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SOPRANOISE – a New Quick Method for Measuring the Acoustic Quality of Noise Barriers In-Situ

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Abstract

Nowadays EN 1793-5 and -6 allow acoustic measurements on noise barriers, what is essential for approving new installed noise barriers. This is increasingly done by National Authorities in many European countries. However, these methods require careful application by expert users, which result in lengthy and costly tests limiting their use. Therefore, there was a need for a quicker method that should be faster and easier to be applied on a larger part of the noise barrier, even if with a broader uncertainty compared to the full standards. SOPRANOISE was European research funded by CEDR on simplified methods to characterize the in-situ acoustic performances of road and railway noise barriers: the present paper shows the main outcomes of the project, for non-experts in the field, some general information on the methods and diagrams of the results will be provided during the presentation.

Keywords: noise barrier evaluation; noise protection; securing noise performance.

1. Introduction

1.1. Background and research need

Noise barriers are extensively used by National Road Administrations (NRAs) as effective devices to reduce road traffic noise. In order to optimize and secure the performance of these noise barriers, one has to understand that their

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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 related to the products themselves). NRAs logically draft relevant specifications that contractors and manufacturers of noise barriers products must respect, in order to not only 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 following their intended use (i.e.: under direct sound field conditions).

Since 1990, CEN/TC226/WG6 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: EN 1793-1 (sound absorption under diffuse sound field conditions - can only be applied in laboratory), EN 1793-2 (airborne sound insulation under diffuse sound field conditions - can only be applied in laboratory), EN 1793-5 (sound reflection under direct sound field conditions) and EN 1793-6 (airborne sound insulation under direct sound field conditions). Those last two standardized 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 or monitoring installed noise barriers.

This is already and increasingly done by NRAs to characterize installed noise barriers. However, EN 1793-5 and EN 1793-6 methods require quite lengthy tests that could also be affected by practical conditions (weather conditions, safety, accessibility, etc.), as well as the need of expert users: this can limit their use alongside roads. While always keeping the possibility to use EN1793-5 and EN 1793-6 on site, there is a need for new methods that could be easier, faster, and safer.

Some NRAs already undertake in-situ inspections to monitor the integrity of the different parts of their road 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 (meaning via measurements), a new "quick method" 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 and -6: this has been done successfully and led to the brand new and validated quick "SOPRA" method.

As noise barriers 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. The SOPRANOISE project (Securing and Optimizing the Performance of Road traffic noise barriers with new methods and In-Situ Evaluation) successfully replies to all those needs.

1.2. Consortium and research structure

The SOPRANOISE consortium included the following main partners: A-Tech, AIT, UNIBO, BASt and ERF. Each work package had a WP leader and involved all the other partners. The customer CEDR (Conference of European Directors of Roads) closely followed and helped the research as representing the relevant road authorities, while ERF (European Road Federations) represents the noise barriers market stakeholders (manufacturers and installers). The structure of the project and the mid-term report was presented in past papers (J.-P. Clairbois et al. (2020)).

WP1 concerned the project management, while the scientific parts have been managed within WP2 to WP5.

WP2 had three main objectives: first to perform State of the Art research about physical significance, correlations, and possible trends between the diffuse sound field methods (EN 1793-1 and -2) and the corresponding direct sound field methods (EN 1793-5 and -6); secondly to update and extend the database of the acoustic performances of EU noise barriers products, and third research to what extent degradations could affect the global noise barrier performance (insertion loss). This last objective was the basement of the new in-situ method of WP3.

WP3 was entirely dedicated to in-situ inspections methods: such methods will now allow to assess the noise barriers acoustic performances in a much more cost effective and systematic way.

WP4 was dedicated to design the new “SOPRA” quick and safe methods to measure in-situ sound absorption and airborne sound insulation: from an in-depth analysis of the existing techniques, up to the design and validation of the method and equipment.

Finally, WP5 was dedicated to the following issues: a website on which the public deliverables are available, a technical report on the physical behavior of noise barriers, a State of the Art on today’s noise barriers use in the EU, and the synthesis of the research within this final scientific report, as well as its main outcomes stated in comprehensive guidelines on how to improve the use of noise barriers.

1.3. SOPRANOISE 3-step approach

The SOPRANOISE research addresses new tools to assess the acoustic performances of noise barriers as they are effectively used along road and railway networks. The target is to facilitate the assessment of the acoustic performances of noise barriers, not only at or just after their installation, but also throughout their whole lifetime: at the end of this research, one can say that the target has been successfully reached.

Within this research project a new concept of performance assessment has been developed: the so-called SOPRANOISE 3-step approach. This approach 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 standardized methods EN 1793-5 and EN 1793-6), following an “engineering progressive approach”.

