Conférence Européenne
des Directeurs des Routes

Conference of European
Directors of Roads

Technical Report 2017-02
State of the art in managing road traffic noise: noise barriers

January 2017

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Approved by the CEDR Executive Board in December 2016
Edited and published by CEDR's Secretariat.
Ref: CEDR Technical Report 2017-02 State of the art in managing road traffic noise: noise barriers
ISBN: 979-10-93321-27-1

1 Executive summary

In the framework of CEDR Strategic Plan 2013-2017, this Task Group Road Noise report presents a general overview of the domain of noise barriers used along European roads. It primarily focuses on the collation, dissemination, implementation and use of results from research and development of noise barriers from:

- recent innovative research projects undertaken within specific CEDR member countries;
- the reports QUESTIM and DISTANCE from the CEDR Noise Call 2012.

The main purpose of the report is to make such results available and known to all the CEDR member countries. The report intends to assist each National Road Authorities (NRA) 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 countries. The last chapter offers a review of recent research projects on noise reducing devices in various CEDR member countries.

The report highlights the following issues to be given special attention in the choice of a noise barrier:

- *Clarification of the noise level reduction achievable with a noise barrier*

Each noise barrier must be long and high enough to block the line of sight between a source and receiver. In principle, a barrier is most effective located as close to the road as possible. If the noise barrier dimensions are well proportioned, a noise level reduction of 10 dB(A) can be achieved at ground level in the area situated closely behind the noise barrier. As the distance to the noise barrier increases, the noise level reduction decreases. At a distance of 250 m, the L_{Aeq} reduction is limited to a few dB(A).

- *Check the acoustic characteristics of a noise barrier*

The sound transmission and absorption characteristics of a noise barrier are commonly determined using laboratory based tests (EN 1793-1 and 2). It is noted that the laboratory based tests will be restricted to the assessment of devices used only "*under reverberant conditions*". The in-situ tests (EN 1793-5 and 6) will be the reference in the future.

- *Check the conformity and the correct installation of a new noise barrier in situ*

After installation, barriers should fulfil the acoustic requirements in accordance with the contract specifications. It is recommended that some form of assessment is undertaken as a form of project sign-off, to check compliance with contract specifications or conformity-of-installation of the barrier, to ensure that the noise barrier is fit for purpose.

- *Check the lifetime of a noise barrier*

It is also important that the barriers maintain their acoustic performance characteristics for a reasonably long lifetime with minimal maintenance wherever possible. It is recommended to undertake during the noise barrier lifetime specific monitoring programmes with regular visual surveys and periodic appropriate acoustic tests.

- *Take into account the possibility to use a new innovative noise barrier*

Innovative noise barriers not only mitigate noise, but they also use more innovative designs or materials for the construction of the acoustic elements. Also, they may have additional functions like power generation. Some interesting examples of multifunctional noise barriers are described and analysed in terms of their benefits, potential and disadvantages.

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3 Definition of the Issue of noise barriers

The Task Group Road Noise Technical Report on noise barriers presents a general overview of the domain of noise barriers used along European roads. It primarily focuses on the collation, dissemination, implementation and use of results from research and development of noise barriers from:

- recent innovative research projects undertaken within specific CEDR member countries
- the reports QUESTIM 4.1 and DISTANCE 3.1 from the CEDR Noise Call 2012.

The main purpose of the report is to make such results available and known to all the CEDR member countries. The report intends to assist each NRA in the planning, building and maintaining processes of noise barriers for new and existing road infrastructure.

The 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 lifetime.

The report is produced by the CEDR Task group Road noise the in the period 2013 to 2016. A subgroup has written the report based on material supplied by the members of the CEDR Task group Road noise, as well as on discussions on relevance and implementation potential within the CEDR Task group. The main authors are:

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The report is structured as follows:

- Chapter 4 focuses on the working principles of noise reducing devices (NRD): the use of NRD, the different acoustic standards and the acoustic (insulation, absorption, influence of leaks, diffraction top and monitoring) and non-acoustic performances.
- Chapter 5 presents an overview of different noise barriers types looking at the aesthetic appeal, shapes and materials completed with a list of book references with examples of (nice) design constructions of noise barriers and a collection of bad examples.
- Chapter 6 focuses on innovative noise barriers with a comprehensive review of recent research projects on NRD's in the various CEDR member countries: combined noise and safety barriers, photovoltaic noise barriers, noise barriers with TiO_2 coating, et cetera.
- Chapter 7 presents the conclusions and recommendations.

4 Working principles

4.1 Use of noise reducing devices

Since the introduction of more stringent noise legislation across Europe, environmental noise barriers have become ubiquitous features along many road corridors. Barriers to mitigate noise and views of traffic may be located wherever there is development and human activity, along inner city routes, suburban byways and also along more rural routes where villages and recreational areas require protection. It must be recognized that noise barriers are architectural features in their own right and that 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 alien visual elements and diminish landscape character and landscape quality. The main aspects of good environmental noise barrier design include the appropriate manipulation of elements and materials.

The primary function of noise barriers is to shield receivers from excessive noise generated by road traffic. While the responsibility of mitigating road traffic noise lies with the road projects, noise barriers are considered the most reasonable noise mitigation measures available besides noise reducing pavements.

Many factors need to be considered in the detailed design of noise barriers. First of all, barriers must be acoustically adequate. A proper design of noise barriers would need considerations from both acoustic and non-acoustic aspects. Acoustical design considerations include barrier material, barrier locations, dimensions and shapes. However, they are not the only requirements leading to proper design of noise barriers. A second set of design considerations, collectively labelled as non-acoustical design considerations, is equally important. As is often the case, the solution of one problem (in this case noise), may cause other problems such as unsafe conditions, visual blight, maintenance difficulties, lack of maintenance access due to improper barrier design and air pollution in the case of full enclosures or deck over. With proper attention to maintainability, structural integrity, safety, aesthetics, and other non-acoustical factors these potential negative effects of noise barriers can be reduced or even avoided. The material, location, dimensions, and shapes of noise barriers can affect the acoustical performance.

4.1.1 Acoustical Design Considerations

The Figure 1 is a simplified sketch showing what happens to road traffic noise when a noise barrier is placed between the source (vehicles) and receiver (houses). The original straight line path from the source to the receiver is now interrupted by the noise barrier. Depending on the noise barrier material and surface treatment, a portion of the original noise energy is reflected or scattered back towards the source. Other portions are absorbed by the material of the noise barrier, transmitted through the noise barrier, or diffracted at the top edge of the noise barrier.

The transmitted noise, however, continues on to the receiver with a ’loss’ of acoustical energy (acoustical energy redirected and some converted into heat). The common logarithm of energy ratios of the noise in front of the barrier and behind the barrier, expressed in decibels (dB), is called the Transmission Loss (TL). The TL of a barrier depends on the barrier material (mainly its weight), and the frequency spectrum of the noise source.

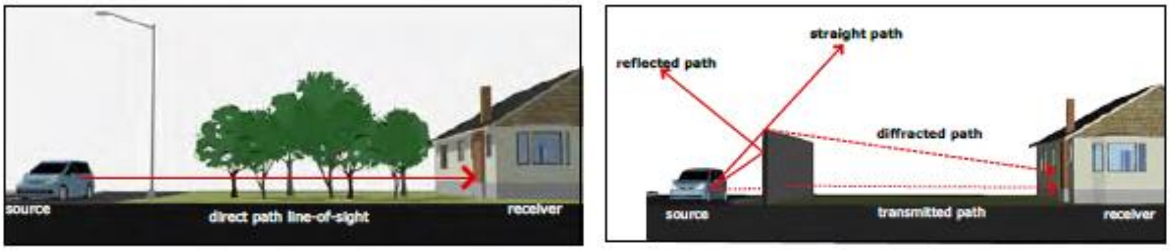


Figure 1 - Alteration of noise paths by a noise barrier

The transmitted noise is not the only noise from the source reaching the receiver. The straight line noise path from the source to the top of the barrier, now is diffracted downward towards the receiver (Figure 2). This process also results in a 'loss' of acoustical energy.

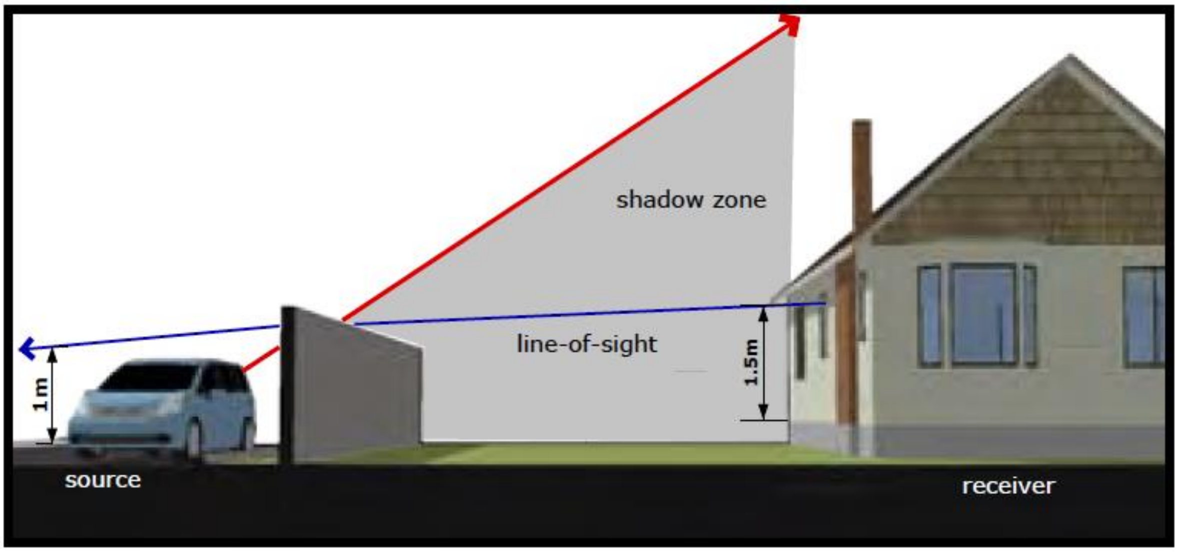


Figure 2 – Barrier diffraction

The receiver is thus exposed to the transmitted and diffracted noise. Whereas the transmitted noise only depends on barrier material properties, the diffracted noise depends on the location, shape, and dimensions of the barriers.

Where there are noise sensitive receivers on the opposite side of the road, absorptive type noise barriers, either alone or in combination with reflective type, could be used to avoid causing reflection of noise to these receivers. The same may also be required for barriers along the medium barrier in the case of a dual carriageway. In case where this is required, the lower portion of at least 2 to 3 meters should be of absorptive materials.

4.2 Influence factors

4.2.1 Location of the receiver

The reduction of the sound level is greater as the detour (the difference in distance that the traffic noise must travel between the source and receiver, respectively before and after the installation of a noise barrier) increases.

In the case of houses built at a short distance (see Figure 3), this detour is greater than it is in the case of houses built at a far distance (see Figure 4).

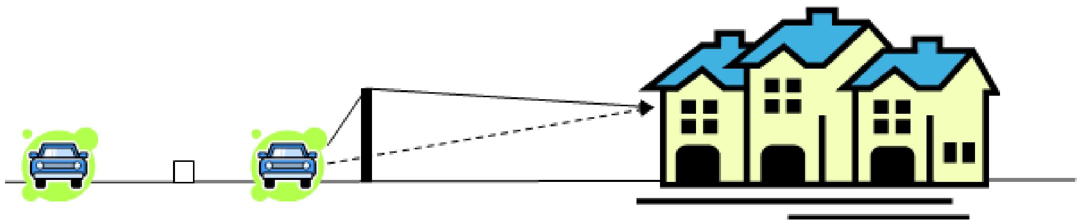


Figure 3 - Effects of a noise barrier for a receiver at a short distance

At a far distance, the effects of a sound barrier are reduced as the distance travelled over is becoming shorter.

The sound radii show a curvature due to the wind and the influence of the road traffic on traffic lanes further away increases as the houses are located at a greater distance of the noise barrier (see Figure 4).

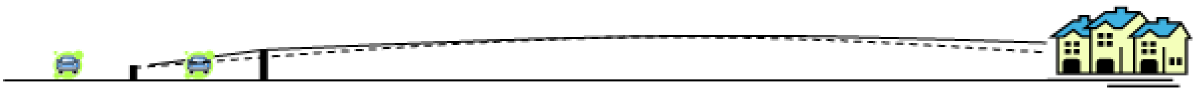


Figure 4 - Effects of a noise barrier for a receiver at a far distance

4.2.2 Wind

Increasing wind speed curves the propagation directions of the sound waves with increasing intensity. This creates a zone on the downwind side with an increased sound pressure level and a shadow zone on the upwind side (see Figure 5).

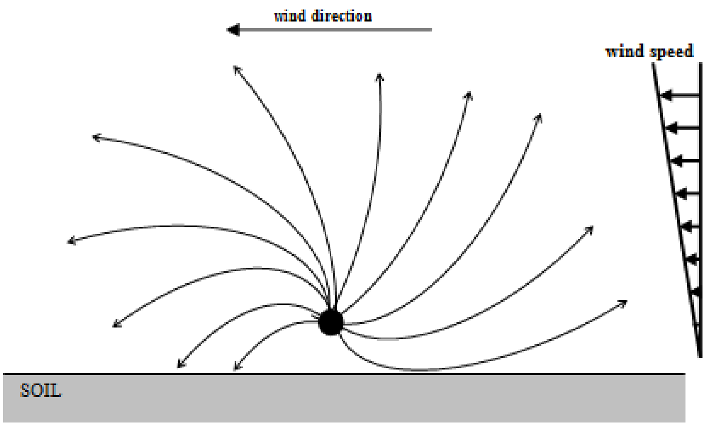


Figure 5 - Creation of a shadow zone and of a zone with increased sound pressure level under the influence of the wind

Winds play an important part, especially when the houses are situated at a distance over 50 m of the motorway. The greater this distance is, the greater the influence of weather conditions.

4.2.3 Nature of the sound

The **nature of sound** is crucial because low frequency sounds, due to their large wavelength, bend more easily over a sound barrier than high frequency sounds. The result is that the sound spectrum recorded before the installation of a noise barrier is situated rather in the medium-and high-frequency region than the spectrum recorded after the installation of a noise barrier. This also means that a noise barrier will be less effective along a road with a high percentage of trucks emitting a sound of a lower frequency than the sound that cars would normally emit.

As a test, a noise measurement is conducted behind a 4 m high noise barrier and a bit farther at the same distance (20 m) from the edge of the motorway in a measurement location without noise barrier. The microphone was placed at a height of 5 m. Figure 6 shows the sound spectrum of the measured sound levels L_{eq} (A value not considered). The difference between the measured sound levels is presented in figures on the chart. It appears that especially the high-frequency sound waves are blocked while the noise reduction for the medium and especially the low frequency waves is less apparent.

