /m:** height of the entire noise barrier field. Possible entries are numerical values in 0.5 m steps. *The entry is important for the 'Acoustic assessment' sheet.* In the present example, the height of the noise barrier field is "**2**" m.

4 **defect location:** location of the defect at the noise barrier field. For the entry you can choose between "at element", "at post", "between elements", "between element and post" or "between element and foundation". Following the example, the defect is located "**at element**".

5 **type/cause of defect:** this column is divided into six fields with check boxes; every check box stands for a single type or cause of a defect. The six indicators are "impact", "deformation", "rust", "vegetation", "degradation" and "lacking material", multiple selections are possible. In the example, parts of some glass elements are broken off at the top edge, so "**lacking material**" is chosen.

6 **view through:** how deep is the damage? Is it only on the surface or does it go all the way through the wall? Possible entries are "yes" or "no". *The entry is important for the 'Acoustic assessment' sheet.* In the described example it is possible to look through the noise barrier, thus "**yes**" is chosen here.

7 **position /m vertical:** position of the centre of the defect in vertical direction in ranges of 0.5 m. Choose from a list beginning from "0.0 – 0.5" m up to "9.5 – 10.0" m. *The entry is important for the 'Acoustic assessment' sheet.* If uncertain between two ranges, choose the lowest one. In the example, the defect is vertically located in the height range "**1.5 - 2.0**" m.

8 **position horizontal:** locates the position in the noise barrier field. The purpose of this entry is to facilitate retrieval in case of re-inspection. The entry has no influence on the acoustic assessment. Possible entries are "left", "middle" or "right". The defect in the example is horizontally located in the "**middle**" of the inspected noise barrier field.

9 **size /cm vertical:** describes the medium vertical extension of the defect under investigation. Choose from a list ranging from small defects smaller than 4 cm ("< 4") to a defect extension larger than 415 cm ("> 415"), with sizes gradually doubling in extension. *The entry is important for the 'Acoustic assessment' sheet.* If uncertain between two ranges, choose the lowest one. In the example the average size of the defect in vertical direction is in the range between 15 and 35 cm, thus "**15 - 35**" is selected.

10 **size /cm horizontal:** describes the medium horizontal extension of the defect under investigation. Choose from a list ranging from small defects smaller than 4 cm ("< 4") to a defect extension larger than 415 cm ("> 415"), with sizes gradually doubling in extension. *The entry is important for the 'Acoustic assessment' sheet.* If uncertain between two ranges, choose the lowest one. The average size of the defect in the example in horizontal direction is in between 65 and 125 cm, thus "**65 - 125**" is selected.

11 **additional notes:** in this last column additional notes can be entered to describe the defect in free text or record other information that may be important for evaluating and/or repairing the damage. Together with photos taken, better decisions can be made in the office. In the example, the inspector entered the notes "**Breakouts probably due to expansion stresses and vibrations**".

Additionally, there is a summary box at the right side of the input block with the most important information of the sheets 'Location' and 'Construction'. This side header serves for a better assignment of the sheets in printouts.

Results

Sheet 4: Acoustic assessment (results / outcomes of the in-situ inspections)

SOPRANOISE in-situ inspection protocol for noise barriers

Sheet 4 - Acoustic assessment

Assessment for each NB field individually			Estimated overall assessment (superposition)		
field no.	acoustic condition	critical radius /m	field no.	acoustic condition	critical radius /m
35	G	5	35	G	5
57	G	9	57	G	9
83	Q	17	83	Q	33
84	G	8	84	Q	34
86	G	3	86	Q	32
87	G	9	87	Q	29
98	Q	17	98	Q	17
					0
					0
					0
					0

Inspection location:
B42 near Oberwalluf, direction of Frankfurt.

Figure 12: Screenshot of *sheet 4: Acoustic assessment* with demo output results

After completing the entries in *input sheets* 1 to 3, *Sheet 4: Acoustic assessment* becomes available. This sheet is an *output sheet*: no entries are possible here.

The corresponding results of the in-situ inspections done on our example are presented in Figure 12: this sheet immediately shows an estimation of the degradation of the acoustic performance caused by the corresponding recorded damages.

Two types of assessment are available:

- The left table shows the effect of each defect considered individually.
- The right table shows the estimated total effect of all recorded defects in superposition: this naturally results in more extensive areas of influence, which can be directly read off in the numerical value of the "critical radius".

Both sides of this representation have a meaning: while on the right side the estimated *overall* assessment of the acoustic condition can be read, on the left side it can be quickly recognised which damage has a large or small impact on this overall result.

In those tables, the acoustic consequences of the damages are shown by different ways:

- *acoustic condition:*
  a traffic light colour rating using a **red**, **yellow** and **green** colour scheme: **green** stands for a *tolerable* influence of the damage and **red** for such a large damage that a repair is unavoidable to restore the necessary acoustic properties. In the **yellow** transition area, further acoustic checks should then be carried out using Step 2.
- *critical radius:*
  the estimated radius of influence of the damage of influence.