To reach the objective, the missing two first levels have been now filled by the purposely designed In-situ inspection and the “SOPRA” quick method.

The scope of application for the SORPANOISE 3-step approach is summarized in Figure 1.

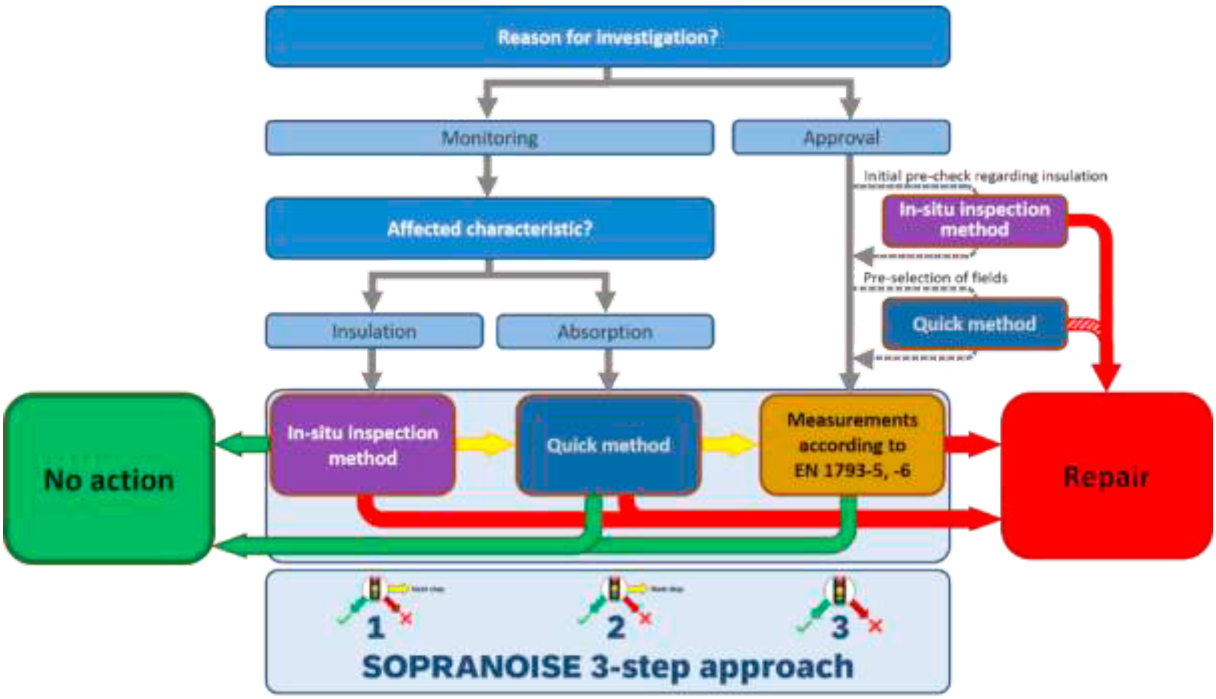

Fig. 1. Flow chart visualizing the scope of the SOPRANOISE 3-step approach.

Initially, it is necessary to define the reason for the planned noise barrier investigation. For the approval of a newly built noise barrier (i.e., for legal reasons which require quantified values of intrinsic characteristics DL_{RI} and DL_{SI}), the only way is to carry out measurements according to the EN 1793 standards.

Since approvals according to EN 1793 standards can be expensive and time-consuming – especially for long noise barriers – it is advisable to first carry out in-situ inspections and/or measurements via the quick method. With the in-situ inspection, apparent defects can be found and directly rejected, and sampling via the quick method also allows a fair pre-selection of relevant locations for the actual approval.

The 3-step approach comes into action when a noise barrier investigation is planned within a monitoring process of an existing noise barrier. For the evaluation of sound absorption properties, it is unavoidable to carry out acoustic measurements via the quick method (step 2). No conclusions about the degradation of sound absorption characteristics can be drawn from in-situ inspections only. The purpose of in-situ inspections (step 1) is to obtain useful indications and spot out major defects, to deliver a very quick and relevant estimation of the degradation of the insertion loss of the noise barrier (due to a diminished sound insulation). This facilitates the follow-up monitoring and maintenance of installed noise barriers, considering its insertion loss performance. In-situ inspections do not give a quantitative value of airborne sound insulation. The acoustic rating obtained via the in-situ inspection method identifies defects with negligible consequences for the insertion loss (green rating), defects which surely have to be repaired (red rating) and defects which require an actual assessment via acoustic measurements (yellow rating). This case establishes the transition to step 2, i.e., the quick measurement method.

