State of the art of noise barriers in CEDR experience

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ABSTRACT
In the framework of CEDR Noise group’s Strategic Plan 2013-2017, the report “Noise barriers: State of art” presents a general overview of the domain of noise barriers used along European roads. The report intends to assist each NRA (National Road Authority) in the planning, building and maintaining processes of noise barriers for new and existing road infrastructure.

The first part of the document is dedicated to the different acoustic and non-acoustic standards and guidelines used to insure the performances of the devices. The second part focuses on the types of barriers looking at the aesthetic appeal, shapes and materials with a reference to the experience and the bad examples collected from the CEDR member states. The last chapter offers a comprehensive review of recent research projects on NRD’s in the various CEDR member states: combined noise and safety barriers, photovoltaic noise barriers, noise barriers with TiO₂ coating, ...

This publication aims to provide a framework of the working principles of a noise barrier focusing on minimum requirements for the device to ensure its best life time.

1. INTRODUCTION
In Europe the National Road Authorities (NRAs) form the Conference of European Directors of Roads (CEDR). The road directors of Europe are aware of the importance of improving European cooperation. This is a key element for making progress in the road and road transport sector and strengthening the relationship with other modes of transport and with society at large.

The Conference of European Directors of Roads (CEDR) included the task group “Road Noise” (Task I 6) in its Strategic Plan 2013-2017. Each CEDR member state was invited to appoint a member to the CEDR noise group. One of the main objectives of the CEDR noise group was to collate the information on the results of recent innovative road noise research in order to improve road traffic noise quality in close proximity to road infrastructure and reduce costs in planning, building and maintaining road infrastructure.

This paper describes the main results described in the report “Noise barriers : State of art” of CEDR Road Noise in the plan 2013-2017.

2. WORKING PRINCIPLES
Noise barriers can be used as a soundproofing measure in order to protect people living near busy roads against traffic noise. The reduction and the sound level behind the sound barrier depends on the acoustic properties of the noise barrier, the dimensions of the noise barrier, the position of the source, the noise barrier and the receiver, the traffic intensity, the road surface, the speed condition of the vehicles, the nature of the terrain between the road and the houses and the weather conditions.

The purpose of noise barrier is to reduce noise levels at noise sensitive receivers by influencing the propagation path between the source and the receiver. The noise reduction in the areas close to the barrier, with sufficiently high insulation value and possibly an absorption value, can be outlined as:
• 5 dB is relatively easy to obtain
• 10 dB is obtainable using barriers of considerable size
• 15 dB is difficult to obtain
• 20 dB is possible to obtain only with a coverage, a tunnel

Noise barriers are also relatively ineffective at screening properties at some distance from the road (say more than 100m).

So informing the citizens about the reducing effect of the new noise barrier (info meeting, brochure, audiotape, etc.) to avoid/reduce misunderstandings afterwards is an important task of a NRA.

2.1 Standards

2.1.1 Introduction

To assess the performances of noise barriers the CEN standardization working group “TC226 (road equipment) / WG6 (noise reducing devices)” works on drafting standards. The overarching European Standard that specifies the performance characteristics against which 'road traffic noise reducing devices' should be assessed and the corresponding standards defining the test methods is EN 14388 (CEN, 2015). The framework of standards includes several subsets of standards, targeting acoustic (EN 1793 set) and non-acoustic (EN 1794 set) performance.

2.1.2 Acoustic performances – EN 1793 set

Currently, the sound transmission and absorption characteristics of a noise barrier are commonly determined using laboratory-based tests according the standards EN 1793-1 (CEN, 2012) and -2 (CEN, 2012). Figure 3 illustrates the mounting conditions for the test specimen. Noise barriers shall have a minimum sound insulation $D_{LR}$ value (EN 1793-2) of at least 25 dB and a minimum absorption value $D_{La}$ (EN 1793-1) of at least 8 dB.