Additional settings

Sheet 5: Settings (available on special request, otherwise locked)

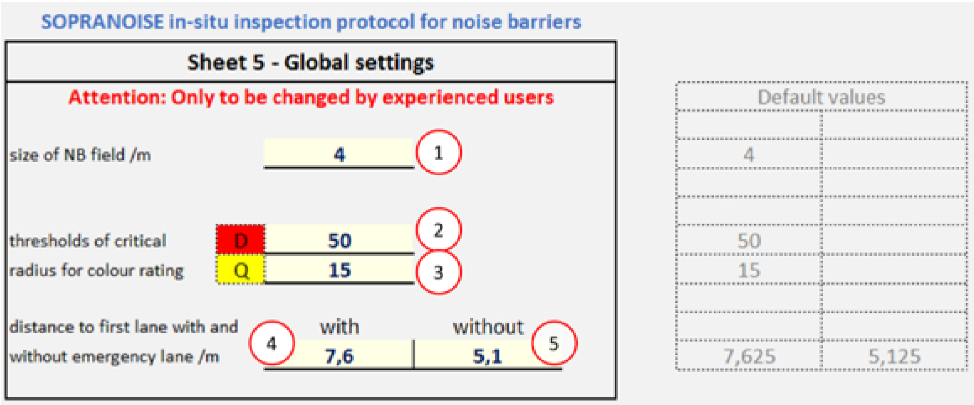

Figure 13: Screenshot of fifth sheet 'Settings' with default values

Demo values are shown in Figure 13, its right table states the pre-set default values.

Usually, no changes are necessary here.

Changes can have a great effect on the acoustic assessment and should be restricted to specialists usage: therefore, the sheet is locked against accidental entries.

3.3 Step 2: Quick method (SOPRA method)

3.3.1 Introduction

The quick method developed in WP4 - also called SOPRA method - corresponds to the second step of the SOPRANOISE 3-steps approach.

The quick method is a quick test method for determining the intrinsic characteristics of noise barrier *sound absorption* and *airborne sound insulation* under a direct sound field, i.e., in non-reverberant conditions. The measuring procedure is borrowed with several simplifications from EN 1793-5 and EN 1793-6, which are supposed to be known to the reader. The application procedure is summarized in a compact way in report D4.2 *Report on the validation of the new quick methods in-situ with recommendations for proper use* [6] , referring to EN 1793-5 [3] and EN 1793-6 [4] whenever possible.
The quick method differs from the visual/aural inspection method used in Step 1, because the quick method gives *quantitative* indications, based on *measured* values of the acoustic performance of the noise barrier. The quick method differs from the full EN standards EN 1793-5 and EN 1793-6 used in Step 3 because it is designed for quick and easy application, at the price of a reduced accuracy compared to that one of the full EN standards.

The importance of the quick method can be understood considering the two main tasks where acoustic measurements are necessary. If the noise barrier is new, accurate measurements are needed to accept the work. If the noise barrier has been in use for some years, measurements must be used to check whether the acoustic performance of the noise barrier is still acceptable. EN 1793-5 and EN 1793-6 allows to test installed noise barriers wherever they are, what could also be alongside roads or railways, and using a sound field similar to those coming from those surface traffic, i.e. a direct sound field. Thus, the above tasks could in principle be performed using the EN standards. However, their application requires skilled personnel and a careful operation of the equipment, which limits the amount of tests than can be reasonably done on an installed noise barrier. For example, according to EN 1793-5 the measurements must be repeated displacing the microphone grid few centimetres apart, and in situ on an irregular terrain this means spending a considerable amount of time just to properly place the grid.
The new quick method developed in the frame of the SOPRANOISE project helps road authorities to extend *quantitative* tests to a larger portion of the noise barrier. In fact, a single application of the quick method is easy and quick. Thus, the quick method can be routinely applied in several locations along the noise barrier, giving a reasonable estimate of the noise barrier performance, and of the related range of variability over a large sample of noise barrier fields, even if with an uncertainty greater than that one of the full EN standards. Then, when requested and relying on the results of this systematic scan of the noise barrier, some sites where to apply the full EN standards for the final assessment (Step 3) could be selected.

Therefore, the quick method is a good substitute of the EN full test when many rapid measurements are need for survey purposes. However, it must be remarked that, in all situations where legally binding values of the intrinsic characteristics of a noise barrier in a direct sound field - typically expressed as DL_{RI} and DL_{SI} in dB - are required, e.g. to check the compliance of a new noise barrier with the specifications book, the only way to assess them is to use the full EN standards EN 1793-5 and EN 1793-6, while Step 1 (in-situ inspections) and Step 2 (quick method) are very useful tools to prepare the selection of the elements / posts to be tested in full.

3.3.2 Sound absorption/reflection

General principle

The sound source emits a transient sound wave that travels past the microphone antenna position to the device under test and is then reflected on it (Figure 14).

Each microphone, being placed between the sound source and the device under test, receives both the direct sound pressure wave travelling from the sound source to the device under test and the sound pressure wave reflected (including scattering) by the device under test.

The direct sound pressure wave can be better acquired with a separate free field measurement keeping the same geometrical setup of sound source and microphone antenna but without the noise barrier (see Figure 15).

The ratio of the power spectra of the direct and the reflected components gives the basis for calculating the "quick" sound reflection index.