2. WP2: State of the Art, SOPRANOISE database and effect of degradations

The general objective of WP2 was to provide both theoretical and practical background information on measurement methods of the acoustic performance of noise barriers and on meaningful results. In a first task a systematic review on the State of the Art regarding correlations available in literature and possible trends between measurement results between methods under diffuse sound field conditions and methods under direct sound field conditions was performed. The results of this task are summarized in report D2.1 (Reiter et al. (2020)).

The second task had to update and analyze the noise barrier database including new current measurements. It focused on the extension of the relevant database of EU noise barriers that was started within the QUIESST project, including single-number ratings and third-octave band spectra from manufactured products, and already installed noise barriers. The SOPRANOISE database now shows facts and figures about acoustic performances obtained from both the diffuse sound field and direct sound field methods, together with a better understanding of the respective significance, similarities, and differences of these standardized methods, improving data analysis and correlations between these methods. The outcomes of this task are summarized in report D2.2 (Conter et al. (2021)) and in a past paper (Conter et. al. (2021) Fuchs et. al. (2021)).

In the third task the effect of acoustic degradation on the global acoustic performance of noise barriers was considered in detail. The results yield the theoretical background for the assessment of the acoustic degradation due to leaks in a noise barrier and allow to calculate the (acoustic) radius of influence for different leak characteristics. This work builds the basis for the in-situ inspection procedure developed in WP3 and is also part of the report D2.2.

2.1. Main outputs of WP2

As a main output of WP2 the SOPRANOISE database contains now results on 448 different noise barriers manufactured and installed by 58 different noise barrier manufacturers or construction companies, from 9 different European countries (Austria, Belgium, France, Germany, Ireland, Italy, Spain, The Netherlands, and United Kingdom) for a total of 2029 datasets and 1263 single number ratings. The measurements collected have been performed by 39 different testing laboratories from the European countries listed before.

Regarding the correlations between the single-number rating of sound absorption under diffuse sound field conditions $DL_{\alpha,\mathrm{NRD}}$ and the single-number rating of sound reflection under direct sound field conditions DL_{RI}, the statistical distribution shows clearly that values obtained with the method according to EN 1793-1 are in general considerably higher than the values obtained with the methods according to EN 1793-5. Therefore, the median value for the method according to EN 1793-1 is between 9 and 10 dB, while for the method according to EN 1793-5 the median value is around 6 dB. In conclusion, regarding the correlation between results of sound absorption under diffuse sound field condition and sound reflection under direct sound field condition, only very rough estimates are possible, which are limited to low sound absorbing samples with no practical use for certification or quality assurance purposes.

Regarding the correlations between the single-number rating of airborne sound insulation under diffuse sound field conditions DL_{R} and the single-number rating of airborne sound insulation under direct sound field conditions DL_{SI} the statistical distributions shows that values obtained according to EN 1793-2 are in general slightly lower than the values obtained according to EN 1793-6. Element values are in general higher than results at the post, while the global values are between these values. The median value for the method according to EN 1793-2 is around 28 dB, while for the method according to EN 1793-6 the median values are around 34 dB for element, 30 dB for post and 31 dB for global values. Furthermore, the shape of the probability functions is rather similar, nevertheless the values according to EN 1793-6 can reach higher values up to 66 dB (especially at the acoustic element), while the values according to EN 1793-1 reach maximum values around 50 dB. In conclusion, regarding the correlation between results of airborne sound insulation under diffuse sound field conditions and results under direct sound field conditions, a promising fit could be achieved due to the wide data range. Nevertheless, the significant uncertainties of the regression models must be considered when predictions are made, which also limits the practicality of using prediction models for certification or quality assurance purposes.

Finally, the possibilities of finding correlations between the measurement methods were pushed to its limits regarding the use of external information and applying statistical linear and non-linear multi-variate regression models as an empirical approach. Possible further research on these topics has been delineated in report D2.2.

3. WP3: In-situ inspection tools

In WP3, an inspection protocol that can also be implemented in existing inspection routines was developed for recording and evaluating acoustically relevant damage to noise barriers: it consists of an Excel tool with accompanying explanatory descriptions for its application. With this tool, it is possible to log damage and prioritize pending repairs to ensure noise protection.

The first task was on the review of existing in-situ inspection tools: based on a questionnaire sent to the CEDR Member States (covering European Road Authorities and Research Institutes), information was collected on existing inspection routines and knowledge/experience on various aspects of noise barrier acoustic performance. The outcomes of this task are summarized in report D3.1 (Chudalla et al. (2021)).