![Figure 1 - Sound Reflection (left) and Insulation (right) Measurement according to EN 1793-1 and 2](QUIESST, 2012)

It is noted that the test methods in the forthcoming revised EN 1793-1 and EN 1793-2 are restricted to the assessment of devices used only "under reverberant conditions". This means that the method is no longer considered applicable for the assessment of noise barriers along roads in non-reverberant conditions. The in-situ test method according the standards EN 1793-5 (CEN, 2016) and -6 (CEN, 2012) will be the reference. Unlike EN 1793-1 and 2, these measurements are not performed in a reverberation chamber but on a test sample installed in "open" sound field conditions, typically outside, and constructed exactly as the barrier would be installed in service, with, for the sound insulation, a loudspeaker and microphone array on the same side of the barrier, and for the sound absorption, a loudspeaker and microphone array on the same side of the barrier. Figure 4 illustrates the basic test set-up shown in the current published version of the standards.

Research has shown that there is a moderate correlation between sound absorption results measured according to EN 1793-5 and EN 1793-1 (Conter, 2013), when all barrier types are considered as a single dataset, with the laboratory method dramatically over-estimating the sound absorption properties of a noise barrier compared to the in situ method. For the airborne sound insulation there is potentially a good correlation between the results measured according to the laboratory method and in-situ method. The two methods give different results because the Part 1 and 2 test assume a diffuse
sound field (where all angles of sound incidence are equally probable) while the Part 5 and 6 test use a directional sound field, which is more representative of what would be the case for noise barriers at the roadside. Further research is required to investigate the correlation between the two methods for individual noise barrier types.

Figure 2 - Sound Reflection Measurement according to EN 1793-5 (QUIESST, 2012) and Sound Insulation Measurement according to EN 1793-6 (Nachtegael, Van Eekert (2013))

2.2 Monitoring the acoustic performance of noise barriers

Despite good results in laboratory the problems often arise during installation of the noise barriers. The weakest points of insulation are often the joints or post fixings or installed barriers with lower quality than tested (see 3.3 Bad examples of barriers). After installation a visual and audible inspection of the whole barrier is recommended as the minimum requirement, supplemented, when the in-situ test method (EN 1793-5 and -6) will be the reference, if necessary by acoustic assessments, as a form of project sign-off, to check compliance with contract requirements, or conformity-of-installation of the barrier or to ensure that the noise barrier is fit for purpose.

It is also important that the barriers fulfil not only the acoustic requirements with any NRA/contract specifications after installation but also maintain their acoustic performance characteristics for a reasonably long life time with minimal maintenance wherever possible.

2.2.1 For new barriers installations

Visual and audible inspections
Wherever possible, visual and audible assessments during installation and/or of the whole barrier within 1-2 months after installation should be performed using the manufacturer's installation instructions as a guideline for defect detection. Depending upon the type of noise barrier and the expertise of the assessor, this would be expected to mainly identify obvious physical defects in the installed product that may require correction before the installation can be accepted or is deemed fit-for-purpose.

The following is a summary of key areas that should be addressed by the visual and audible inspection, although this list is not exhaustive. Other areas of focus may arise depending upon the type of barrier, the method of construction, etc.

- Physical defects in/damage to the materials that comprise the acoustic elements, including any membranes that are used to protect sound absorptive materials and that are directly exposed to the elements.
- The quality/correct placement of seals between the acoustic elements, between acoustic elements and posts or between acoustic elements and the bottom of the NRD.
- The stability and alignment of posts (if used).
- The quality of fastenings (if any) used to secure acoustic elements.
- The quality/correct placement of gravel boards and/or ground level seals
- The quality, alignment and fitment of doors, access gates, etc.

Acoustic assessments
If the acoustic measurements according EN 1793-5 and 6 are used to supplement visual and audible inspections, measurements at one or two positions at random locations along the barrier are required. The measurements can be taken during or as soon as possible after completion of the installation, preferably within 1-2 months.