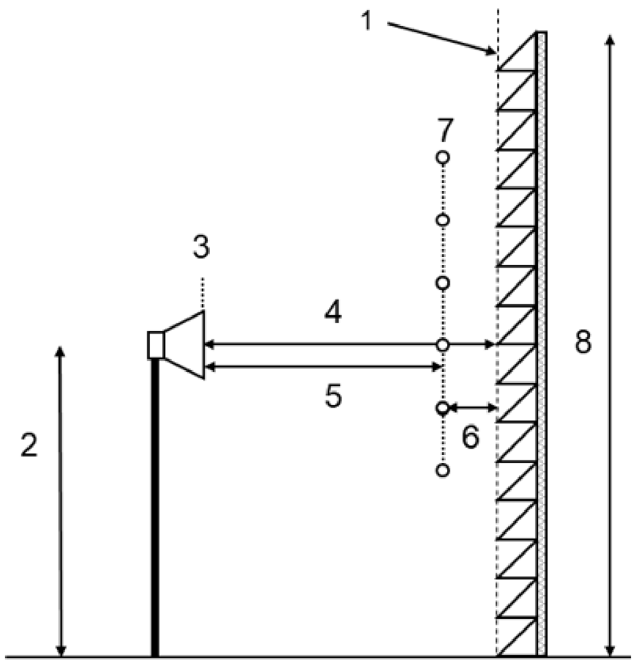

Figure 14. (not to scale) Sketch of the sound source and the microphone antenna in front of the road traffic noise reducing device under test for sound reflection index measurements.

Key

1 Source and microphone reference surface

2 Reference height h_S [m]

3 Loudspeaker front panel

4 Distance between the loudspeaker front panel and the reference surface, d_S [m]

5 Distance between the loudspeaker front panel and the microphone antenna, d_{SM} [m]

6 Distance between the microphone antenna and the reference surface, d_M [m]

7 Microphone antenna

8 Noise barrier height, h_B [m]

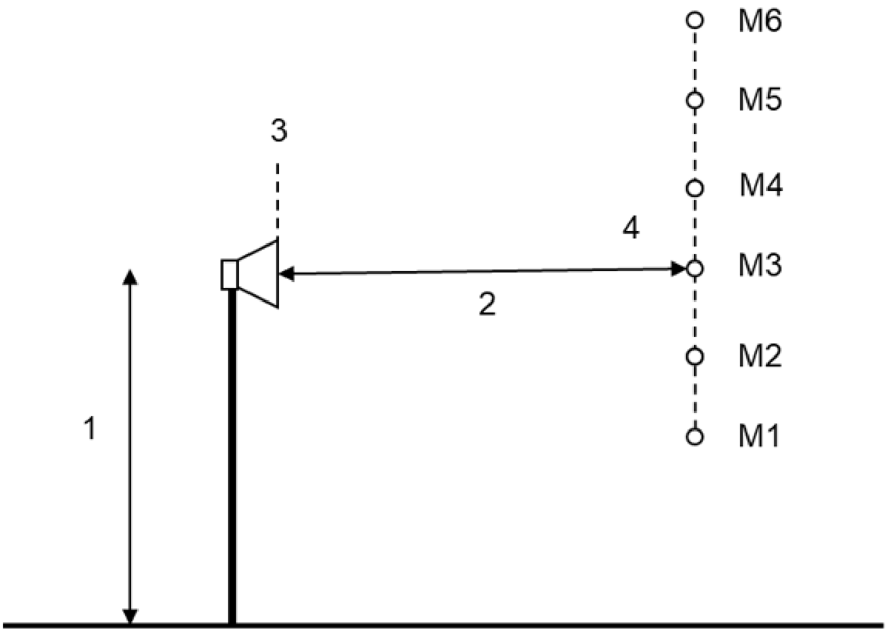

Figure 15. (not to scale) Sketch of the set-up for the reference “free-field” sound measurement for the determination of the sound reflection index. The microphones are labelled “M1” to “M6” from the bottom to the top.

Key

1 Reference height h_S [m]	2 Distance between the loudspeaker front panel and the microphone antenna d_{SM} [m]
3 Loudspeaker front panel	4 Microphone antenna

The measured quantity is the “quick” reflection index RI_Q as a function of frequency, in one-third octave bands from 200 Hz to 5 kHz. Limitations to the frequency range apply for noise barriers with a height less than 4 m.

The equipment consists of a lightweight sound source and a linear microphone antenna, see Figure 16. The microphones are labelled “M1” to “M6” from the bottom to the top. On a flat ground, M1 is at 1,20 m from the ground. The spacing between subsequent microphones is 0,40 m.

The sound source is placed facing the noise barrier side exposed to road traffic noise, at a height *of* 2,00 m and placed so that the horizontal distance of the loudspeaker front panel to the reference surface of the noise barrier is 1,50 m.

The microphone antenna is placed in a position compliant with all the following conditions: i) the microphone antenna is on the noise barrier side exposed to traffic noise; ii) the microphone n. 3 (M3) is located at a height of 2 m; iii) the shortest distance of the microphone n. 3 (M3) to the reference surface is 0,25 m.

All necessary processing is done in situ using a small control and processing device, purposely designed for SOPRANOISE.

The signal processing is very similar to that in EN 1793-5 (input signal, time analysis window, etc.) and a single-number rating, called $DL_{RI,Q}$ can be calculated from the one-third frequency band values.

For further details see report D4.2 *Report on the validation of the new quick methods in-situ with recommendations for proper use* [6] and EN 1793-5 [3] .

Figure 16. The linear microphone antenna on a supporting stand. The microphones are labelled “M1” to “M6” from the bottom to the top. On a flat ground, M1 is at 1,20 m from the ground. The spacing between subsequent microphones is 0,40 m.