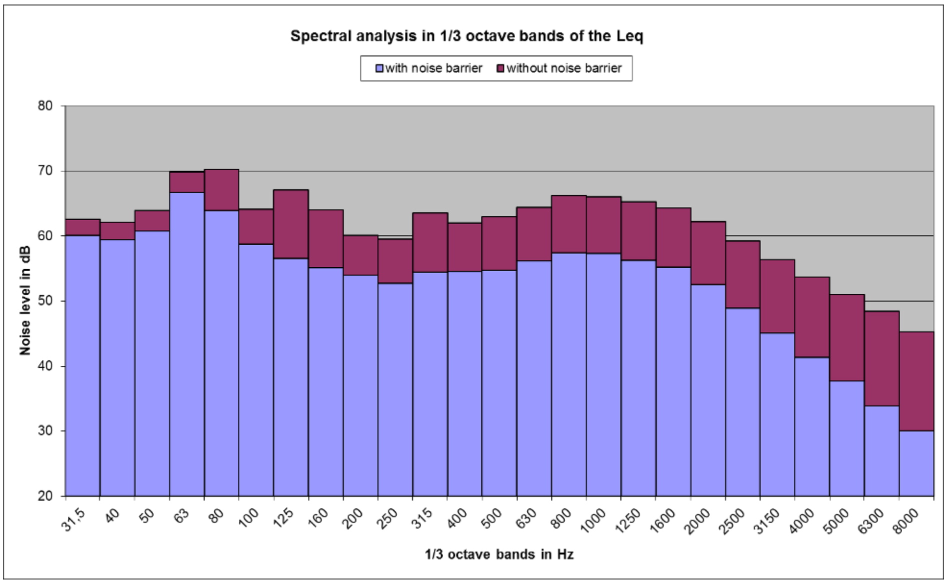


Figure 6 - Spectral analysis of the third octave bands measured L_{eq} with and without noise barrier

Figure 7 shows the sound spectrum of the same sound signals with A value considered. The sound level L_{Aeq} is 9 dB(A) lower with a noise barrier installed. However, the sound level measurement was conducted with a microphone placed at a height of 5 m. The noise barrier is 4 m high. At a lower height, as at ground level, the noise reduction will increase.

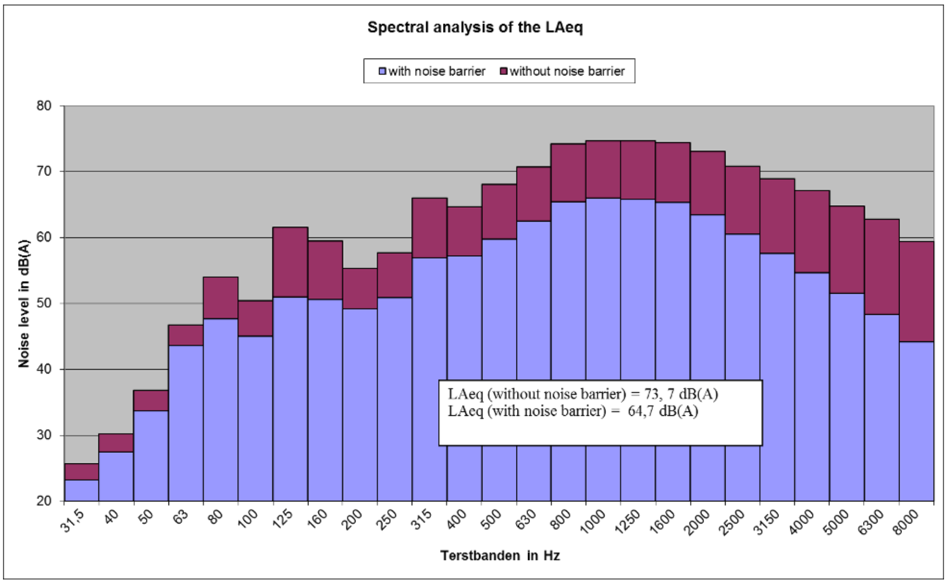


Figure 7 - Spectral analysis in the third octave bands measured L_{Aeq} with and without noise barrier

4.2.4 Effect of a noise barrier

If the noise barrier dimensions are well proportioned, and taking into account all these parameters, a L_{Aeq} reduction of 10 dB(A) can be achieved at ground level in an area situated closely behind the noise barrier. As the distance to the noise barrier increases, the noise level reduction decreases. At a distance of 250 meters, the L_{Aeq} reduction is limited to a few dB(A).

Distance between receiver and road	Expected noise reduction after installing a noise barrier	Experience by the human ear
30 m	12 dB(A)	Perceived to be ’half as loud’ as before
50 m	10 dB(A)	Perceived to be ’half as loud’ as before
100 m	5 dB(A)	The reduction is readily detectable, but the influence of the wind direction plays an important role
250 m	3 dB(A)	The reduction is just detectable. But because the influence of the wind direction might be greater than the noise reducing effect of the noise barrier, the receivers don’t always perceive this as a reduction

Table 1: Effect of a noise barrier

4.2.5 Informing the public about the acoustic effect of a noise barrier

It is important to inform the citizens about the reducing effect of the new noise barrier to avoid misunderstandings afterwards. There are several possibilities to do this: information meetings, brochures, noise maps, audiotape, et cetera. Just to make clear that people ‘behind’ a new noise barriers do get (much) lower noise levels, but it will not become silent.

4.3 Standards

4.3.1 Introduction

The CEN standardization working group “TC226 (road equipment) / WG6 (noise reducing devices)” works on drafting standards to assess the performance of noise reducing devices (NRDs).

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. Within the standard road traffic noise reducing devices include noise barriers, claddings, covers and added devices.

The framework of standards (see Figure 8) includes several subsets of standards, targeting acoustic (EN 1793 set) and non-acoustic (EN 1794 set) performance.

Procedures for assessing the long term performance (EN 14389 set), that is how the initial product performance can be evaluated along years of use, has been also considered.

The CEN working group started in 2014 considering sustainability as a new characteristic to be objectively assessed. They will development sustainability indicators for NRDs, so it will be possible to compare NRDs not only on price and performances.

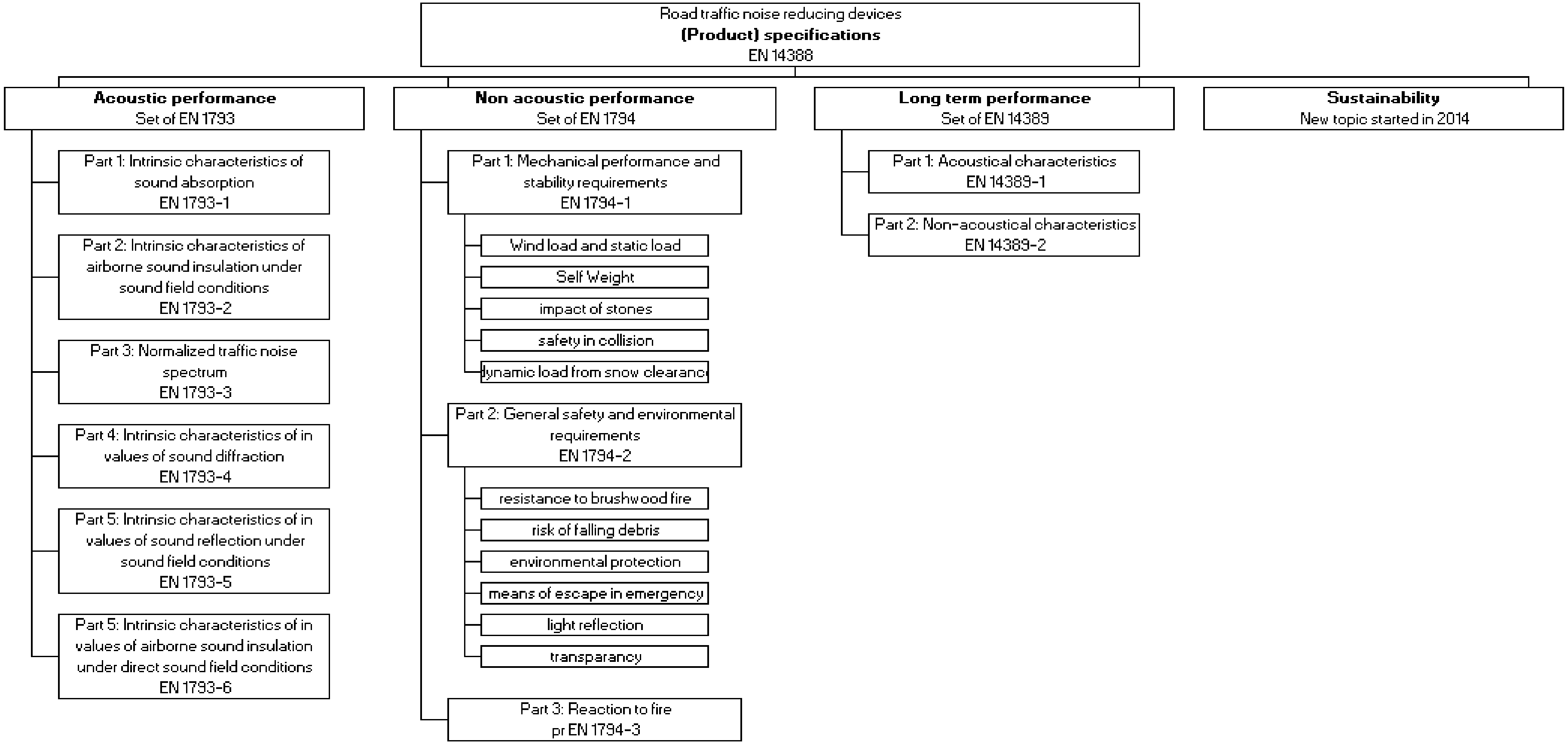


Figure 8: The framework of standards for road traffic noise reducing device

4.3.2 EN 14388

The standard EN 14388 (CEN, 2015) sets out requirements for acoustic performance, non-acoustic performance and long-term performance characteristics. The standard also includes guidance on the CE marking of road traffic noise reducing devices, i.e. declaration by a manufacturer that his product satisfies the requirements of the Construction Products Regulation (EU) No. 305/2011. From 01 July 2013, under the Construction Products Regulation 2011 (CPR; European Commission, 2011), it became mandatory for manufacturers to apply CE markings to products covered by harmonised European standards due to the existence of EN 14388. This requirement applies to all road traffic noise reducing devices.

4.3.3 EN 1793 set

The standards describe the intrinsic characteristics for the three performance mechanisms, i.e. sound transmission, sound reflection and sound diffraction (see description in section 4.4). Part 1 and 2 describe the acoustic performance test methods under laboratory conditions using a reverberation room. In the EU-funded projects ADRIENNE and QUIESST (www.quiesst.eu) in-situ methods were developed and have been adopted as the standard methods (part 4, 5 and 6).

The following sections summarise the different test methods.

A) Laboratory based test methods:

EN 1793-1 (CEN, 2012) sets out a test method for the determination of sound reflection characteristics. Measurements are performed under laboratory conditions using a reverberation chamber; Figure 9 illustrates the mounting conditions for the test specimen. The performance is expressed in terms of the single-number rating of sound absorption, DL_{α}. The scope and title of this standard will be similarly revised in the future to restrict the applicability of the test method to the assessment of devices used only '*under reverberant conditions*', as has already been done with EN 1793-2 (see below). The revised standard is expected to be published in 2016. From that point, the method will no longer be considered applicable for the assessment of noise barriers along roads in non-reverberant conditions, but along roads in reverberant conditions, e.g. inside tunnels or deep trenches or under covers. In case of direct sound field conditions, the sound absorption properties shall be declared based on the in-situ test in EN 1793-5 (see section 4.4.2 of this report).

Figure 9: Sound reflection measurement according to EN 1793-1 (QUIESST, 2012)

EN 1793-2 (CEN, 2012, currently under revision) sets out a test method for the determination of airborne sound insulation characteristics. Measurements are performed under laboratory conditions using a reverberation chamber. Figure 10 illustrates the mounting conditions for the test specimen*.* The performance is expressed in terms of the single-number rating of airborne sound insulation, DL_R. It is noted that the 2012 edition of the standard has a revised scope and a revised title which restricts the applicability of the test method 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, but along roads in reverberant conditions, e.g. inside tunnels or deep trenches or under covers. In practice, this change is unlikely to be enforced until the publication of the revision of EN 14388 in 2015, from which point the airborne sound insulation characteristics of noise barriers under direct sound field conditions shall be declared based on the in-situ test in EN 1793-6 (see section 4.4.3 of this report).

Figure 10: Sound insulation measurement according to EN 1793-2 (QUIESST, 2012)

B) In-situ test methods

EN 1793-4 (CEN, 2015) sets out a test method for determination of the sound diffraction characteristics of added devices installed on the top of traffic noise reducing devices (see Figure 11). Measurements can be performed both on existing barriers in situ and on samples purposely built to be tested; measurements can also be performed indoors or outdoors. The performance is expressed in terms of the single-number rating of sound diffraction, $DL_{\delta DI}$. See section 4.4.4.

Figure 11: Sound diffraction measurement (source: http://www.akustikforschung.de/en/leistungen/umweltakustik/strassenlarm/larmschutzwand-schallschirm/)

EN 1793-5 (CEN, 2016) sets out a test method for the determination of sound reflection characteristics. Unlike EN 1793-1, 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 a loudspeaker and microphone array on the same side of the barrier. Figure 12 illustrates the basic test set-up shown in the current published version of the standard. The performance is expressed in terms of the single-number rating of sound reflection, DL_{RI}.

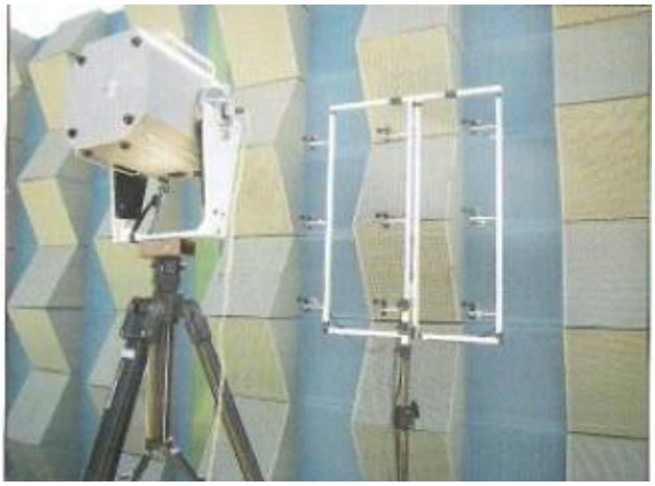


Figure 12: Sound reflection measurement according to EN 1793-5 (QUIESST, 2012)

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) with the laboratory method dramatically overestimating the sound absorption properties of a noise barrier compared to the in situ method. The two methods give different results, because the Part 1 test assumes a diffuse sound field (where all angles of sound incidence are equally probable), while the Part 5 test uses 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.