2.2.2 Monitoring condition and performance over working lifetime

Monitoring of the condition and potentially the acoustic performance of noise barriers over their working lifetime will be necessary for NRAs to ensure that the barriers remain robust, intact and fit-for-purpose.

Visual inspections are recommended as a minimum requirement. Unless there is a need to examine the acoustic performance of damaged elements based on the outcomes of visual inspections, acoustic assessments to provide supplementary data may only be required if the acoustic performance of the materials used for the acoustic elements is expected to degrade over the working lifetime.

It has also identified that there is a lack of published data on the long-term acoustic in-situ performance of noise barriers. Further practical data are required, even though many noise barrier products are not currently considered to acoustically degrade over time.

These visual inspections will seek to identify physical defects that were not previously present. If inspections highlight damage to/defects on a noise barrier that are considered likely to have an adverse effect on its ability to effectively screen noise sensitive receivers, then acoustic assessments may be required to supplement the inspections.

- The physical condition of the materials that comprise the acoustic elements, including any membranes that are used to protect sound absorptive materials and that are directly exposed to the elements.
- The condition of seals between the acoustic elements or between acoustic elements and posts and whether any seals are missing.
- The stability and alignment of posts (if used).
- The condition of fastenings (if any) used to secure acoustic elements and whether any fastenings are missing.
- The condition and placement of gravel boards and/or ground level seals and the presence of gaps/holes at the foot of the barrier.
- The condition, alignment and fitment of doors, access gates, etc.
- Structural damage caused by vandalism or impact.
- Damage caused by vegetation growth on, up against the barrier or through the joints between panels or between panels and posts.

3. NOISE BARRIERS TYPES

3.1 Aesthetic appeals and shape

Noise barriers are architectural features in their own right and they should be designed to fit into their local environments. If these barriers are not designed for each individual location they are likely to remain dull, contrived visual elements and diminish landscape character and landscape quality.

Noise is not only an acoustic issue, but the visual qualities of any noise barrier should be considered on an equal footing with the noise issue. The visual effect of the noise barrier on the receiver depends on the barrier height, the distance of the barrier from the receiver, and the surface texture and colour of the side of the barrier facing the receiver.

Figure 3 Example of barrier blending with the landscape
Whichever approach is taken, it is advantageous that the visual appearance of the noise barrier reflect the historical and architectural context of the region in which it is placed.

Depending on the acoustic and non-acoustic requirements and the configuration of the terrain where noise barriers should be installed, the process of configuring a noise barrier should provide a multitude of different variants and combinations which are presented in continuation.

![Figure 4 Different types of barriers](image)

### 3.2 Materials of noise barriers

As explained earlier the choice of barrier materials (and potentially colour of the barrier) are likely to be influenced by a range of factors including the physical dimensions of the barrier and the location of the barrier.

Several materials are available with consequences on the visual aspects. In the following the main materials used are presented:

*Timber acoustic elements:* They may be fully reflective or sound absorptive. For reflective barrier all the timber elements are jointed to avoid leaks. For sound absorptive elements the current structure is composed of absorbing materials covered with timber elements using a tongue and groove construction.

![Figure 5 Example of timber acoustic element](image)

*Metal acoustic elements:* They are typically cartridge/cassette-type panels constructed from aluminium, steel or both and can be sound reflective of sound absorptive.

![Figure 6 Example of metal acoustic element](image)
Concrete acoustic elements: They are in general composed for the structural part in precast panels in concrete covered by a porous concrete which can be wood-fibre or cement composite concrete.

Figure 7 Example of concrete acoustic element

Transparent acoustic elements: They are used to either provide a fully transparent barrier or are incorporated as components within an 'opaque' barrier constructed from other materials. Their main benefit is to reduce the visual impact for the people and offer a view across the road for the drivers.

Figure 8 Transparent acoustic element

Plastic/composite acoustic elements: The structure is comparable to the metal acoustic elements. These panels are manufactured from plastics or recycled plastics, reinforced with glass fibre. They can also be sound reflective or absorptive. As metal acoustics elements if they are absorptive the front of the panel is perforated.