Example: sound reflection tests on a metal noise barrier

This sub-chapter gives an example of results on a metal noise barrier (borrowed from report D4.2 *Report on the validation of the new quick methods in-situ with recommendations for proper use*): the noise barrier under test is made up of modular aluminium panels with the road side face perforated and the external face solid. The barrier is built by overlapping several panels of the same length, equal to 3,00 m, and with a height of 0,50 m, on a porous concrete curb 1,00 m high. The panels are inserted into HEA 180 posts spaced 2,67 m apart. The overall height of the barrier is 5,00 m. The barrier is about two years old (See Figure 17).

Figure 17. Microphone antenna, loudspeaker and control device in place for the quick sound reflection index measurements.

In one day, from about 10 AM to 16 PM, twenty-two quick reflection index tests and eleven quick sound insulation tests have been done.

The quick reflection index tests have been done placing the linear antenna and the lightweight loudspeaker in twenty different positions facing a field (post-to-post span) on the road traffic side of the noise barrier. Two of these measurements were repeated twice for control.

Figure 18 presents the results of all 20 quick measurements, averaged over the four microphones M2 to M5. The bottom microphone, M1 has been excluded to avoid the reflection of the sound waves emitted by the loudspeaker over the reflecting ground inside the analysis window. The top microphone, M6, has been excluded to avoid the strong influence of the sound waves emitted by the loudspeaker and diffracted back by the top edge of the noise barrier. The black lines are the results of a full EN 1793-5 test done 3 months before (continuous line) and the tolerance interval defined by adding or subtracting to/from the EN 1793-5 measured value the measurement uncertainty at 95% confidence level (dotted lines). The general trend of the full EN measurement is captured quite well from the 400 Hz one-third octave band.

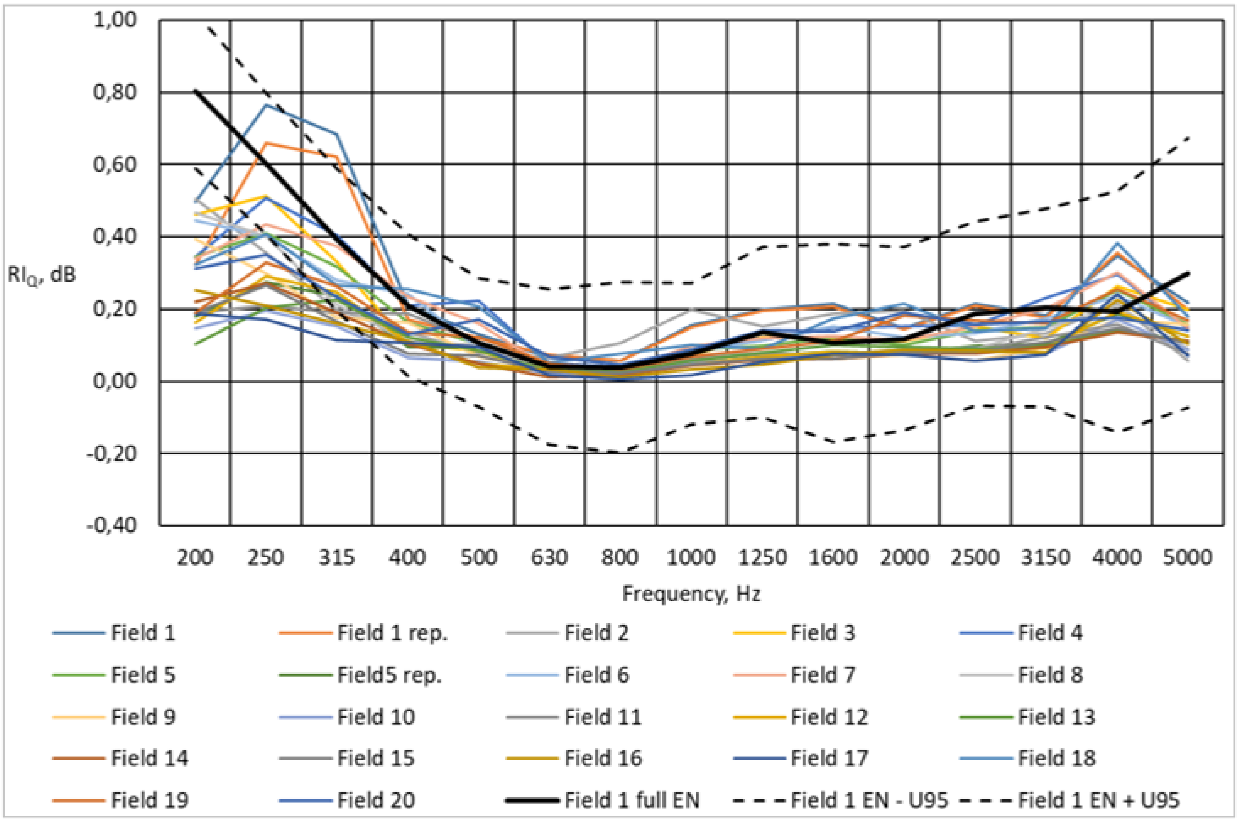

Figure 18. Colour lines: RI_Q spectra obtained with the quick method on the metal noise barrier for 20 different fields (2 repeated). Average over mic. M2-M5. Black continuous line: result of a previous EN 1793-5 measurement on a single field. Black dashed lines: EN 1793-5 measured value ± the expanded measurement uncertainty at 95% confidence level.