EN 1793-6 (CEN, 2012, currently under revision) sets out a test method for the determination of airborne sound insulation characteristics. Unlike EN 1793-2, 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 a loudspeaker on one side of the test sample and a microphone array on the opposite side (see Figure 13). The performance is expressed in terms of the single-number rating of airborne sound insulation, DL_{SI}.

Figure 13: Sound insulation measurement according to EN 1793-6 (Nachtegael, Van Eekert (2013))

Research has shown that there is a good correlation between airborne sound insulation results measured according to EN 1793-6 and EN 1793-2 (Conter, 2013) with the laboratory method underestimating the sound insulation properties of a noise barrier compared to the in situ method. The two methods give different results, because the Part 2 test assumes a diffuse sound field (where all angles of sound incidence are equally probable), while the Part 6 test uses 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.

4.3.4 EN 1794 set

The calculation of noise barrier elements (panels, posts, plates, anchorage, foundations) has to consider the specificity of this structure, often located by high intensity traffic flows and therefore liable to particular actions.

The reference supporting standard is EN 1794 under the general title "Road traffic noise reducing devices – Non acoustic performance".

The EN 1794 consists of the following parts:

- Part 1: Mechanical performance and stability requirements
- Part 2: General safety and environmental requirements.

Part 1 considers the range of forces to which road traffic noise reducing devices are exposed. In particular:

- wind;
- dynamic air pressure caused by passing traffic;
- self-weight of component parts;
- dynamic force of snow ejected by equipment used to clear roads in winter;
- vehicle impact;
- shocks caused by stones or other debris thrown up by vehicle tyres.

Part 2 considers the hazards which road traffic noise devices could pose to road users, other people in the vicinity or to the environment. Some requirements and criteria are specified for assessing the general safety and environmental performance:

- fire resistance;
- danger of falling debris;
- environmental protection;
- means of escape in emergency;
- light reflection;
- transparency.

All the requirements have to be certified by an authorised laboratory. The standards are currently under revision.

4.3.5 EN 14389 set

It is recognised that the acoustic and non-acoustic performances of a road traffic noise reducing device can deteriorate significantly over the duration of its working life due to factors which may include

- exposure to general environmental conditions, such as rain or ultraviolet light;
- exposure to roadside environmental conditions, such as splash/spray, substances used for winter maintenance, e.g. salt, and
- installation and/or maintenance that is not in accordance with manufacturer instructions or recommendations.

The need to be able to monitor acoustic performance characteristics over the lifetime of a noise reducing device is therefore of importance to ensure that products are fit for purpose.

EN 14389-1 (CEN, 2015) sets out the procedure for determining long-term acoustic performance for a specified set of environmental classes. The manufacturer has to declare the working life of the acoustic performances (DL_{α} and/or DL_R and/or DL_{SI}) as a function of environmental classes of exposure.

EN 14389-2 (CEN, 2015) sets out the procedure for determining long-term non-acoustic performance for a specified set of environmental classes. The manufacturer has to declare the working life of the non-acoustic performances as identified in EN 1794 parts 1,2 and 3 as a function of environmental classes of exposure.

4.3.6 Sustainability

The CEN working group started in 2014 considering sustainability as a new characteristic to be objectively assessed. In the QUIESST project relevant parameters and generic sustainability criteria (e.g. land use, social acceptance and life cycle cost) and associated assessment methods and tools were researched.

4.3.7 Recommendations regarding standards

- It can be recommended to monitor all acoustic performances of installed noise barriers using the in-situ test methodology set out in EN 1793-5 and EN 1793-6. Further research is required to ameliorate the correlation between the in-situ and laboratory method.
- A check of the CE marking (EN 14388) of new installed barriers is advised.
- It is recommended to declare minimum requirements according the non-acoustic performance (static load, wind load, impact load) using the forthcoming revision of EN 1794.
- To follow the developments of standards and test methods, NRAs should be represented in the CEN standardization working group 'TC226 (road equipment) / WG6 (noise reducing devices)'. Also to indicate the advantages (mainly safety reasons) if in-situ test methods could be implemented without the need for operators and/or equipment to be static on the carriageway side of the barrier.
- Sustainability of noise barriers becomes a more important issue. The CEN working group on this topic just started in 2014. It will take some years to have an useful tool. As CEDR/NRAs we need to give attention to the evolution on this theme.

4.4 Acoustic perfomances

4.4.1 Introduction

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;
- the weather conditions.

This chapter takes a closer look at the acoustic properties of a noise barrier and the different factors that affect the sound levels behind the sound barrier. Without a noise barrier, the noise generated by the road traffic propagates freely from the source to the receiver. The noise barrier between the road and the houses creates an obstacle for the propagating noise generated by the traffic. The noise behind the noise barrier then originates from (see Figure 14):

- <u>the sound waves alongside both extremities of the noise barrier: diffraction (</u>see section 4.4.4):

  It should be ensured that a noise barrier is long enough. Furthermore, consideration should be given to the sound absorption/reflection of the noise barrier (see section 4.4.2).

- the sound waves through the barrier: transmission, sound insulation of the barrier (see section 4.4.3):

  A noise barrier with a sufficient sound insulation weakens the sound waves propagating directly through the noise barrier. Their contribution to the overall sound level will thus be reduced to a minimum.

- the sound waves over the barrier: diffraction (see section 4.4.4):

  The sound waves have to bend over the noise barrier in order to reach the receiver and, in doing so, travel over a longer distance as they would in a situation without a noise barrier. This causes the sound level to reduce.

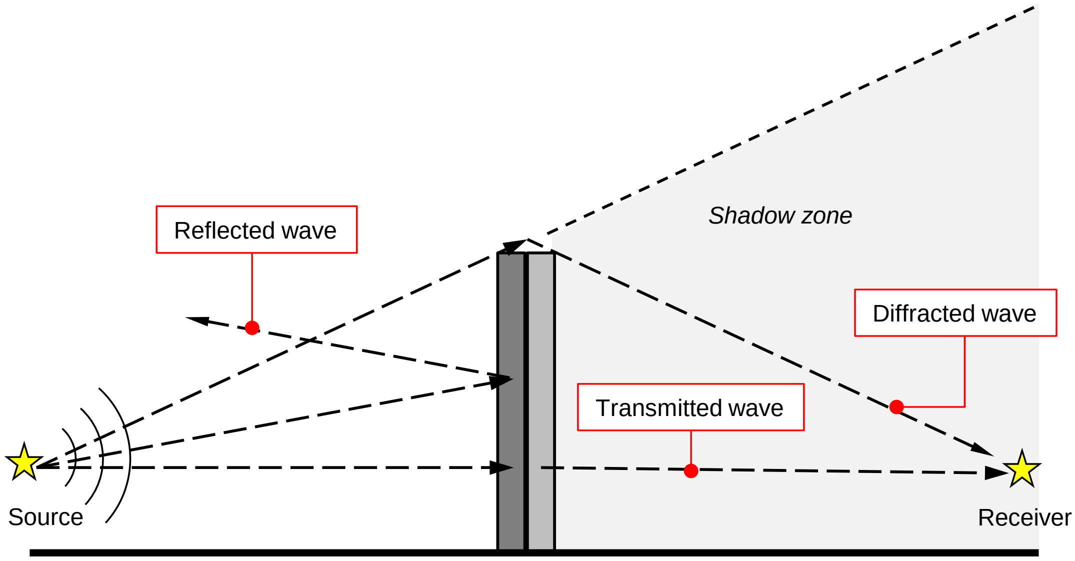


Figure 14: Mechanisms affecting noise barrier performance (Questim, 2014)

4.4.2 Sound absorption/reflection

The greater the sound absorption of the noise barrier, the less the incoming road traffic sound is reflected back to the houses on the opposite side of the road on the one hand, and between the trucks and the noise barrier itself on the other hand.

Reflections between the noise barrier and passing trucks or other reflecting objects on the opposite side.

A noise barrier protects the houses from the direct sounds generated by the traffic. Nevertheless, non-absorbing or reflecting noise barriers allow the sound to travel over the noise barrier after repeated reflections between the sound barrier and the trucks. (see Figure 15). This might cause the sound level to increase in the vicinity of the houses behind the noise barrier. In order to prevent this event from happening a sufficiently high absorption value should subsequently be provided for.

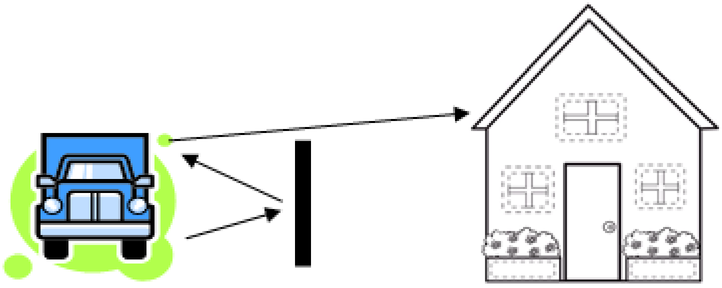


Figure 15: Reflection between the noise barrier and passing trucks

Houses on the opposite side.

Both the direct sound and the reflected sound between the traffic and the noise barrier reach the houses on the opposite side (see Figure 16). The contribution of the reflected sound amounts up to a maximum of + 3 dB(A). So, in case houses are built on the opposite side or close behind the barrier, absorptive noise barriers are recommended.

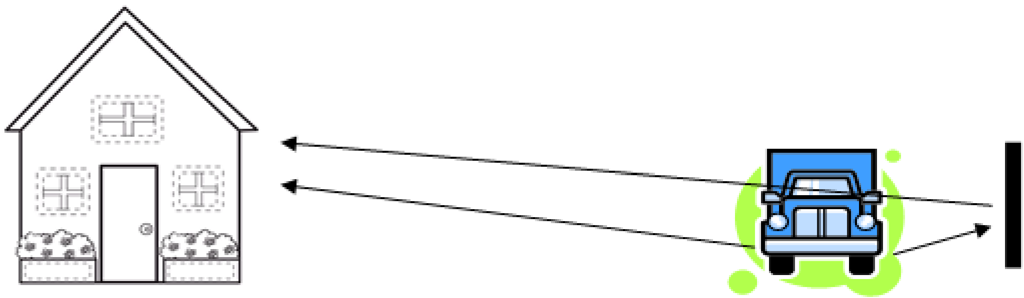


Figure 16: Reflection between the noise barrier and an opposite house (receiver)

The sound absorption characteristics of a noise barrier are commonly referred to in terms of DL_{α}, the single number rating of sound reflection (see section 4.3.3). Typically a good absorber would have a DL_{α} value of at least 10 dB. The absorption characteristics are determined using laboratory based tests. Recent research has resulted in the development of a similar index, DL_{RI}, based on in-situ test methods.

Research has shown that there is a moderate correlation between the single number rating DL_{α} and DL_{RI}. Figure 17 shows the correlation between measurement results of the laboratory method and the in-situ method for sound reflection over all barrier types available in the QUIESST-database.

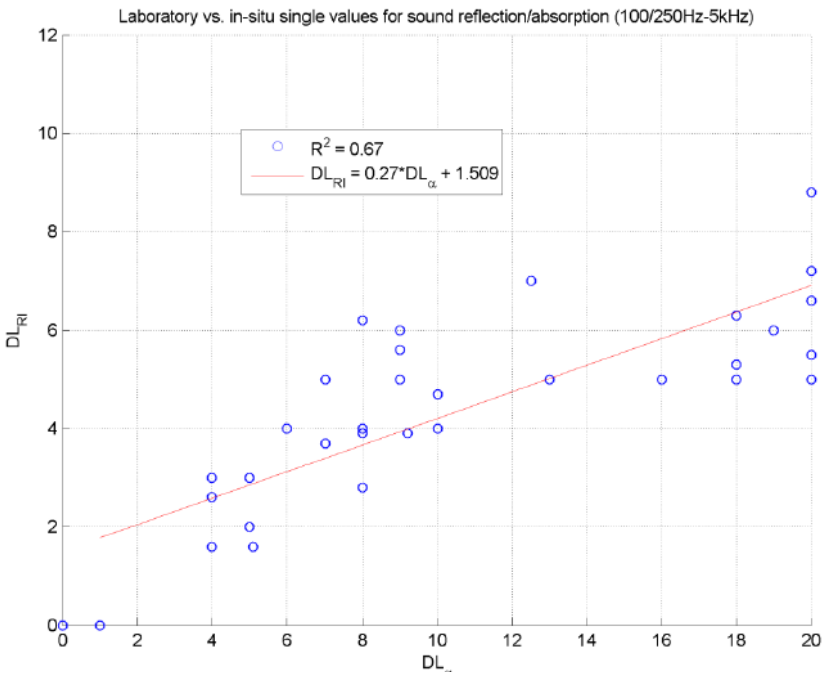


Figure 17: Laboratory vs. in-situ single values for sound reflection (100/250 Hz-5kHz) (Quiesst, 2012)

Further research is required to investigate the correlation between the two methods for individual noise barrier types.

4.4.3 Sound insulation

A noise barrier with a sufficient sound insulation weakens the sound waves propagating directly through the noise barrier. Their contribution to the overall sound level will thus be reduced to a minimum. The sound insulation properties of a noise barrier are especially determined by its mass and the thickness of the barrier. Densities of the order of 15-20 kg/m^2 or greater appear to be sufficient for this purpose.

Currently, the sound transmission characteristics of a noise barrier are commonly referred to in terms of DL_R, the single number rating of airborne sound insulation, although the development of new test methods has resulted in a similar index, DL_{SI}, based on in-situ rather than laboratory testing (see section 4.3.3).

Research has shown that a correlation can be determined between both parameters, but these resultants have to be considered carefully. Further investigation have to be done. Figure 18 shows the correlation between measurement results of the laboratory method and the in-situ method for sound insulation over all barrier types available in the QUIESST-database.

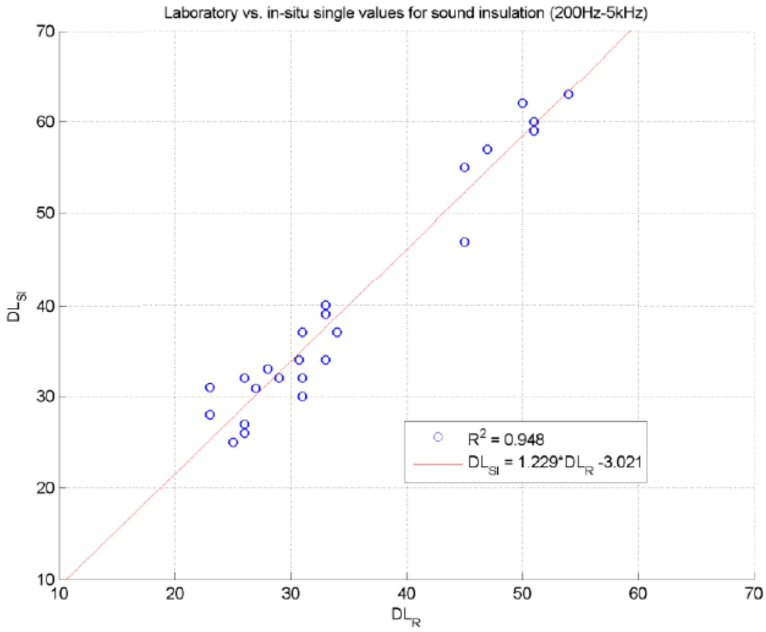


Figure 18: Laboratory vs. in-situ single values for sound insulation (200 Hz-5kHz) (Quiesst, 2012)

The receiver is thus exposed to the transmitted noise through the barrier and the diffracted noise at the top edge and sides. With a noise barrier with a sufficient sound insulation, say 10 dB(A) higher than the ideal noise level reduction just behind the barrier (around 15 dB), the contribution from the sound waves transmitted through the noise barrier to the overall level is reduced to a minimum.