The second task was on the development and testing of methods based on in-situ inspection, where the acoustic in-situ inspection procedure was developed. It allows an initial acoustic assessment of the effect of defects on the insertion loss of noise barriers. The inspection is mainly based on a visual screening, from which the detected defects are characterized. Based on a theoretical model and considering the recorded defect characteristics and geometrical parameters, an acoustic radius of influence is calculated, leading to the acoustic rating of the inspection. Tests showed that this calculation method provides a realistic assessment of the acoustic effects of leakages in a noise barrier.

In the third task of this WP3, the in-situ inspection procedure was further developed and finalized, based on several feedbacks and additional testing. The scope of application was defined and the corresponding user-oriented documents containing all information required for the implementation and understanding of the inspection procedure were prepared. In particular, herein it is emphasized that (i) the in-situ inspection yields a first evaluation for the acoustic degradation due to one or more defects in a noise barrier; (ii) the underlying theoretical model is a qualitative approximation with several simplified assumptions; (iii) no conclusions regarding sound absorption properties can be drawn and (iv) for the legal approval of a noise barrier quantitative acoustic measurements will always be necessary.

With the availability of the Excel file to record defects recognized at inspections, the short description of the in-situ inspection procedure and the manual of the in-situ inspection protocol, every NRA is now given the opportunity to carry out a first qualitative acoustic assessment of noise barriers using visual inspection. The outcomes of this WP are summarized in a past paper (Strigari, et al. (2021)).

3.1. Main outputs of WP3

The result is a hands-on in-situ inspection procedure for the qualitative evaluation of the degradation effect in the acoustic insertion loss of a noise barrier due to leaks. The inspection protocol allows a simple and fast application on site, can be used in parallel to existing inspection procedures, follows a physics-based approach and has a well-defined scope and user-oriented documentation.

Regarding the future application of the in-situ inspection tool, the implementation of the inspection protocol can be easily modified to adapt new requirements. In this context, especially the practical experiences from users and other demands raised by stakeholders will surely help to further improve the procedure and eventually realize a relevant tool for facilitating the systematic characterization of noise barriers.

4. WP4: Quick and safe methods alongside roads

The goal of WP4 was to develop the quick methods corresponding to the second step of the 3-step SOPRANOISE approach. The quick methods are measurement methods for determining the noise barrier intrinsic characteristics sound absorption and airborne sound insulation under a direct sound field, i.e., in non-reverberant conditions.

In the first task on the review of existing quick methods, the existing proposals of quick methods for determining the intrinsic acoustical characteristics of noise barriers have been analysed and compared with a multi-criteria approach. In the second task the development and testing of reliable quick methods was performed.

Relying on the outcomes of the literature review and the researchers' experience in developing the EN full methods, new quick methods have been designed and tested on full-scale laboratory samples. Both the procedure and the equipment are simpler and faster than for EN 1793-5 and EN 1793-6 standards, allowing the use by normal operators after a short training. The quick methods give reliable and quantitative conclusions on the noise barrier performances. The same laboratory samples have been tested with the quick methods and with the full EN methods to assess the degree of correlation of the quick methods with the acknowledged qualification standards. At the end of this task, the new quick method was ready for validation in real on-site conditions.

Within task 4.3 the validation of quick methods by comparison with full methods in-situ was carried out. This task has been accomplished applying both the new quick methods and the EN 1793-5 and EN 1793-6 methods on noise barriers installed along the A22 motorway connecting Northern-Italy to Austria. Metal barriers and timber barriers have been tested. It has been proved that the quick methods allow to test many more noise barrier fields at the same time, at the price of a slightly reduced accuracy, compared to the full EN standards. In addition, laboratory measurements with purposely newly developed equipment were performed to systematically compare the new developed quick methods with the full EN standards and evaluate the repeatability of the quick method, which proved to be excellent (see report D4.1, Garai et al. (2021)).

The last task of WP4 was devoted to write the final report on the new quick methods developed in the frame of SOPRANOISE (see report D4.2, Garai et al. (2022)). The report includes: a summary of the equipment designed for the quick methods; a summary of the proposed measurement procedure; the data measured applying both the new quick methods and the full EN methods on noise barriers installed along the A22 motorway and the results of the activities performed in the laboratory. The report also includes some recommendations for proper use of the quick methods, an acceptance criterion for each individual quick measurement, based on a statistical approach; two proposals, following two different approaches, for a "sampling criterion" when applying the quick methods to a noise barrier, to assess the representativity of the acquired sample of quick measurements. Clearly this is something that goes beyond the SOPRANOISE project; investigations on this topic will continue after the end of the project.