Figure 9 Plastic acoustic element

3.3 Bad examples of barriers

For many years different noise barriers have been installed by NRAs all around Europe. Due to time and weather conditions some degradations (important or not) developed on the devices with sometimes important consequences. Some of these were consequences of insufficient requirements or problems with manufacturers or during the installation on site.

The CEDR Road Noise Group has asked several Member states in order to make an overview of the devices and show their evolution over time. The result of the consultation shows that the problems may be classified in the major categories: materials problems and general problems.

- Materials problems:

For metallic barriers the most current default is the rust. This is mostly the consequence of an insufficient thickness of the galvanizing. Due to their structure (caissons) water due to rain can remain in the caissons and humidity may develop inside. Over time this can be a problem for the absorbing material.

Figure 10 Degradation due to rust
For timber barriers, due to their structure the absorbing ones are vulnerable to vandalism and debris coming from the road. For the “timber” part phenomena of warping, shrinkage and crocking are often observed.

The transparent barriers are used to reduce the visual impact and offer a view on the landscape. But over time the transparency diminishes and the main characteristic of this device is no more available.

- **General problems:**

Noise barriers are susceptible to vandalism. When selecting barrier type it is important to consider the likelihood of vandalism and selecting an appropriate barrier type.

Vegetation may be used to minimize the visual effect of barriers and help to integrate the device in the surrounding landscape. Nevertheless the vegetation is often found to be overgrown and reduce the access to the device. Indeed over time it becomes too heavy and caused damages to the barriers.
It is also important to identify the problems regarding the acoustic seal. To insure a perfect sealing to noise, the junctions between the elements of the barriers and the foundation and the columns must be perfect. Often these elements are neglected and the barrier has no more its performances.

Figure 15 Problem with acoustic seal

4. INNOVATIVE NOISE BARRIERS

Innovative noise barriers solutions can be considered as solutions that have been identified which either use more innovative designs or materials for the construction of the acoustic elements or which perform additional function, e.g. power generation, in addition to noise mitigation.

The most interesting examples of multifunctional noise barriers used along the road are described the main features of them are illustrated in terms of advantages and disadvantages.

4.1 Combined noise and safety barriers

Integrated noise barrier, using both concrete and steel guard rails, is a safety barrier and simultaneously serves the function of acoustic barrier, ensuring a double advantage: recovery of the mounting width and optimization of the bearing structure.

The use of systems where the noise barrier and safety barrier are integrated into a single structure have shown positive response for the existing road when the separation of the vehicle restraint and the noise barrier is limited to allow it to deform in case of impact without affecting the noise barrier.

Other potential advantages are that this barriers can be installed closer to the source of noise in this way the effectiveness of noise protection increases significantly. Furthermore a lower operating width is needed for their installation and some of them are free-standing, no foundations or anchor to the soil are required.

The main disadvantages is that is a rigid solution. In terms of dimension, for example the maximum height tested is 5.00 m with metal guardrail and 4 m with concrete safety barriers When total cost of safety and noise barriers are considered, combining both might be more economical than separate safety barriers and noise barriers. For this reason it will not be suited to all situations where it’s better that noise barriers are/can be used simultaneously with the safety barriers.

Figure 16 - Example of integrated noise and safety metal barrier with steel guardrail (left photo) and of fully concrete self standing barrier (right photo)
4.2 Photovoltaic noise barriers

Photovoltaic noise barriers (PVNB) allow the simultaneous abatement of noise and the production of renewable energy, by converting solar energy into electricity, thus limiting the production of greenhouse gas emissions into the atmosphere.

Photovoltaic modules can be directly integrated within the surface of the barrier or ‘retrofitted’ mounted onto the barrier in the form of solar panels.

Several positive effects can be ascribed to PVNB application from the economic, environmental and social perspective first of all the possibility of earning money from the production of renewable energy for the residents.