So, with an airborne sound insulation DL_R value of at least 25 dB the contribution of the transmitted sounds to the overall level at the receiver is almost nihil. A first suggestion for the sound insulation index DL_{SI} becomes 28 dB, using the formula 'DL_{SI} = 1,229 * DL_R – 3,021'. Further research is required to investigate the correlation between the two methods for individual noise barrier types.

In case of very high noise barriers or receivers very close to the barrier the value must be higher.

4.4.4 Diffraction

Diffraction is a form of sound wave scattering by the objects, the size of which is comparable to the wavelength of the sound wave. The sound diffracted over the top of the noise barrier is the most important factor limiting its acoustic performance. If the receiver is in the shadow zone of the noise barrier, then significant reductions in noise level will occur. It has been found that path length difference is an important parameter affecting the performance and therefore the height of the barrier is a significant characteristic.

Added devices

The performance of a noise barrier is influenced in part by the angle in which the sound waves diffracted over the top; the steeper the angle, the greater the yield of screening. In some cases it may be convenient to avoid increasing the height of a barrier through the addition of a shaped cap which moves the position of the leading diffracting edge closer to the source.

CEDR
Conférence Européenne des Directeurs des Routes
Conference of European Directors of Roads

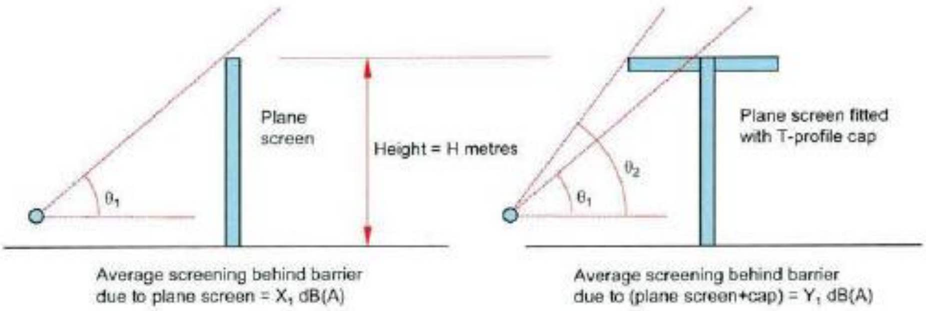


Figure 19: Definition of barrier cap screening performance

Added devices are components that are fitted to the top of conventional plane-screen noise barriers to enhance performance, serving primarily to affect diffracted sound energy. This is typically achieved with either no or a small increase in the height of the original noise barrier, and therefore offers potential for improving screening performance both during the initial design of new barrier installations or via retrofitting the devices to existing barriers. They work by moving the position of the leading diffracting edge closer to the noise source, adding additional diffracting edges, increasing the surface area of sound absorptive material at the top of the barrier or a combination of these effects.

Many studies have been carried out in order to optimize the profile of the cap element, in order to optimize the acoustic performance with other factors such as cost, safety and aesthetics of the article. using combinations of numerical modelling and full scale testing, e.g. de Roo et al (2004) and considerable work has been undertaken on the performance of these devices in Japan; see, for example, the summary by Morgan (2004). Other studies where the performance of specific devices have been investigated include assessments of multiple-edge diffracting devices (Watts, 1996), interference devices (Watts and Morgan, 1996), T-profile devices (Kaptein et al, 2004), and cylindrical caps (Asdrubali, 2007).

The types most used, however, appear to be those with T-profile, Y-profile, cylindrical profile, or more complex design, such as a rounded top or branched curved. The use of absorbent treatments on the cap can further enhance the projection of the acoustic barrier

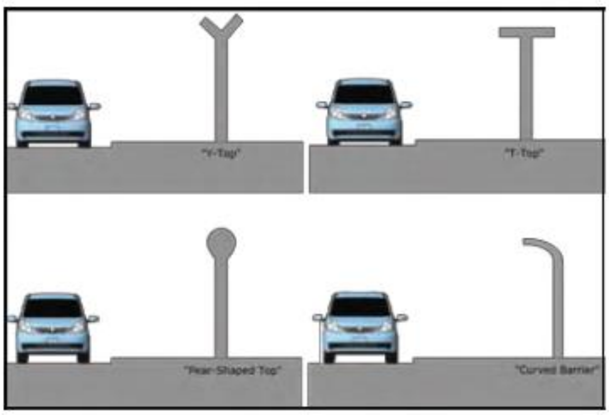


Figure 20: Different examples of added devices

An example of added devices is shown in Figure 21.

Figure 21: Example of added devices (AWV, Belgium)

Based on the responses from NRAs received as part of the QUESTIM noise barrier survey, such devices are not widely used across Europe. Various reasons were put forward as to why such devices are not used; the primary reasons were a lack of data confirming the effectiveness of the devices (although the EN standard 1793-4 on diffraction performance (see section 4.3.3 of this report) provides a standard way of characterising performance and comparing the efficiency of different devices) and an inability to robustly take account of their effects in noise modelling software. Costs were also seen as prohibitive relative to simply increasing the height of the screen.

Based on the results of the IPG report "*Diffractietesten en Simulaties Schermtoppen"* a T-shaped noise barrier is cost-efficient. It costs just as much to build a T-shaped noise barrier as it costs to increase an already existing noise barrier by 1 m, in the case where the foundations should not be strengthened or modified. And when the insertion loss of the barrier is taken into account, the cost for a T-shaped noise barrier proved to be 5 to 15% less than for increasing the height of a screen.

Because of the higher costs, added devices are only recommended on bridges and fly-overs where the height is limited because of wind and static load.

4.4.5 Leaks

However density only addresses the acoustic quality of the component materials themselves. The main source of leaks will occur at the interfaces between components of the noise barrier, e.g. between adjacent panels/acoustic elements and/or at the interfaces between panels and posts. The effects of leaks become more significant as the height of the barrier increases although they diminish with distance from the barrier, so the position of the receiver relative to the barrier can be a key factor. It should be noted that any declared structural lifetime for the barrier is unlikely to take into account the occurrence of such small holes/gaps.

The effects of leaks have been investigated in a number of different studies, which can be summarised as follows. The Finnish National Road Administration reported on a study using the EN 1793-2 laboratory test to look at the effects of leakage through timber barriers (Finnish National Road Administration, 1994). Measurements were undertaken in a reverberation room using simple board and plywood fences with artificially generated gaps (width 2 mm) to simulate leakage due to shrinkage of the wood. The board fence used 125 x 22 mm boards with a 12 mm overlap on each joint. The results indicated that if the sound insulation requirement was only DL_R = 15 dB, then leakage due to ageing (shrinkage) is permissible. If the requirement is DL_R = 20 dB, no leakage is allowed with a 22 mm thick board and if the requirement is 25 dB, the joints between the boards should be sealed with a filling material or with a thin plywood.

The Finnish National Road Administration also reported a separate study to look at the effects of holes and gaps under noise barriers (Finnish National Road Administration, 1997). However, this study focussed on changes in absolute noise level at distances behind the barrier, rather than in changes in the single number rating. The effects were investigated using timber or metal sound absorptive noise barriers (with a height range of 2.4-3.5 m) installed at four roadside sites and included the effects of two or five 0.1 m x 0.1 m holes close to ground level and large gaps at/close to ground level ranging from 0.06 m x 40 m to 0.4 m x 60 m. At receivers close to the barrier (2 m away, at a height of 1.5 m), the openings resulted in an increase in sound pressure level of up to 3 dB(A) relative to the barrier without holes/gaps. At receivers up to approximately 7 m away (at heights from 1.5-1.8 m), the openings resulted in an increase in level of up to 1.3 dB(A). At receivers approximately 20 m way, the openings resulted in an increase in level of up to 0.5 dB(A). A further scenario, based around multiple vertical slits in a 2.5 m high barrier constructed from vertical, overlapping wooden planks (where the slits were created every third plank by pulling the bottom of the plank 100 mm outwards from the barrier), resulted in an increase in level of 2.3 dB(A) at a distance of 7.5 m from the barrier and a height of 1.8 m.

Garai and Guidorzi (2010) have also examined the effects of slit-shaped apertures, such as those that occur between acoustic elements or between elements and posts, using the in-situ test method for airborne sound insulation that was specified in EN 1793-5 (section 4.3.3). As with previous studies, it was observed that the reduction in sound insulation performance caused by an aperture is greatest close in to the barrier and reduces with distance, and the reduction in performance increases with aperture width. The effect was found to be of increasing importance at frequencies above 600-700 Hz, however no results were presented in terms of the scale of the effect on the overall single number rating.

The EN 1793-6 in situ test method (see section 4.3.3) has also been applied to examining sound leakage at the post/acoustic element interface on roadside barriers in New Zealand (NZTA, 2013) due to either poor quality installation (acrylic barriers) or ageing materials (timber barriers). For the former, a drop in airborne sound insulation of approximately 10 dB or greater was observed across the full one-third octave band frequency range, whilst for the latter, ageing reduced the sound insulation performance at frequencies below 1 kHz by up to 7 dB. However no information is given on the physical dimension of the gaps examined.

The outcomes of a Belgian thesis (Nachtegael, Van Eekert (2013) show that a relative small leak between the panels (see Figure 22) results in a drop in the airborne sound insulation of almost 10 dB at the post. A bad interface between the post and a panel (see Figure 23) gives a difference of 10 to 30 dB in the airborne sound insulation between the post and the panel.

Figure 22: Leak between two panels (Nachtegael, Van Eekert (2013))

Figure 23: Connection post/acoustic element (Nachtegael, Van Eekert (2013)

Since the dimensions of the barrier and its position relative to receivers will vary from site to site, it is therefore important to ensure that barriers are well designed to minimise the likelihood of gaps/holes occurring and that barriers are installed in accordance with the manufacturer's instructions.

4.4.6 Monitoring the acoustic performance of noise barriers (EN 1793-5 and 6)

For the specification of the acoustic performance of noise barriers the majority of NRAs use the single number ratings used within EN-1793-2 for the airborne sound insulation and within EN-1793-1 for the sound absorption

With the forthcoming revision of EN 14388, manufacturers will declare airborne sound insulation performance according to EN 1793-5 and EN 1793-6. For the future it's desirable that NRAs will demand acoustic requirements as values determined from these in-situ test standards instead as the single number ratings.

It is recommended that all acoustic performance monitoring of installed noise barriers be performed using the in-situ test methodology set out in EN 1793-5 and 6. This will allow performance of intrinsic characteristics to be assessed against declared values.

For new barrier installations

It is recommended that some form of assessment is undertaken as a form of project sign-off, to check compliance with contract requirements, conformity-of-installation of the barrier or to ensure that the noise barrier is fit for purpose. Such checks will serve to primarily provide an indication as to whether the product has been correctly installed in accordance with manufacturer/supplier instructions or is compliant with the intended design. If this is the case, then the intrinsic acoustic performance[1] of the barrier should, in principle, be in line with the values declared as part of the products CE mark.

Visual and audible inspections are recommended as the minimum requirement, supplemented if necessary, when the in-situ test method (EN 1793-5 and -6) will be the reference, by acoustic assessments. The following paragraphs provide further details.

Visual and audible inspections

Wherever possible, visual and audible assessments 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.

- Timing of inspections. A visual and audible inspection during the installation of the barrier can help to ensure that any potential defects are identified quickly, allowing them to be rectified or prevented from being repeated elsewhere on the barrier. However, if inspections at that time are impractical or are considered unnecessary, then when used for project sign-off/acceptance, the inspection should ideally be taken as soon as possible after completion of the installation, preferably within 1-2 months.
- Quantity of the barrier to be inspected. A visual and audible inspection of the whole length of the installed barrier is preferable, ideally on both sides. The latter point may be particularly necessary if sound absorptive barriers are installed and different materials are visible on each side, e.g. sound absorptive materials on the traffic side protected by a membrane and timber planks on the rear face. If such a comprehensive inspection is impractical or considered unnecessary, then randomly selected sections should be inspected. If direct access to the barrier façades are not possible, the level of detail of the inspection will be reduced. In such instances, a drive-by inspection will allow only the most visible flaws/defects (if any) to be identified, but only on the visible façade of the barrier.
- What to look/hear for. 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.
    - et cetera.

Acoustic assessments

[1] The acoustic performance of the materials/components from which the barrier is constructed rather than the noise reduction experienced at noise sensitive receivers screened by the barrier.

There are several reasons for performing on site acoustic assessments, namely:

- To verify compliance with declared performance specifications. This may also be particularly important in situations where a barrier is installed using acoustic elements that are constructed on site from different component materials rather being prefabricated acoustic elements.
- To identify the potential impacts of defects picked up during the visual inspections, relative to declared performance specifications. This would identify whether the defects were acceptable or would need to be rectified.
- To establish the consistency of installation of a barrier on a given scheme.
- To provide baseline data for performance monitoring over the lifetime of the noise barrier.
- Methodology: the acoustic assessments should be performed using the in situ test methods within the EN 1793 suite of standards (e.g. EN 1793-6 for airborne sound transmission).
- Timing of assessments: measurements can be taken during or as soon as possible after completion of the installation, preferably within 1-2 months.
- Quantity of the barrier to be assessed: there is no standardised approach for determining the quantity of a roadside barrier to be assessed. The approach adopted may be subject to budget constraints or influenced by the proposed use of the data collected. The ability to perform in situ sound transmission measures will also be strongly influenced by the availability of access to the rear of the barrier.

  In the majority of cases, as it is proposed that acoustic measurements are used to supplement visual and audible inspections, it is expected that measurements at only one or two positions will be required, at random locations along the barrier. If the visual inspections identify obvious defects that might affect performance, then additional measurements should be taken at one or two of these positions so that the resulting measurement report would indicate typical performance and a 'lower limit' defined by the faulty sections.