The research on the above topics is going to continue after the end of the SOPRANOISE project. Both UNIBO and AIT are willing to investigate more on the acceptance criterion for the individual quick measurements and on the sampling criterion. With the fading out of the pandemic, it is hoped that this research could be done in-situ along some main motorways. At the same time, the acquisition of many more data, which is possible with the new quick methods, should allow to assess the in-situ repeatability of the quick methods and its correlation with the full EN method.

4.1. Main output of WP4

Summarizing the results of WP4: the new quick methods 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 methods is easy and quick. Thus, the quick methods 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 of SOPRANOISE approach) could be selected.

5. WP5: Final report and guidelines for noise barriers use

WP5 assembled the results of the research in a comprehensive manner and delivered guidelines to provide an improved and wider practical approach on how to consider noise barriers as powerful tools to reduce road noise: all of this from planning, design, procurement, control, use and maintenance phases within a long-term perspective.

Within task 5.1 a project website was implemented, where all project reports are publica available.

Task 5.2 was dealing with the physical behavior of noise barriers, clarifying how noise barriers could be efficient (or not) and up to what extent their intrinsic performances do act in the overall process of sound propagation toward the environment. Starting from the physical phenomena, up to the final noise reduction in the environment (Insertion Loss IL), throughout all the factors involved in the process (both the extrinsic and intrinsic ones), its report is presented in the report D5.1.

Task 5.3 was on the State of art on the today's noise barriers use within the EU Market: the aim of this task was to understand how different authorities, NRAs, railway companies are considering, specifying and using noise barriers along their respective networks. A questionnaire with seven key questions has been circulated to numerous EU Noise Barriers stakeholders: a database of the 32 replies has been built and analyzed: this survey is presented in report D5.1.

Task 5.4 assembled the outcomes of the In-situ inspections methods (developed in WP3) and the ones of the new "SOPRA" method (developed in WP4), summarizing the SOPRANOISE 3- step approach to characterize the intrinsic acoustic performances of noise barriers: these results are integrated in report D5.2.

Task 5.5 was mainly dedicated to draft the guidelines, aiming to provide guidance to NRAs and railway companies to better use of noise barriers thanks to all the outcomes of this research (see report D5.2).

The final event is integrated in the CEDR 2018 Noise and Nuisance - Final Conference held on 7-8 June 2022 in Liège, Belgium.

6. Conclusions and outlook

The objective of the SOPRANOISE research was to improve the specific knowledge on how to assess the acoustic performance of noise barriers and to reach a new level of understanding on how noise barriers can be relevant tools to reduce road and railway noise.

Thanks to the assembly and the thorough analysis of the purposely updated database of the different test reports on the noise barriers intrinsic performances, a relevant overview on how the noise barriers are characterized and what can be the realistic intrinsic performances we can expect from the EU noise barriers products was achieved within WP2. The database developed in this WP contains now results on 448 different noise barriers manufactured and installed by 58 different noise barrier manufacturers or construction companies, from 9 different European countries and gives a good overview of the European market.

Thanks to comprehensive research on how the extrinsic performance can be affected by degradations of noise barriers elements, WP3 designed and validated a new in-situ inspections tool. This method allows simple and effortless investigations on the airborne sound insulation of installed noise barriers, which can easily be integrated into existing inspection procedures.

WP4 successfully achieved the design of the brand new "SOPRA" method: this method allows a quicker and safer procedure than the "full" standardized methods (EN 1793-5 and EN 1793-6). It works as a link in between those accurate but long and requiring standards and the simplest in-situ inspections. New equipment has been independently designed by the University of Bologna and the Austrian Institute of Technology and the "SOPRA" method has been validated.

WP 5 assembled relevant elements to understand how noise barriers can be better designed through a better understanding of how they work, while a survey between EU noise barriers users shows how different stakeholders do consider noise barriers on their networks.

Finally, SOPRANOISE significantly improves the knowledge and understanding of noise barriers, as well as how to assess their acoustic intrinsic performances, whenever and wherever they are installed. The innovative SOPRANOISE 3-step approach ensures that the respective relevant method is used for the relevant analysis and allows NRAs to better manage their noise barriers.

The work performed in SOPRANOISE will be implemented at the EU level due to the SOPRANOISE experts who are CEN/TC226/WG6 convenor, CEN/TC256/SC1/WG40 convenor, CEN/TC226/WG6/TG1 convenor, as well as member states experts of those WGs: as soon as possible the new method will be transmitted to WG6 and WG40 for standardization. At the same time, the “Guidance for noise barrier use” (see report D5.2) is already a relevant reference for NRAs in their planning, design, procurement, installation, approval, maintenance, and decommissioning stages.

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