Figure 19 shows the differences of the single-number ratings of the individual RI_Q measurements on 20 different fields (plus 2 repetitions) from their mean value. The lower and upper boundary lines are calculated multiplying the standard deviation of the 22 values by ±1,645, which are the values of the abscissa of a standardized Gaussian distribution corresponding to a 90% coverage probability (bilateral) and summing by the mean value of the 22 values.

This figure point out the actual differences existing among the different fields of a noise barrier in good conditions. Due to the combined variance of manufacturing, installation workmanship, etc., the single-number rating values range from 6,9 dB to 12,0 dB. **Only a quick method, allowing to do multiple measurements in a short time, can give this information.** A visual inspection cannot appreciate this variance: it would conclude that all fields are very similar and in good order and thus should get the same single-number rating. See again Figure 17.

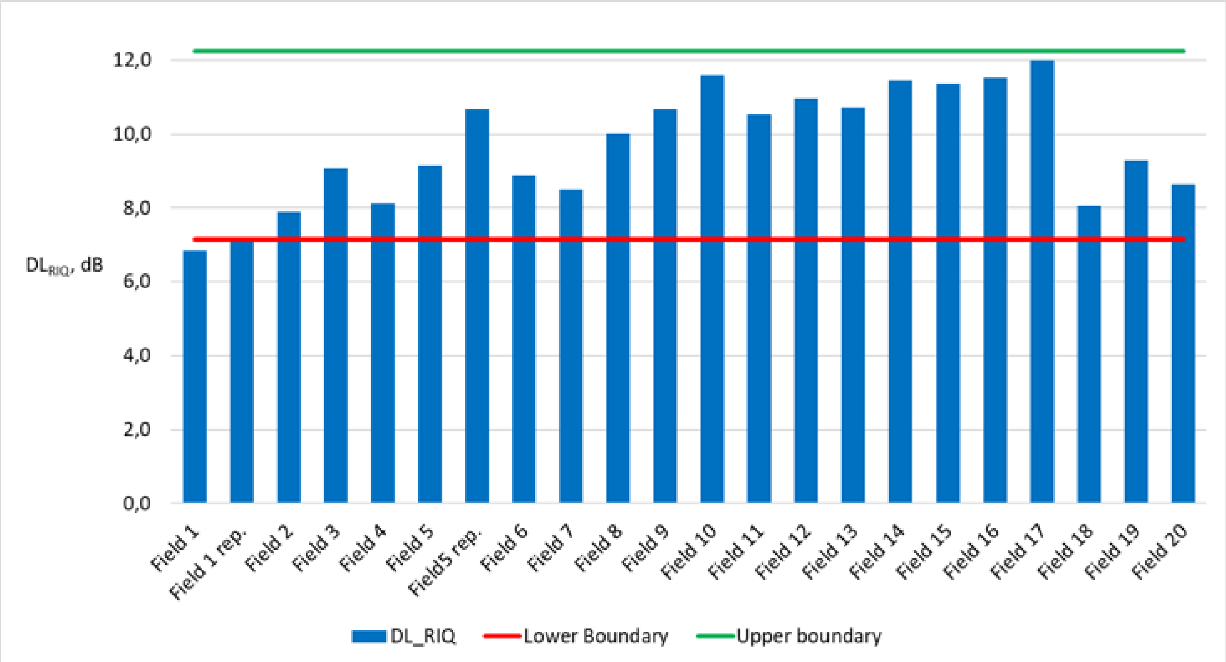

Figure 19. Differences of the single-number ratings of the individual RI_Q measurements on 20 different fields (plus 2 repetitions) from their average value. The lower and upper boundary lines are calculated as ±1,645 times the standard deviation.

3.3.3 Airborne Sound insulation

General principle

The sound source emits a transient sound wave that travels toward 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 under test receives both the transmitted sound pressure wave travelling from the sound source through the device under test, and the sound pressure wave diffracted by the top edge of the device under test (Figure 20).

If the measurement is repeated without the device under test between the loudspeaker and the microphone, the direct free-field wave can be acquired (Figure 21).

The power spectra of the direct wave and the transmitted wave give the basis for calculating the “quick” sound insulation index.

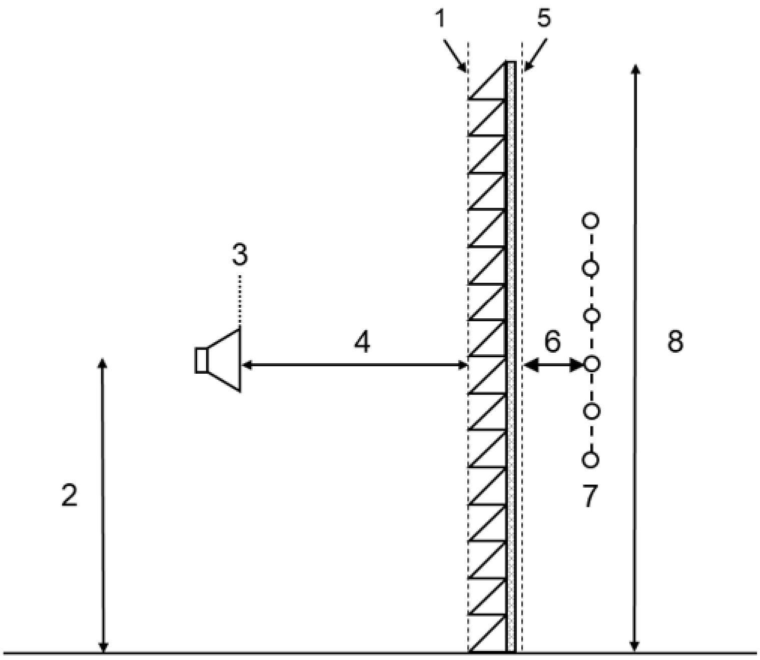

Figure 20. (not to scale) Sketch of the sound source and the microphone antenna close to the noise barrier under test for quick sound insulation index measurements.