  If a more detailed assessment is considered necessary, it is suggested that these should be performed at regular intervals along the length of the barrier, e.g. every 100 m, covering sections of the barrier spanning between 2 or 3 adjacent posts, subject to the availability of access to both sides of the barrier.
- Costs: the use of the in-situ assessment techniques in the EN 1793 suite of standards is largely confined to research and is therefore not currently commonplace for post-installation checks at the roadside. The cost for one measurement set (three measurements, one reflection measurement at the acoustic element plus one insulation measurement at the acoustic element plus one insulation element at a post or interface between two acoustic elements) will be around several thousand euros. It should be noted that, depending upon the position of the barrier relative to the road, such measurements might require the use of traffic management, which would increase the overall costs.

Monitoring condition and performance over lifetime

Monitoring of the condition and potentially the acoustic performance of noise barriers over their 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. The following paragraphs provide further details.

Visual and audible inspections will seek to identify physical defects that were not previously present. If inspections highlight damage to or 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.

- Frequency of inspections: it is recommended that visual inspections of noise barriers should ideally be undertaken on at least an annual basis, irrespective of type/materials. However, if this is not considered practical, then inspection frequencies should be informed by the type of barrier and their location. For example, barriers constructed from natural materials such as timber may require more frequent inspection than those constructed from materials such as metal or concrete. Similarly, barriers exposed to harsher climatic conditions or which are more exposed to splash and spray from traffic might require more frequent inspections than those in more sheltered environments.
- Quantity of the barrier to be inspected: the recommendations here are the same as for newly installed barriers, i.e. visual and audible inspection of the whole length of the installed barrier is preferable, ideally on both sides. If such a comprehensive inspection is impractical or considered unnecessary, then randomly selected sections should be inspected. If direct access to the barrier façades are not possible, a drive-by inspection will allow only significant physical defects (such as physical damage missing acoustic elements or where elements are missing) to be identified.
- What to look for: the following is a summary of the key areas that should be addressed by the visual inspection, although this list is not exhaustive. Other areas of focus may arise depending upon the barrier type/materials, the method of construction, etc.
    - 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.

It is important to note that the aesthetics/visual condition of a noise barrier will have an impact on the perceived performance of the barrier by members of the public, especially those at noise sensitive receivers closest to the barrier. A barrier in poor visual condition will be perceived as less effective than a well-maintained barrier, even if the level of acoustic screening provided is identical. Visual inspections are therefore just as important to ensure that physical appearance as structural integrity.

Acoustic assessments: 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 and there is a desire to monitor this. Also, people living in the neighbourhood of the noise barrier who are complaining about the acoustic performance of the noise barrier, might be a incentive to do acoustic assessment.

- Methodology: same as new barrier installations
- Frequency of assessments (routine monitoring): for timber barriers or other barriers where performance might be expected to degrade, acoustic monitoring is recommended 1, 3 and 5 years after installation and subsequently every 5 years; for barrier types where changes in the intrinsic acoustic performance are unlikely, then monitoring after 1 year and then every 5 years after installation is recommended.
- Quantity of the barrier to be assessed: there is no standardised approach for determining the quantity of a roadside barrier to be assessed as part of routine monitoring. The ability to perform in situ sound transmission measures will be strongly influenced by the availability of access to the rear of the barrier in the years after installation. In the majority of cases, as it is proposed that acoustic measurements are used to supplement visual inspections, the number of measurements will be similar to those for a barrier in new condition.
- Costs: same as new barrier installations

Factors affecting both visual and audible inspections and acoustic assessments

Ensuring the health and safety of assessors working on their network is a key requirement for NRAs. Where noise barriers are located at the edge of the carriageway, the ability to undertake either visual and audible inspections or acoustic assessments of intrinsic characteristics may be dictated by whether or not there is a hard shoulder/ emergency lane present and any local requirements set by the responsible road authority or site contractor for traffic management, e.g. hard shoulder or outer lane closures, provision of impact protection vehicles, et cetera.

4.4.7 Example inspection of noise barriers: experience in Wallonia

Since 2013, the Road Noise Division of the '"Public Service of Wallonia (Belgium)" is responsible for the management of the noise barriers along the roads in Wallonia. In 2014, the Ministry of public works of Wallonia asked the Road Noise Division to establish a state of art of the noise barriers along the roads in Wallonia. After making a database including all their characteristics and positions, a procedure was defined to determine the health of the noise barriers. The procedure was developed taking into account the material aspects and the technology of the devices.

All the developments were made by following two keywords: easy and complete. After several versions, the final one is composed of three main-documents to compile in order to implement the inspection's report.

- The first document is a list of the major defects found in the investigations made by the Road Noise Division. The final version is represented on Figure 24.

Noise barriers Investigation

List of the defects

N°	Name	Comments	Fig.	N°	Names	Comments	Fig.
1	Pole / Column			4	Foundation		
110	Coating degradation	Spalls, ...		41	*Concrete foundation*		
120	Rust			411	Cracks		
130	Deformation			412	Rust		
140	Impact			413	Spall		
150	Degradated settings	Bottom of the column		414	Apparent frames		
160	Lacked or moved lateral joint			415	Moved joint	Junction Caisson/Slab	
170	Degradated joint			416	Degradated joint		
1900	Other defects			4190	Other defects		
2	Caissons, Pannels			42	*With concrete retaining structure*		
210	Rust			421	Cracks		
220	Impact			422	Rust		
230	Lacked or degradated settings	Identify moving caisson		423	Apparent frames		
240	Végétation			424	Spall		
250	Moisture	Dark patch, ...		425	Degradated neoprene joint	Including settings	
260	Lacked element	Face of NRD, whole element		426	Lack of neoprene joint		
270	Soiling of the face	including graffities		4290	Other defects		
2900	Other defects			5	Environment		
3	Absorbing material			510	Vegetation		
310	Moisture			520	Soiling		
320	Degradated material	Pieces, ...		530	Uninspected		
330	Lacked material			5900	Other defects		
340	Apparent material			6	Other element		
350	Degradated geotextile			610	Defect to define		
3900	Other defects			620	No defect		

Figure 24 List of the defects

As showed on Figure 24 each part of the screen has its particular defects and associated codes. For instance if we consider the part 'Caissons and Panels', after several investigations the Road Noise division found that rust, moisture, impacts, degraded settings are the most common defects found on these elements of the barrier.

- The second document has been developed to help the inspectors to identify the defects. For each defect there is a reference picture that helps the inspector to identify the right defect. Different examples are given in Figure 25.

Figure 25 Examples of pictures in the "Second document"

- The third document is a Excel sheet on a tablet in which inspectors can indicate the defects, their positions and the pictures of the defects.

N° Pannels-Caissons	N° Defect	Comments	N° Photos

Figure 26 Encoding document

All the information collected during the inspection is used to produce the inspection's report, containing all the remarks and observations about the barrier. The Excel file was developed to help the responsible road engineer to know all the defects on their devices. By ysing this tool they will be able to identify the repairs they have to make. It is composed of eight sheets:

- The two first ones "Encod_Avt" and "Encod_Arr" are encoding files. The first one collect all the defects found on the front part of the noise barrier and the second one all defects of the back. The files on the tablet are downloaded and corrections are made by the inspectors to finalize the documents and associate the pictures to the right defects.

N° Caisson/ Panel	Defect Code	Name	Comments	N° Picture
1A	620	Pas de défaut	Absence de la bavette/joint d'étanchéité avec le New Jersey (0,9m) sur tout l'écran	
1A	210	Rouille		
1A	240	Végétation	La végétation se développe en dessous de l'écran	1
1B	320	Matériau détérioré		
1B	210	Rouille	Rouille sur le montant inférieur	2
1A	320	Matériau détérioré		
1C	320	Matériau détérioré		
1C	210	Rouille		
1D	320	Matériau détérioré		
1E	320	Matériau détérioré		

Figure 27 Example of documents "Encod_Avt" and "Encod_Arr"

- The next sheet "Localisation" refers to the location of the noise barrier. This sheet has to be considered as a ID-card of noise barrier, with its ID-number, the road, the kilometre positions and also the responsible road division. An aerial view of the position is also included.

Wallonie

SPW Service public de Wallonie

Datum : 10/01/2015

Inpectors DUMAY Denis ERNST Christophe

Report of investigation of Noise Barrier

I. ***Localisation***

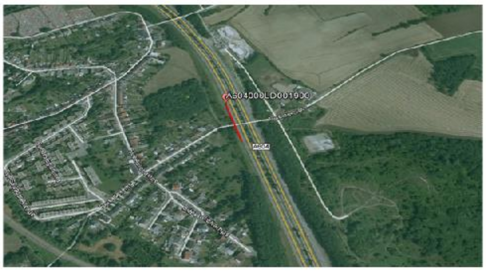
Number ID : A604000LD001900 *Comp :*

Road Division : 151 Direction des routes de Liège

Area Grâce-Hollogne

Begun Road	KP start	Side	KP end	Ended road
A604000	1900	LD	2000	A604000

ID-Card



Aerial views

DGO 1

Cellule "BRUITS"
Direction de l'Expertise des Ouvrages
Département des Expertises Techniques

Figure 28 Example of sheet "Localisation"

- The sheet “Caractéristiques” gives all the characteristics of the noise barrier, including the number of caissons/panels, the number of column and the length of the barrier. Two pictures of the barrier are also given to illustrate the device.

Wallonie

SPW Service public de Wallonie

II. ***Caracteristics***

Number ID	Type	Direction	Material
A604000LD001900	Caisson	H	Métal

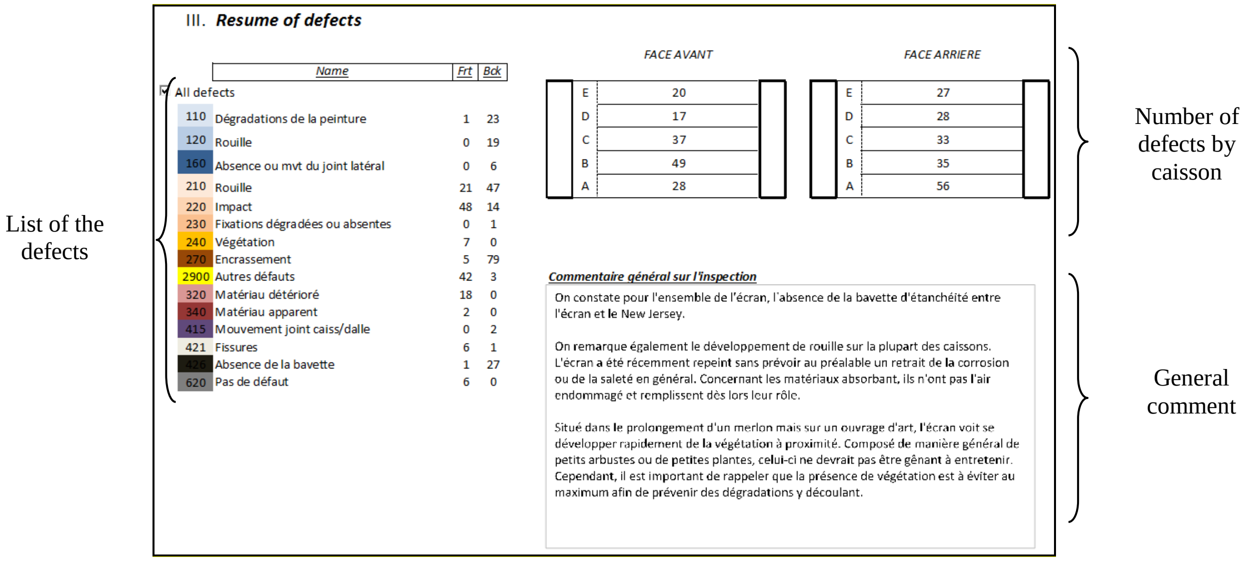
	Number [-]	H [m]	L [m]
Frame	28	3	114
Column	29	3	0.4
Caisson/Pannel	5	0.6	5

General views

Figure 29 Example of sheet "Caractéristiques"

- The sheet "Catalog_def" is a copy of the first document of the procedure, to ensure a good understanding of the codes and defects linked to.

- An overview of the inspection is available on the "Bilan" sheet. The list of all the defects found during the inspection is also given and the number of these on the front and the back of the device too. A general comment of the inspection helps the road responsible to know the general health state of his device.

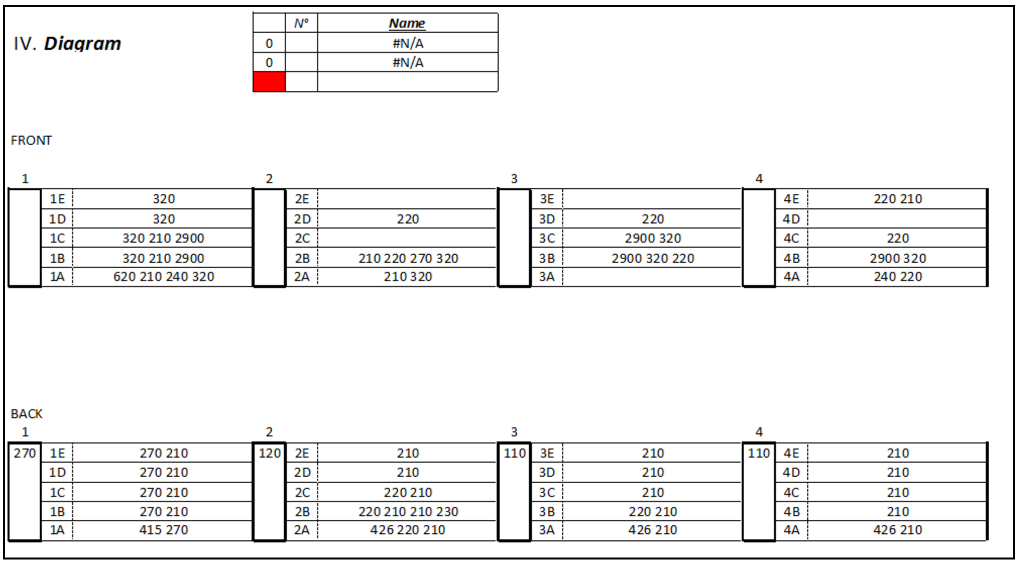


Code	Name	Frt	Bck
	All defects		
110	Dégradations de la peinture	1	23
120	Rouille	0	19
160	Absence ou mvt du joint latéral	0	6
210	Rouille	21	47
220	Impact	48	14
230	Fixations dégradées ou absentes	0	1
240	Végétation	7	0
270	Encrassement	5	79
2900	Autres défauts	42	3
320	Matériau détérioré	18	0
340	Matériau apparent	2	0
415	Mouvement joint caiss/dalle	0	2
421	Fissures	6	1
426	Absence de la bavette	1	27
620	Pas de défaut	6	0

Caisson	FACE AVANT	FACE ARRIERE
E	20	27
D	17	28
C	37	33
B	49	35
A	28	56

Figure 30 Example of the sheet "Bilan"

- The next file "Schema" gives a picture of the entire noise barrier. This sheet has been developed to give an overview of the device and all the defects identified during the inspection using their codes in the catalogue of defects. All the comments and pictures linked to the defects are included in the schema.