However, it will not be suited to all situations where noise barriers are/can be used since the efficiency and scale of energy generated by the photovoltaic cells will be dependent upon the orientation of the barrier, number of photovoltaic cells and the climate (amount of sunshine) and the potential use for the energy. If the barrier is low in height, the investment and benefits may be insufficient. The financial benefits of the generated energy must be carefully weighed up against the cost of energy storage/transfer infrastructure.

4.3 Noise barriers with TiO₂ coating

The noise barriers incorporating TiO₂ coatings employ photocatalysis, a chemical reaction in which titanium oxide acts as a catalyst to eliminate nitrogen oxides.

When photocatalytic TiO₂ on the surface of noise barriers is exposed to ultraviolet radiation in sunlight, NOx is converted into stable nitrogen compounds. These stable compounds are washed away by rainwater.

Noise barriers incorporating TiO₂ coatings had a limited success and effectiveness during practical trials. The concept still requires further development and proof of effectiveness before it would be ready for use as a recognized air pollution mitigation measure by road administrations. Based on the variation of reported effectiveness during trials, it is not considered that the technique will ever be appropriate for widespread use.
4.4 Inox/corten steel noise barriers

These barriers made of stainless steel or corten steel combine a lot of performance requirements, in fact they are able to provide a good environmental insertion, a positive perception by the population, and maximum features mechanical strength and stability as well as in the years of durability, ease of maintenance and of attitude to the removal of dirt and graffiti, possibility of complete recycling over its useful life.

The difference between the two types of steel is purely chromatic, in fact, the stainless steel is the grey that reduces the visual impact in urban and suburban areas, while the Corten steel assumes a purple coloration / brown that integrates more with the rural and suburban landscape.

The main disadvantage of these barriers is the cost, both type are considerably more expensive than an average noise barrier.

Figure 19: Examples of Inox steel noise barriers (left photo) and corten steel noise barriers (right photo)

4.5 Sonic crystals

Sonic crystals (SCs) barriers are structures of circular cylinders scatterers periodically in a arranged in a lattice with a vertical and horizontal alignment.

The sound attenuation characteristics of a sonic crystal can be tuned by appropriate selection of lattice constant and cylinder radius.

The overall height of this barriers is in order of 6m and in particular the heights of the cylinders varied along both the length and the cross section of the barrier.

Figure 20: Examples of Sonic crystals noise barriers (right photo with permission of Van Campen Industries)
4.6 Other measures of noise abatement

Additional noise protection can be achieved by arranging the site plan to use buildings as noise barriers.

A long building, or a row of buildings parallel to a highway can shield other more distant houses or open areas from noise. A two storey building can reduce noise levels on the side of the building away from the noise source.

Figure 21: In Denmark a common carport facility was constructed as a two storey high noise barrier

5. CONCLUSIONS

The main points of this study can be summarised as follows:

- The aim of NRAs is to build durable noise barriers with a low cost and almost no maintenance. The reputation of NRAs and public perception are also important.
- Barriers are manufactured/constructed from a wide variety of materials and to different designs, but all serve the same basic purpose, namely to reduce noise levels at noise sensitive receivers away from the roadside, e.g. at residential properties, by acting upon the sound propagating away from the road by influencing the propagation path between the source and the receiver.
- It is recommended that some form of assessment is undertaken as a form of project sign-off, to check compliance with contract requirements, or conformity-of-installation of the barrier or to ensure that the noise barrier is fit for purpose. Visual and audible inspections are recommended as the minimum requirement, supplemented if necessary by acoustic assessments.
- Despite good results in laboratory the problems often arise during installation. The weakest points of insulation are often the joints or post fixings or installed barriers with lower quality than tested. Use joints between panels, panels/foundation and panels/posts to ensure there are no gaps/leaks.
- Innovative noise barriers solutions can be considered as solutions that have been identified which either use more innovative designs or materials for the construction of the acoustic elements or which perform additional function, e.g. power generation, in addition to noise mitigation.

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