Key

1	Loudspeaker reference surface	5	Microphone reference surface
2	Source reference height, h_S [m]	6	Distance between the microphone antenna and microphone reference surface, d_M [m]
3	Loudspeaker front panel	7	Microphone antenna
4	Distance between the loudspeaker front panel and source reference surface, d_S [m]	8	Noise barrier height, h_B [m]

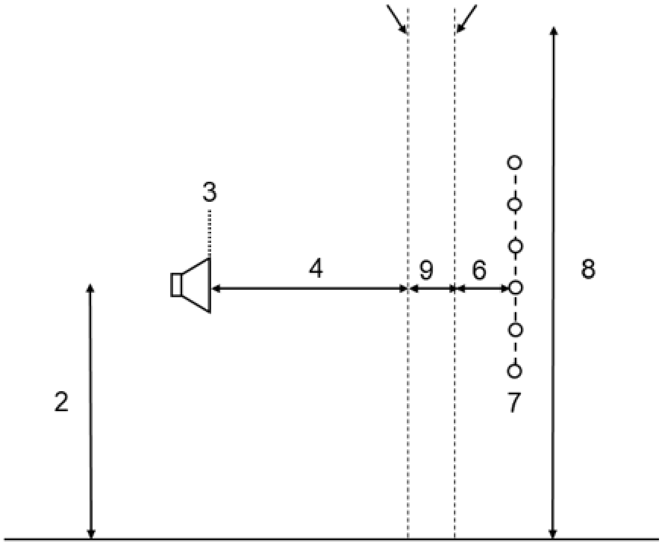

Figure 21. (not to scale) Sketch of the of the set-up for the reference “free-field” sound measurement for the determination of the quick sound insulation index.

Key

1	Loudspeaker reference surface	5	Microphone reference surface
2	Source reference height, h_S [m]	6	Distance between the microphone antenna the microphone reference surface, d_M [m]
3	Loudspeaker front panel	7	Microphone antenna
4	Distance between the loudspeaker front panel and source reference surface, d_S [m]	8	Noise barrier height, h_B [m]
9	Nominal noise barrier thickness, t_B [m]		

The measured quantity is the “quick” sound insulation index SI_Q as a function of frequency, in one-third octave bands from 200 Hz to 5 kHz. Limitations to the frequency range apply for noise barriers with a height less than 4 m.

The equipment consists of the same lightweight sound source and a linear microphone antenna used for measuring sound reflection, see Figure 16. The microphones are labelled “M1” to “M6” from the bottom to the top. On a flat ground, M1 is at 1,20 m from the ground. The spacing between subsequent microphones is 0,40 m.

The sound source is placed facing the noise barrier side exposed to road traffic noise, at a height of 2,00 m and placed so that the horizontal distance of the loudspeaker front panel to the reference surface of the noise barrier is 1,00 m.

The microphone antenna is placed in a position compliant with all the following conditions: i) the microphone antenna is on the noise barrier back side, not exposed to traffic noise; ii) the microphone n. 3 (M3) is located at a height *of* 2 m; iii) the shortest distance of the microphone n. 3 (M3) to the microphone reference surface is 0,25 m.

All necessary processing is done in situ using the same small control and processing device used for sound reflection measurements.

The signal processing is very similar to that in EN 1793-6 (input signal, time analysis window, etc.) and a single-number rating, called $DL_{SI,Q}$ can be calculated from the one-third frequency band values.

For further details see report D4.2 *Report on the validation of the new quick methods in-situ with recommendations for proper use* [6] and EN 1793-6 [4] .

Example: sound insulation tests on a metal noise barrier

As previously said, in one day, from about 10 AM to 16 PM, twenty-two quick reflection index tests and eleven quick sound insulation tests have been done.

The quick sound insulation index tests have been done placing the linear antenna and the lightweight loudspeaker on the opposite sides of ten different fields of the noise barrier; one measurement was repeated twice for control. See Figure 22 and Figure 23.

Three months before this test, a field of the same noise barrier was measured applying the full EN 1793-6 procedure with the standard equipment.

Figure 22. Microphone antenna and control device in place for the quick sound insulation index measurements.

Figure 23. Loudspeaker in place for the quick sound insulation index measurements.

Figure 24 presents the results of all 11 quick measurements, averaged over the four microphones M2 to M5 (excluding the lowest microphone, M1, and the highest microphone, M6), the results of a full EN 1793-6 test done 3 months before and the tolerance interval defined by adding or subtracting to/from the EN 1793-6 measured value the measurement uncertainty at 95% confidence level. The general trend of the full EN measurement is captured.