	N°	Name
0		#N/A
0		#N/A

FRONT

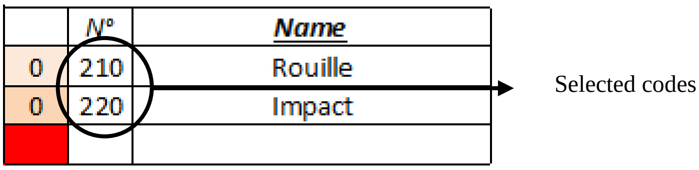
Caisson	1	Caisson	2	Caisson	3	Caisson	4
1E	320	2E		3E		4E	220 210
1D	320	2D	220	3D	220	4D	
1C	320 210 2900	2C		3C	2900 320	4C	220
1B	320 210 2900	2B	210 220 270 320	3B	2900 320 220	4B	2900 320
1A	620 210 240 320	2A	210 320	3A		4A	240 220

BACK

Caisson	1 (270)	Caisson	2 (120)	Caisson	3 (110)	Caisson	4 (110)
1E	270 210	2E	210	3E	210	4E	210
1D	270 210	2D	210	3D	210	4D	210
1C	270 210	2C	220 210	3C	210	4C	210
1B	270 210	2B	220 210 210 230	3B	220 210	4B	210
1A	415 270	2A	426 220 210	3A	426 210	4A	426 210

Figure 31 Example of sheet "Schema"

To help the road manager in his job, it is possible to highlight a particular defect by selecting the code you want to see.



For instance, by selecting the defect “210 – Rust on the caisson” all the places where this defect has been identified will get a colour in this sheet. The manager is allowed to select two major defects and consequently all the caissons/panels with both defects are coloured in red. This tool will help the responsible road engineer to define precisely which repairs he has to make.

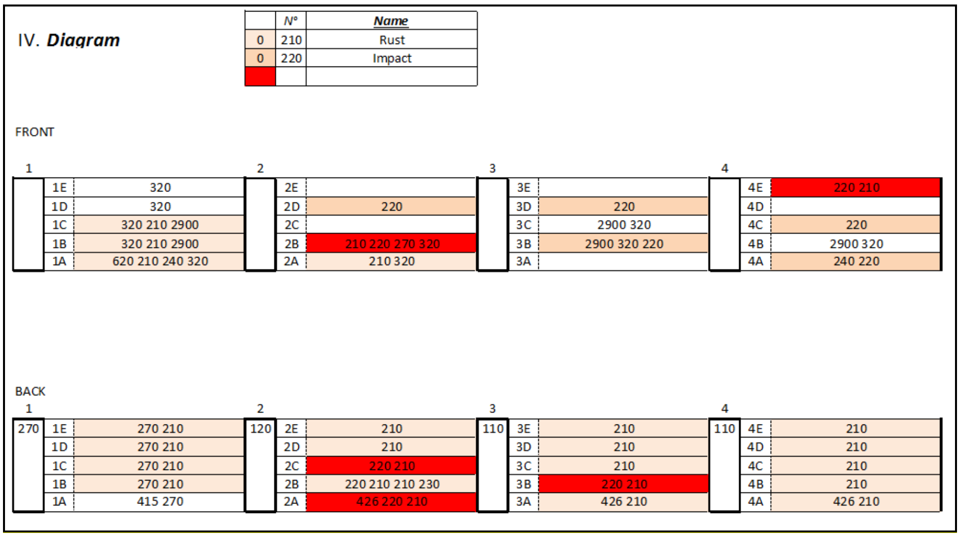


Figure 32 Example of sheet "Schema" with selcted defects

- The last sheet “Photos” is a report with the most important pictures illustrating the defects found during the inspection.

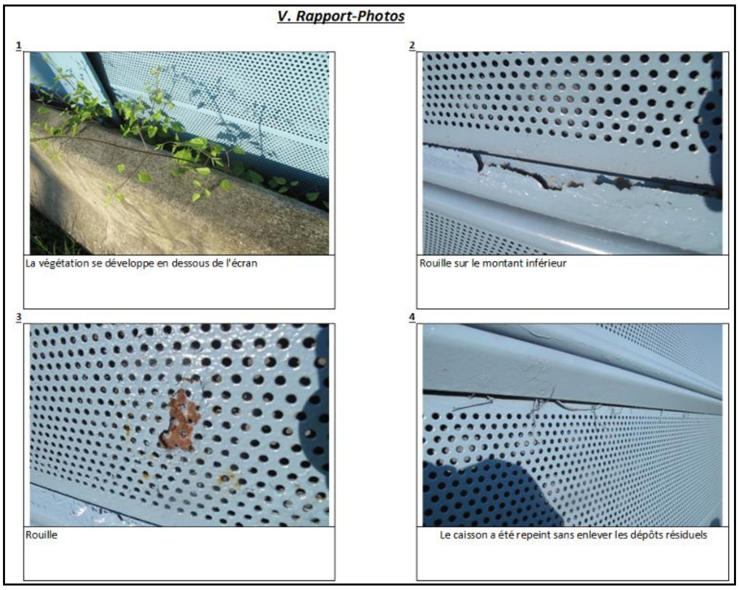


Figure 33 Example of the sheet "Photos"

The goal is to inspect all the noise barriers for October 2016 and give them a health indicator. Based on this 'health indicator', the Road Noise Division will be able to compile a program of repairs and changes of the existing noise barriers.

After having inspected all of the devices and built their inspection's report it is necessary to define their "health indicator". Different ways can be explored to achieve to define this parameter. In the reports different tools have been developed to help the inspector to have the best overview of the state of the device.

The way chosen by the Road Noise Division to define this indicator is quite general. To facilitate the analysis the following points are studied and analyzed to define the parameter in order:

1. *Structural and stability aspects:* we insure that the structure is in good condition and the stability of the device too. If not a warning has to be indicated.

2. *Acoustical aspects:*

   a. Absorbing material: essential in the absorption function of the barrier, this part must be in a perfect condition. If not a warning has to be indicated.

   b. Sound insulation: all the elements placed to insure the insulation between the foundation and the first caisson/panel or between the elements and the columns must be good placed. If not a warning has to be indicated.

3. *Settings of elements:* this part is very particular and a widespread problem is the devices in Wallonia. Having bad settings may generate more noise by allowing the caissons to move and beat between the columns.

4. *Visual aspects:*

    a. Rust: this problem is half a structural problem and half a visual problem. Rust can appear without generating the collapse of the barrier. But when it is widespread and when the back side of the caisson is contaminated the problem becomes serious and have to be taken seriously into account.
    b. Gap between elements: this element is a acoustical aspect and also a visual aspect and may in some cases be indicator of a structural problem.

After having analyzed following this approach all the barriers and prioritization of the repairs will be established. An indicator A, B, C or D will be attributed to characterize their health taking into account that A is the worst “health” and D the best one.

4.4.8 More research/data/measurements needed

Recent research has resulted in the development of a similar indexes based on in-situ test methods more applicable along roads (in non-reverberant conditions and direct field). For the airborne sound insulation, there is potentially a good correlation between the results measured according the laboratory method and in-situ method and a moderate correlation for the absorption indices. Further research is therefore required to investigate the correlation between the two methods for individual noise barrier types.

There is also a need to demonstrate compliance with specified performance criteria. This might be in terms of declared intrinsic performance by a manufacturer or modelled/ predicted insertion loss performance (the difference in noise level with and without the barrier) at noise sensitive receivers. For example, it is the experience in the Flemish Road Administration (Buytaert, 2014) that barrier insertion loss is generally below theoretical expectations.

There is a lack of published data on the long-term acoustic performance of noise barriers. Further practical data are required, because many noise barrier products are not currently considering acoustic degrade over time. The introduction of CE marking under the Construction Products Regulation and the forthcoming revision of acoustic durability standards might perhaps help to achieve this (although declared durability performance may well be based on expert judgement rather than practical testing). Whilst some manufacturers may choose to monitor the barriers that they install, it is also a good idea for road authorities to undertake their own lifetime monitoring programmes for barriers on their networks. Further research can provide other test methods without the need for operators and/or equipment to be placed on the carriageway side of the barrier.

4.5 Non acoustic performances

4.5.1 Mechanical performances and stability requirements (EN 1794-1)

An acoustic screen is an environmental barrier in the form of relatively thin panels. In most cases these span between supports which resist horizontal overturning forces. The major force to be resisted by an exposed surface is that caused by wind. When the acoustic screen is relatively close to the carriageway, other forces may need to be considered, such as aerodynamic forces caused by passing vehicles, the possibility of impact by errant vehicles and the effect of snow being thrown against the face by clearing equipment. These additional forces are to be considered as acting independently of each other and of the design wind loading. In some circumstances, vertical forces may also increase overturning moments.

- *Wind load*

Wind loads vary with geographic location and can be influenced by elevation in relation to existing topography. They affect the overturning moment or rotational force placed upon the barrier, its foundation, and/or the structure to which the barrier is attached. Unlike dead loads, wind loads are essentially the same, regardless of barrier material type.

- *Aerodynamic loading*

If large vehicles pass at high speed close to environmental barriers, the dynamic pressure caused by the dynamic pressure caused by the displaced air can be significant. As an example, a pressure reversal of ± 0.5 kN/m2 may be caused by vehicles passing at 100 km/hr within 3 m of a free standing barrier. Much larger pressure changes may be experienced in the direct vicinity of tunnels and can be an important consideration in the design of fixings for noise absorbent panels attached to walls.

- *Dead load (self weight)*

The weight of the barrier itself must be considered in all barrier design calculations. Weight considerations are particularly critical in the design of structure-mounted barriers and can require modifications to the structure design itself. Lightweight barrier materials are often utilized in situations where existing or proposed structures are limited in the amount of additional weight which they can accommodate. Ice loads represent a special type of dead load caused by water freezing and building up on exposed barrier surfaces.

- *Snow loads*

Unlike ice loads, snow loads are not considered to be dead loads placed upon the barrier. Rather, in barrier design, considerations related to snow relate to the generally horizontal forces of both plowed and stored snow which can be placed on or against the vertical surface of the barrier. Design of the barrier to accommodate such loadings should consider the area available for safe storage of plowed snow as well as the relationship (both horizontally and vertically) of the barrier to the location of snow clearing and snow removal equipment (plows, front end loaders, melters, and blowers). Evaluation is required for the maximum value the noise barrier can withstand from snow projected during clearance activities. Performance can be declared on the basis of test or validated test report. The high value of performance required is due to heavy system for snow removal often used in Nordic countries.

- *Impact loads*

Impact loads can be classified as loads placed on the barrier due to the impact of vehicles and airborne debris. Noise barriers are not themselves designed to withstand the full force of a vehicle impact. Rather, either a protective metal guardrail or a Jersey-type barrier placed in front of the noise barrier is usually relied upon to keep errant vehicles away from the barrier. If the noise barrier is integrated with the traffic barrier, it is required to resist vehicular impact, in this case all such barriers must be crash-tested. In practical terms, the most effective way to meet these requirements is to put a crash-tested vehicle impact barrier in front of the noise barrier. Then the noise barrier itself would not have to be designed for vehicular impact.

Another safety concern is that the vehicular impact may result in detached elements or fragments from the noise barrier penetrating the vehicle or scattering, thereby endangering residents behind the noise barrier.

The risk associated with noise barriers on flyovers falling onto vehicle/pedestrian paths upon impact by vehicles, should also be considered in the design. Additional catching devices such as laminated panels or panels with embedded filaments or mesh should be provided as appropriate.

Where noise barriers are required to be installed on bridge structures, these should only be combined with a parapet if the assembly has been designed to accept the consequences of vehicle impact. Materials and finishes for attached noise barriers need to allow for the considerable distortions of metal parapets under impact. A freestanding noise barrier vulnerable to vehicular impact should be located behind vehicle parapet with adequate clearance for it to deflect upon impact

4.5.2 General safety and environmental requirements (EN 1794-2)

- *Resistance to brushwood fire*

The noise reducing devices can be exposed to flames from dry vegetation or other material in close proximity. Flames of greater intensity may rise as a result of accidents. Especially critical in case of fire is the behavior of the coatings used for tunnels or partial shell of transport infrastructure. For this reason is not recommended to use materials, combustible and non-combustible, capable of developing, in case of fire, nor toxic dense smoke and nor incandescent drops or strands that can be carried by the wind.

- *Risk of falling debris*

The noise reducing devices may be mounted on structures or in such a way that, if they are damaged, they can put at risk the users of the road or other. In particular there is the possibility that parts or whole panels of an acoustic barrier to peel off, due to a violent collision, and that the fragments fall, with risks for those who is below. For this reason the transparent panels should be made shatterproof by using laminated glass or embedding fiberglass within acrylic sheets.

This requirement is particularly important when barriers are installed on bridges or between carriageways.

- *Means of escape in emergency*

In barriers longer than 1000 m emergency exits should be provided every 500 m to give access to either side of the barrier for emergency (and maintenance), in accordance with the directive of tunnels. Emergency exits preferably consist of gaps with overlapping barriers. When gaps are not possible, for example by lack of space, emergency doors should be provided. In barriers with gaps with overlapping barriers, the front overlapping barrier should be absorptive at both sides to avoid reflections of sound waves between the front and the back panel. The overlapping part is at least three times the width of the gap. The width of the gap is preferably approximately 1 m.

Emergency doors need to be designed so as to be acoustically sealed when closed. Doors intended for use as escape in emergency should open away from traffic and be equipped with latches and locks panic.

The location of the escape routes must be clearly indicated by signs.

The position of the emergency exits may not acoustically disadvantage the surrounding houses. Therefore no receiver point (for example a house) may be within a radius of 10 m of an exit.

- *Light reflection*

Light reflection/glare is generally a problem arising from noise barriers with smooth surfaces, such as metal and transparent barriers. It is more prevalent on lighter colored surfaces and can be a problem in daytime (low sun angle) and nighttime periods (due to headlights) and is particularly bad during nighttime periods when the barrier may be wet. Use of rougher types of surface treatments and deep relief patterns can reduce or eliminate glare impacts.

- *Transparency*

For transparent noise barriers, the transparency must be calculated, in terms of transparency static for the people who live 'behind' the noise barriers (for aesthetic reasons) and in terms of transparency dynamic for the users of the transport infrastructure (for safety reasons).

5 Noise barrier types

5.1 Aesthetic appeal

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. They can also be overdesigned, thus becoming over-elaborate and unnecessary elements in the landscape.

Noise is not only an acoustic issue, but it is a landscape issue as well. From a landscape perspective, this means that the visual qualities of any noise barrier should be considered on an equal footing with the noise issue and thus it is important to understand aesthetic considerations when designing these structures.

By their very presence, noise barriers affect their physical surroundings. This effect depends first on the physical setting in which the barrier is placed. A barrier that would be almost imperceptible in an urban setting could visually dominate a rural or coastal setting. The perception of noise barriers must be approached from the viewpoint of the driver and from the viewpoint of the receptor.

The visual effect of the noise barrier on the driver depends on the speed of the vehicle, the height of the barrier, the distance of the barrier from the roadway, and the surface texture of the barrier. If vehicles are generally moving rapidly, close to the barrier, drivers do not notice the details of the barrier. If the vehicles move more slowly, or if the barrier is farther away, the details of the barrier are noticeable and therefore more important. If the barrier is high and close to the driver, and particularly if it is on both sides of the roadway, it may produce, a tunnel effect in which drivers perceive themselves as being uncomfortably surrounded by the barriers.

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. This visual effect can be accentuated if the barrier changes the pattern of light and shadow on the receptor’s property. The surface texture of a noise barrier depends on the type of material used to construct the barrier.

Two design approaches are available to mitigate any undesirable visual effect that noise barriers may have. In the first approach (Figure 34), the barrier is designed to be monumental, dominating the landscape. Its materials and details are selected so that it becomes a pleasing part of the landscape.

Figure 34: Noise barrier dominating the landscape

In the second approach (Figure 35) , the barrier is designed to blend with the landscape. The aim should be to reflect some of its features such as materials, colours, textures and shapes, in a form of barriers which has aesthetic appeal, without being dominant in the field of view.

Figure 35: Noise barrier is blending with the landscape

Whatever 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. For example, noise barriers in a rural area can be coloured to blend with the colours that surrounds them. Or they can be decorated or patterned with symbols that are meaningful for the area.

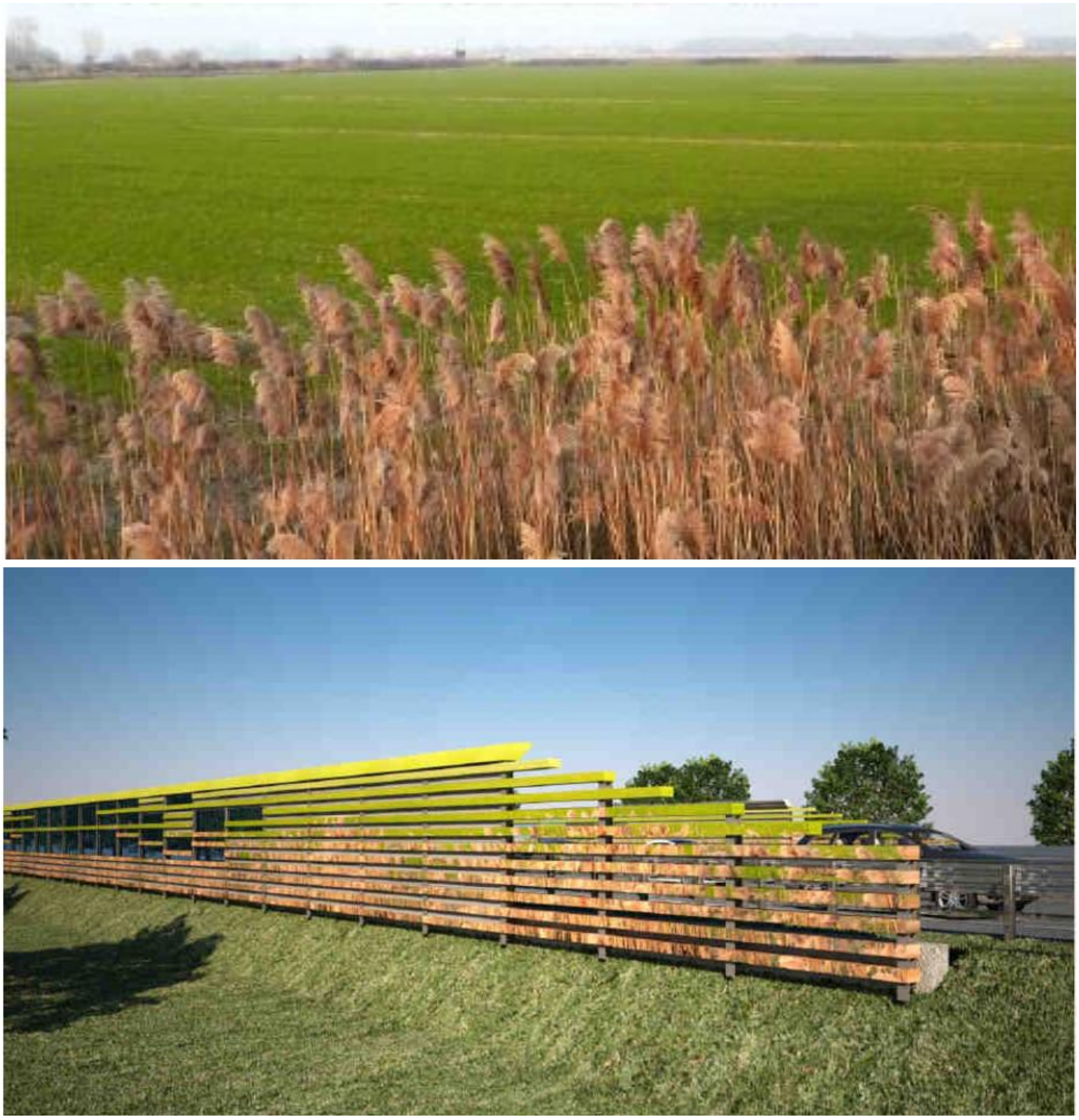


Figure 36: Noise barrier with silk-screen printed panels with images related to the surrounding rural and agricultural landscape

5.2 Shapes

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. There is now a considerable experience in the design and location of noise barriers and design methods are available.

The available information on the acoustic performance of various types of barrier is for most cases sufficient to allow a cost-effective application. Barriers do have also adverse effects, for instance, the degradation of the visual scene and impression, and the increased difficulty of crossing a road.

Barriers that may offer improved performance over simple reflecting barriers and therefore are worthy of consideration can be grouped as follows:

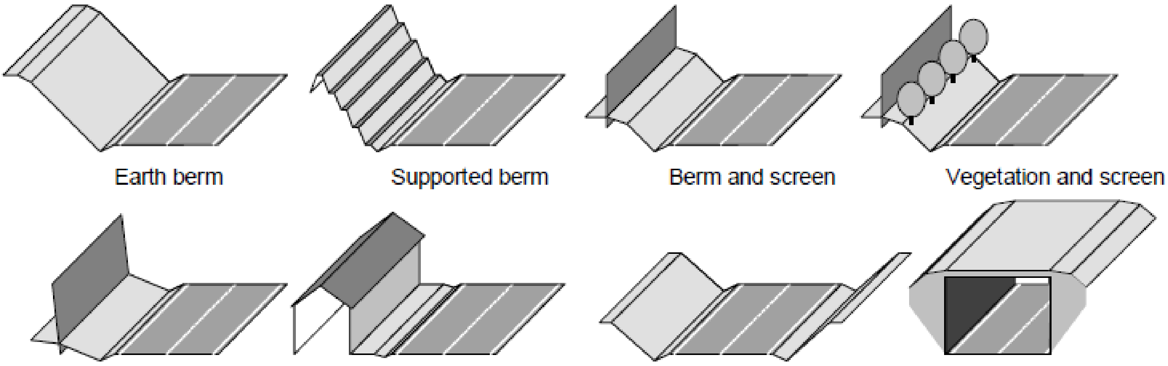


Figure 37 – Different types of barrier

- Embankments and earth mounds which may be used in combination with a conventional barrier.
- Vegetative barriers: barriers made partly or entirely from vegetation, which is rooted in a retained soil mound. The mound can be retained by various means, e.g. woven willow branches.
- Screening can also be realized with a combination of a building and a barrier.
- Covering barriers: for example as a grid set over a road in a cutting or as a complete cover on both sides of and above the road. Such complete covers are quite expensive, but offer very significant noise reduction.

NOISE SCREENING	LOCAL EFFECT, dB(A)
Barriers (Screen)	0-15
Depressed roads	0-5
Buildings as noise barriers	0-20
Tunnels	0-30
Vegetation	0-1

Table 2: Effect of noise screening

5.3 Materials

5.3.1 Type of noise barriers

The following descriptions provide a short overview of the different types of noise barrier that are most commonly found alongside NRA roads.

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, the location of the barrier and local environmental conditions, aesthetic quality requirements including local architectural considerations, the perception and acceptance of the structure by the general public and, last but not least, cost.

Timber acoustic elements: Timber acoustic elements may be fully reflective or sound absorptive and either single-leaf or double leaf constructions. The manner in which timber acoustic elements are constructed varies. They may, for example, be constructed from planks secured to cross members where the joints between the planks on the opposite side to the cross-members are typically covered with additional timber strips. Sound absorptive materials (if used) typically sit in between the cross-members. Alternatively, they may be constructed from interlocking elements using, for example, a tongue and groove construction. Panels may be prefabricated or constructed in-situ from their component parts and are typically supported in between or up against either metal or timber posts. Example of this type of barrier is shown in Figure 38.

Figure 38: Example of a timber noise barriers (Materials: impregnated wood, glass and concrete - Norwegian Public Roads Administration)

Metal acoustic elements: Metal acoustic elements are typically cartridge/cassette-type panels constructed from aluminium, steel or both and can be sound reflective of sound absorptive (when sound absorptive the metal surface in front of the absorptive material is perforated). These elements are typically supported in between metal posts. Examples of this type of barrier are shown in Figure 39.

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Figure 39: Examples of metal noise barriers (picture below with permission of Van Campen Industries)

These types of elements offer aesthetic benefits since the panels can be manufactured in different colours. Recent developments seen from at least one manufacturer, mean that graphics or photographs can be digitally printed onto the surfaces of the barriers, thereby offering the scope to completely change the appearance of the barrier and the perception for both drivers and parties protected by the noise barrier. Elements will always be pre-fabricated, allowing a high degree of quality control and conformity of production and the modular nature of the components offers potential ease of installation and replacement.

Concrete acoustic elements: Whilst noise barriers cast in situ may be used or constructed so as to be self-supporting, more commonly concrete is used for manufacturing precast panels. These may be may be a combination of reinforced concrete with a porous concrete face or manufactured as a wood-fibre/cement composite. Such panels are supported between metal posts. Again, the visual impact of concrete panels is often altered through the use of colour and profile. Examples of this type of barrier are shown in Figure 40.

Figure 40: Examples of concrete noise barriers

Transparent acoustic elements: Transparent acoustic elements are used to either provide a fully transparent barrier or are incorporated as components within an opaque barrier constructed from other materials. As such, their primary benefit is to reduce the visual impact that would result from the use of a conventional opaque barrier. They may allow drivers to view the surroundings beyond the road environment, allow residents a view across the road and reduce unwanted shading on the receiver side. Where they are used as the upper acoustic elements on an opaque barrier, they reduce the perception of being 'enclosed'. The elements may be constructed from glass, acrylics, plexiglas, polymethyl methacrylate, et cetera. Examples of this type of barrier are shown in Figure 41.

Figure 41: Examples of fully or partially transparent noise barriers

It has been found that human sensitivity to noise appears to be greater when the source of the noise cannot be seen (see, for example, Watts et al, 1999) meaning that the perceived noise level at the receiver is lower behind a transparent screen than behind an opaque screen with the same actual noise level behind the barrier. This has been further validated in other studies, e.g. Maffei et al (2013). This therefore suggests that opaque barriers may not provide the optimum protection for noise sensitive receivers. However, it is noted that research by Joynt and Kang (2010) looking at the perception of noise reduction for different noise barrier types based on preconceptions of the performance of different material contradicted this rationale.

Plastic/composite acoustic elements: These are typically cartridge type panels manufactured from plastics or recycled plastics, reinforced with glass fibre. They can be sound reflective or sound absorptive. When sound absorptive, the surface in front of the absorptive material is perforated. These elements are typically supported in-between metal posts. As with metal panels, they offer aesthetic benefits since they can be manufactured in different colours, but the materials also mean the surface of the acoustic elements can potentially be textured so that the barrier appears to be constructed from other materials. Similarly, they also offer benefits in terms of ease of installation and replacement. Examples of this type of barrier are shown in Figure 42.

Figure 42: Examples of plastic/composite noise barrier

Stone gabions: These are metal cages filled with large stones that are more commonly used in civil engineering structures and road building applications as retaining structures. Research has shown (e.g. Koussa et al, 2013) that gabion barriers can be acoustically effective in terms of both sound transmission and reflection, although this is dependent upon the size/grading of stone used. Their acoustic performance is reduced by the gaps between the stones which allow sound to propagate through the structure, so a solid/absorptive core is often included in the centre of the gabion.

The QUESTIM survey for NRAs sought information on the use of noise barriers on NRA networks. Nineteen NRAs responded to the survey request.

The survey results indicate that in terms of the generic (material) type of acoustic elements, a wide cross-section of types are used on the NRA networks (see **Error! Reference source not found.**). Timber acoustic elements are used by fifteen NRAs, metal acoustic elements by thirteen NRAs, concrete acoustic elements by fourteen NRAs, plastic acoustic elements by eight NRAs, and transparent elements by fourteen NRAs. Other material types, such as earth structures, willow/green barriers or stone gabions, are used by six of the NRAs.

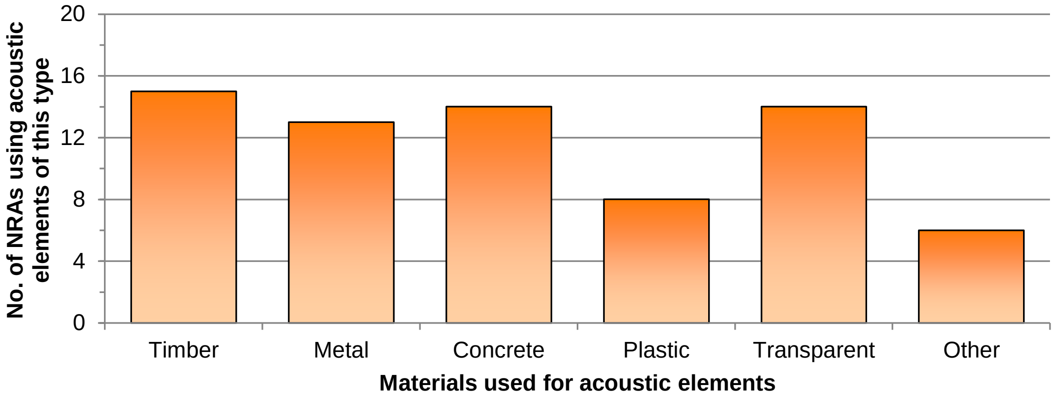

Figure 43: Types of acoustic element used by NRAs (QUESTIM, xxxx)

5.3.2 Bad examples

For many years different noise barriers have been installed by national road administrations all around Europe. Due to time and weather conditions, some degradations 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.