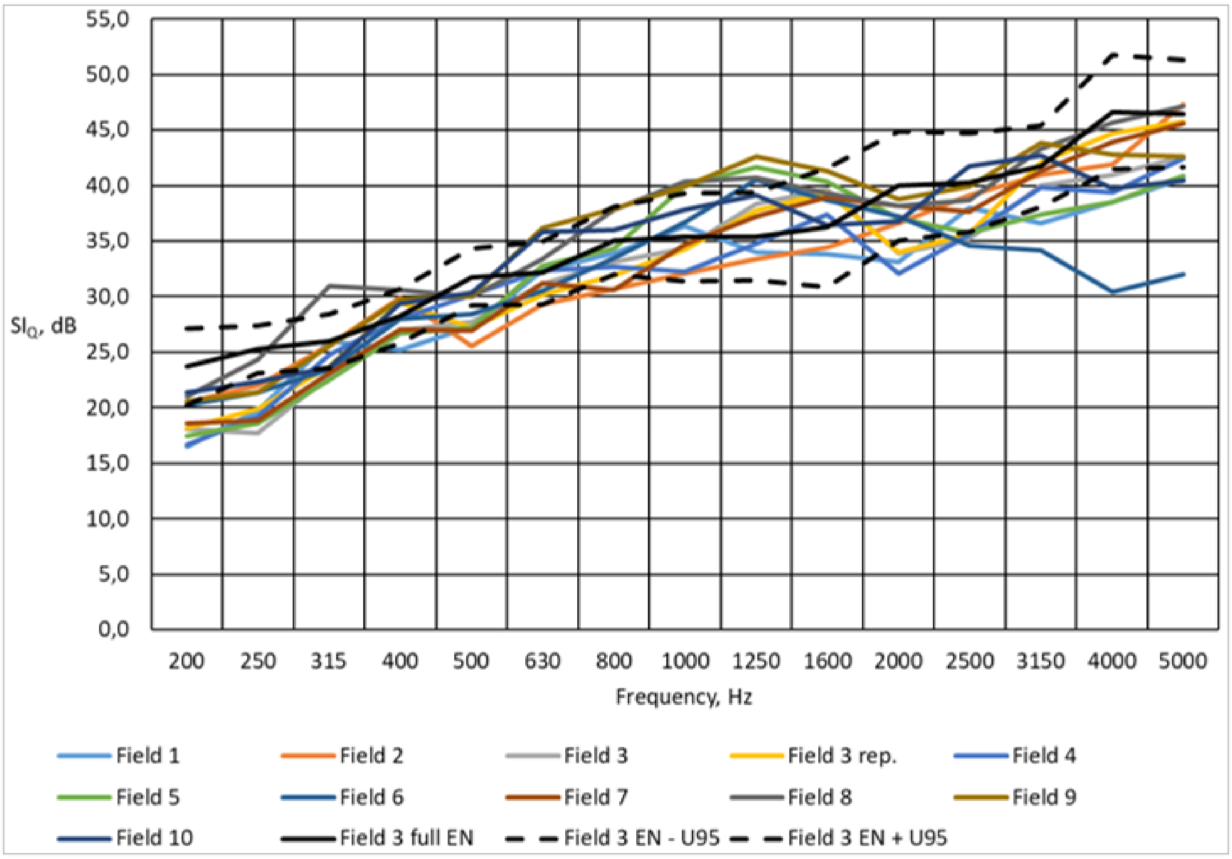

Figure 24. Colour lines: SI_Q spectra obtained with the quick method on the metal noise barrier for 10 different fields (1 tested twice). Average over microphones M2-M5. Black continuous line: result of a previous EN 1793-6 measurement on field n. 1. Black dashed lines: EN 1793-6 measured value plus or minus the expanded measurement uncertainty at 95% confidence level.

Figure 25 shows the differences of the single-number ratings of the individual SI_Q measurements on 10 different fields (1 tested twice) from their mean value. The lower and upper boundary lines are calculated multiplying the standard deviation of the measured values by ±1,645, which are the values of the abscissa of a standardized Gaussian distribution corresponding to a 90% coverage probability (bilateral) and summing by the mean value of the 22 values.

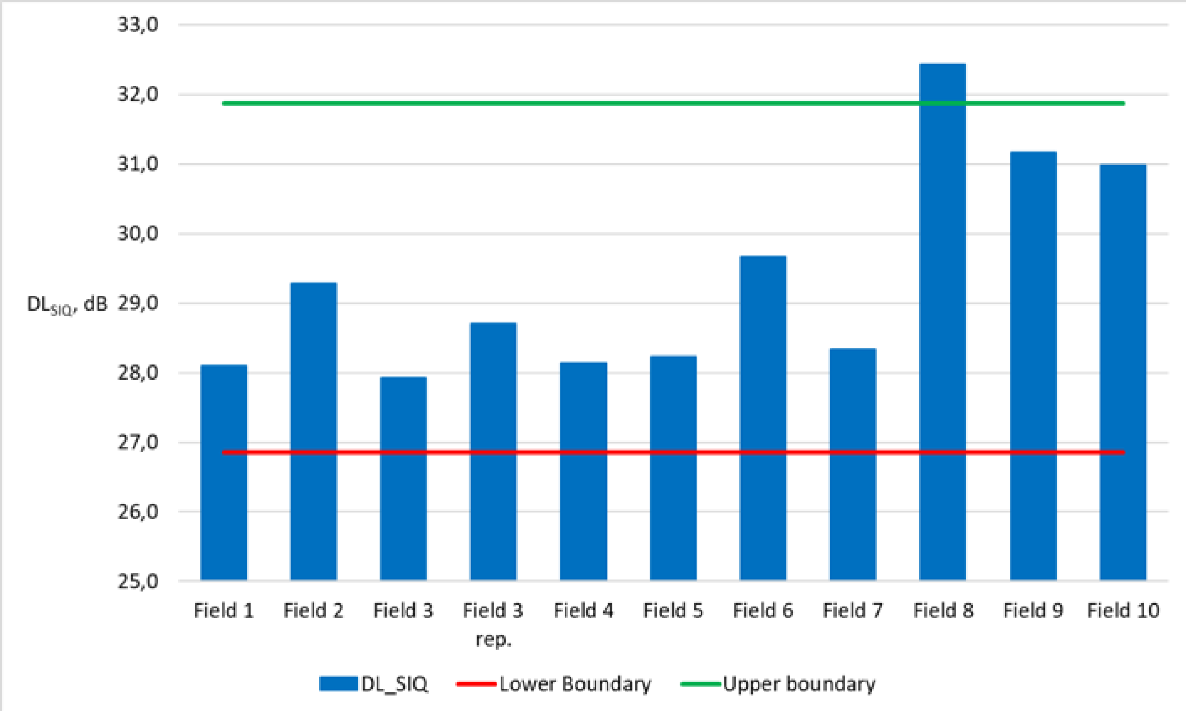

Figure 25. Differences of the single-number ratings of the individual SI_Q measurements on 10 different fields (+ 1 repetition) from their average value. The lower and upper boundary lines are calculated as ±1,645 times the standard deviation.

This figure point out the actual differences existing among the different fields of a noise barrier in good conditions. Due to the combined variance of manufacturing, installation workmanship, etc., the single-number rating values range from 27,9 dB to 31,2 dB. **Only a quick method, allowing to do multiple measurements in a short time, can give this information**. A visual inspection cannot appreciate this variance: it would conclude that all fields are similar and in good order and thus should get the same single-number rating. See again Figure 23.

3.4 Step 3: In-situ "full tests"

Step 3 should normally come after Step 1 and / or Step 2, as those methods can help to reduce the efforts requested by the "full tests":

- not only by simply rejecting NB elements that are obviously damaged in such extent that no accurate method is really necessary to conclude (Step 1)
- but also by establishing a relevant sample of long NB that could be representative of the whole NB length: in such a way, the amount of "full tests" could be limited to a lower amount of relevant elements (Step 2).

"Full tests" methods are fully described in (CEN) standards EN 1793-5 [3] for *sound absorption* and EN 1793-6 [4] for *airborne sound insulation*: those methods are well known by the NB market stakeholders and do not require more information within the present SOPRANOISE task.

3.5 Conclusions

Characterizing the intrinsic *acoustic performances* (*sound absorption / reflection*, *airborne sound insulation*) of Noise Barriers is important to be assured that those NB will correctly (continue to) reduce noise in the environment they have to protect.

As today's NB could often be very long and can be made of a huge amount of elements, testing exhaustively all of those elements with "full tests" as EN 1793-5 [3] and for *airborne sound insulation* EN 1793-6 [4] is not realistic, nor affordable.

The SOPRANOISE 3-step approach allows to place the right effort and money to the right level of analysis: from the easiest (but less accurate) way, up to the most accurate one.

SOPRANOISE has now described and justified the 2 new methods:

- **Step 1**: *In-situ Inspections* method[9], and
- **Step 2**: *SOPRA* method

Thanks to their lower cost and safer use, much more systematic monitoring possibilities are now available thanks to Step 1 and Step 2, while Step 2 is a very good method to "overview" NB and to justify relevant sampling of NB elements.

The next task will now be to submit those 2 new methods to standardization.

3.6 References

[1] CEDR Technical Report 2017-02, State of the art in managing road traffic noise: noise barriers, Brussels, Belgium (2017).

[2] J-P. Clairbois, F. de Roo, M. Garai, M. Conter, J. Defrance, C. Oltean-Dumbrava, C. Durso. Guidebook to noise reducing devices optimisation. European Project QUIESST (FP7-SST-2008-RTD-1 SCP8-GA-2009-233730), Brussels, Belgium (2012).

[3] EN 1793-5:2016+AC:2018, *Road traffic noise reducing devices - Test method for determining the acoustic performance - Part 5: Intrinsic characteristics - In situ values of sound reflection under direct sound field conditions*, 2018.

[4] EN 1793-6:2018, *Road traffic noise reducing devices - Test method for determining the acoustic performance - Part 6: In situ values of airborne sound insulation under direct sound field conditions,* 2018.

[5] M. Chudalla, F. Strigari, W. Bartolomaeus, *SOPRANOISE Deliverable D3.1, Final report on the main results of WP3 (including M3.1, M3.2 and M3.3) – In-situ inspection tools-*, 2021.

[6] M. Garai, P. Guidorzi, *SOPRANOISE Deliverable D4.2, Report on the validation of the new quick methods in-situ with recommendations for proper use*, 2022.

CEDR Contractor Report 2022-09

Final Report from CEDR Research Programme Call 2018 Noise and Nuisance Project SOPRANOISE

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Conference of European Directors of Roads

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