Thanks to the problems on their devices, the road administrations have changed their requirements to improve the durability of their noise barriers. These experiences learnt NRA the importance to take into account the need for future maintenance when deciding on the form of a noise barrier. Noise barriers should be designed to require minimal maintenance. For example, they know that concrete or masonry barriers require little or no maintenance with a service life of 40 years easily achievable, whereas e.g. transparent sections need regular cleaning and may have to be replaced within their service life. Resistance to the elements should also be taken into account, e.g. resistance to ultra-violet light or expansion and contraction of materials where large temperature changes occur.

This chapter gives an overview of bad examples of built noise barriers for different materials and of different parts of the device from different European countries.
By the following the degradations are associated to materials of the barriers. After that specific examples of problems for different parts or configurations of the barrier are given. Finally general aspects like the environmental area or vandalism are also illustrated.

5.3.2.a Materials problems

- *Metallic barriers*

As shown on figures below, rust is the most common default on metallic barriers. Mostly rust is a consequence of an insufficient thickness of galvanizing or the degradation of the coating.

Figure 44 Degradations due to rust

As explained previously, degradations of the coating can occurred and be the starting point of the development of rust. On figures below peeling of the coating on the caissons are observed and will probably evolve to rust over time.

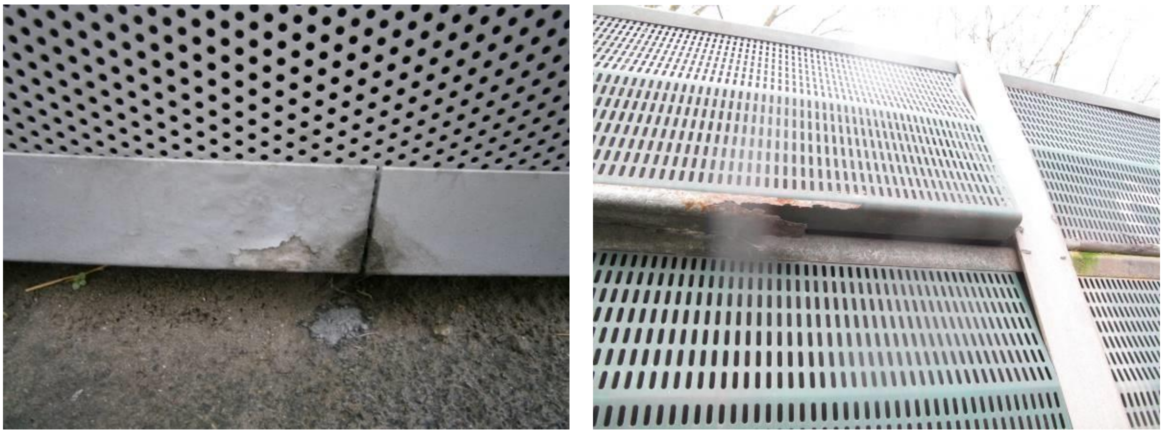

Figure 45 Examples of peeling of coating

Metallic barriers are mostly ’caissons’ devices. Due to their design, humidity at the bottom of these barriers is at the beginning of degradation. This default can evolve and be risk of too much moisture in the absorbing material.

Figure 46 Risk of moisture due to humidity at the bottom of the caissons

Also observed on this kind of device, is the falling down of the caisson and the filling up of the holes by the coating.

Figure 47 Falling down of the caissons (Left) and problem of coating (right)

- *Timber and green barriers*

Due to their design, timber barriers have no protection for the absorbing material. So vandalism and also objects coming from the road can degrade this protection and the material becomes vulnerable. Animals like rodents can also be the origin of these degradations. On figures below examples are given to illustrate this phenomenon.

Figure 48 Degradations on timber barriers

Timber barriers are prone to warping, shrinkage and cracking. Figure 49 shows typical examples of these degradations.

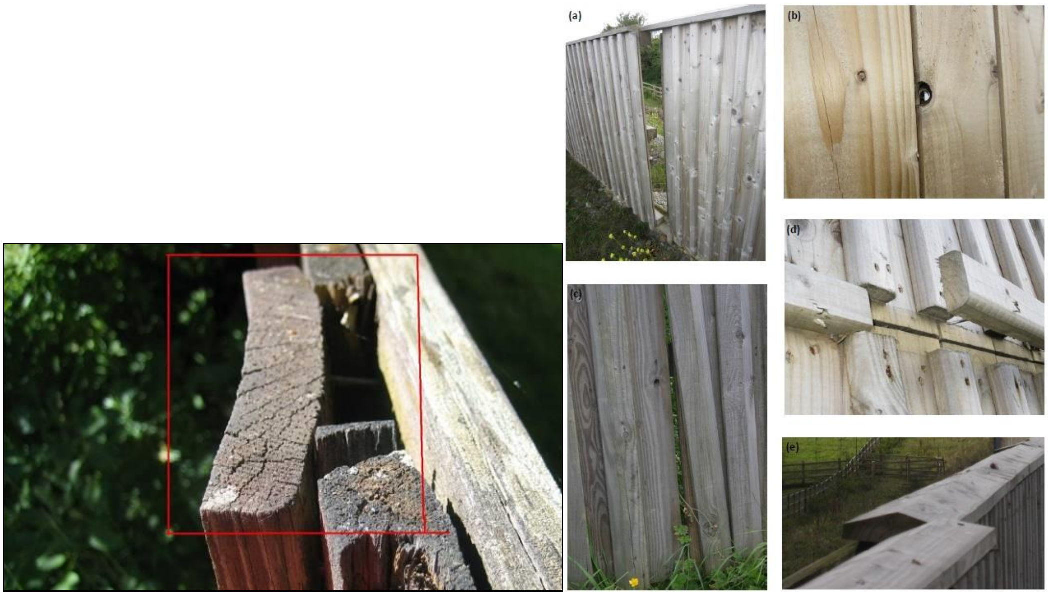

Figure 49 Other degradations on timber barriers

- *<u>Transparent barriers</u>*

The most important damage of this type of device is about degradation of the transparency, due to the dust coming from the road and due to graffiti.

Figure 50 No transparency of barriers

Some NRA observed that cracks can occur on this kind of device.

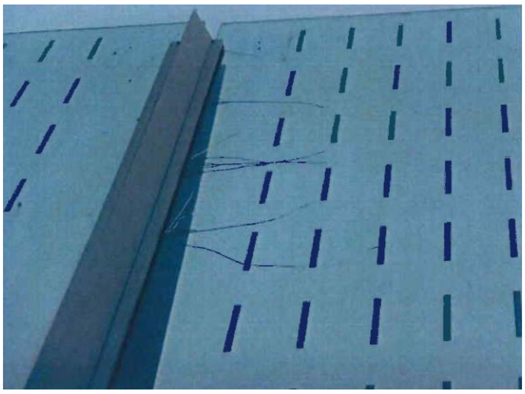

Figure 51 Cracks due to incorrect connections

5.3.2.b Part of the device

- *Absorbing material*

Some cases of the falling down of absorbing materials are illustrated below.

Figure 52 Examples of falling down of the absorbing material

- *Acoustic seal*

Acoustic seal is an important parameter because it has to insure the perfect soundproofing of the device.

Figure 53 Degradations of the acoustic seal

5.3.2.c General problems

- *Vandalism*

Noise barriers are susceptible to vandalism. **Error! Reference source not found.** shows a number of examples of damage caused to noise barriers due to vandalism. When selecting a barrier type, it is important to consider the likelihood of vandalism and selecting an appropriate barrier type accordingly.

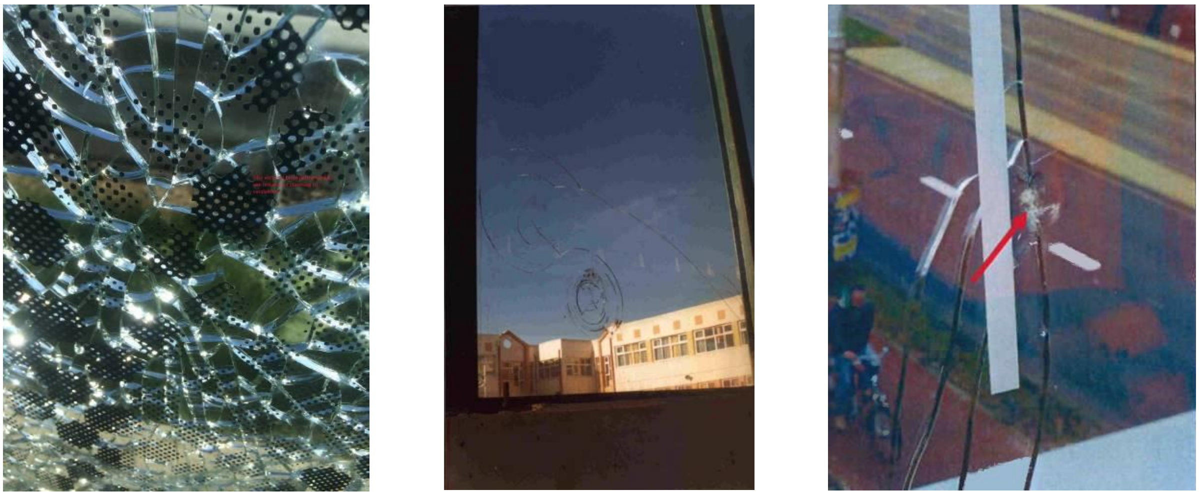

Figure 54 Examples of vandalism on barriers

- *Vegetation*

Planting of vegetation may be used to minimize the visual effect of a noise barrier and to be part of the surrounding landscape. However, vegetation can become abundant and as a consequence make access to noise barriers quite difficult. On several barriers (see Figure 55), vegetation becomes too heavy and the device is damaged.

Figure 55 Degradations due to vegetation

- *Installing problems*

During the installing, it is important to take care of gaps between ground and barrier or between panels. They will be the start of problems with acoustic sealing.

Figure 56 Examples of gaps

- *Emergency exits*

With emergency exits, it is important to be sure that the exit is practicable. Some cases shows that it is sometimes not the case: non-operable exit doors, stairs with no exit door, recovering exits to tight, et cetera.

Figure 57 Problems with emergency exits

- *Insufficient height of barriers*

Examples of insufficient height of the barrier compared to the buildings to be protected.

Figure 58 Insufficient height of barriers

5.4 Design noise barriers (architecture) – List book references

This paragraph gives a list of book references with examples of design constructions of noise barriers:

- **Noise barrier design - Danish and some European Examples**

This report gives examples of noise barriers designed on the background of different design strategies. The report includes noise barriers constructed of many different materials, such as steel, brick, concrete, wood and transparent materials. Earth embankments and various kinds of supported earth embankments are also presented.

Source: Danish Road Directorate, Danish Road Institute, Report 174, 2009

http://www.vejdirektoratet.dk/DA/viden_og_data/publikationer/Lists/Publikationer/Attachments/59/Noise%20barrier%20design%20-%20Danish%20and%20some%20European%20examples%20-%20report%20174.pdf

- **Inspiring examples of noise mitigation measures (Belgium)**

The Flemish Agency for Roads and Traffic and the Flemish Government Architect's Team took the initiative to look for an innovative approach of the noise problem along roads in Flanders (Belgium) by design research. The result is an example book with solutions for recognizable situations in Flanders (Belgium). The example book is based on the results of three workshops organized in 2010 with four design teams. The book summarizes the main results by type of situation for a road (open area, urban area, on bridges, where new development is possible, close to the houses, enough space between houses and road,.etc.).

Source:
http://v4.wegenenverkeer.be/sites/awv/files/bestanden/Geluidswerende%20maatregelen_Voorbeeldenboek%20voor%20gewestwegen%20in%20Vlaanderen_def_0.pdf

- **Good practice guidance for the treatment of noise during the planning of national road schemes (Ireland)**

This good practice guidance is intended to assist road design teams to ensure that noise and vibration is considered in appropriate detail in each phase, including the early stages where potential impacts can often be minimised in the most sustainable manner. In Appendix B, there is a good practice guide for noise barrier design. This section presents observations on current noise barriers in Ireland along with suggestions for good practice in noise barrier design.

- **Modular noise barriers: guideline design and implementation (the Netherlands)**

This manual is intended for all those involved in placing barriers on a national highway to inform and assist with respect to the choices that can be made herewith. The specific barriers are modular because they are designed with a limited number of standard elements: posts in various heights with a variable angle of inclination, with reflecting or absorbing panels of different materials between them.

Source (in Dutch):

http://publicaties.minienm.nl/documenten/modulaire-geluidsschermen-handleiding-configuratie-en-implementa

- **Design of temporary noise barriers to be used in the processes of constructing new roads or other works (Spain)**

CLEAM project (Clean, Efficient and Environmental Friendly Construction) was a national research project leaded by the main Spanish construction companies and fourteen research centres. The study had the following scope:

  - Study of alternative combination of various products made from recycled materials and recycled materials themselves, assessing their advantages and disadvantages. A multi-criteria analysis was applied considering relevant factors: weight, durability, stability, applicability, complexity index, acoustic characteristics, price, ratio price / durability.
  - Material selection of proposals.
  - Physical characterization of materials.
  - Conceptual design of supporting structures that serve as support for the base modules and enable them to adapt to different work environments.
  - Definition of general criteria for the installation of an acoustic screen in a work environment.
  - study about temporary barriers.

Source:

Fernandez, P.; Diez, I.; Eguiguren, JL.; Aspuru, I. “Noise barriers customized to abate non conventional noise sources”. Internoise 2014 Innsbuck

- **Environmental noise barriers: a guide to their acoustic and visual design**

This book examines both the acoustic and landscape issues affecting the design of barriers. The book is a reference for practitioners, acoustic engineers, landscape architects and manufacturers and for highways departments in local and central authorities. It:

- illustrates the wide variety of design solutions for different acoustic and landscape situations in several European countries.
- contains a generous range of full colour photographs.
- provides information on manufacturers, products and services.

Source: Kotzen, B. and English, C. (2009) - *Environmental noise barriers: a guide to their acoustic and visual design.* - Taylor & Francis USA, 2nd edition

- **Design of road traffic noise reducing devices (Finland)**

This report starts with the need for noise abatement and the applicability of various noise reduction methods. It also contains a chapter about the design principles and a chapter about procurement.

Source: Tien meluesteiden suunnittelu 16/2010 (in Finnish); Liikennevirasto.

http://www2.liikennevirasto.fi/julkaisut/pdf3/lo_2010-16_melueste_suunnittelu_web.pdf

- **Optimized noise barriers**

This report contains a state-of-the-art on the international research carried out on noise barriers around the world. It focuses on the acoustic characteristics of the screen rather than on its appearance, design or maintenance. The report points out different types of noise barriers that might be worthwhile trying in Denmark in the coming years.

Source: Gilles Pigasse, Jørgen Kragh. Optimised noise barriers. A state-of-the-art report. Danish Road Directorate, Danish Road Institute, Report 194 – 2011. See: http://www.vejdirektoratet.dk/DA/viden_og_data/publikationer/Lists/Publikationer/Attachments/499/rapport%20194_web.pdf

- **Example noise barrier E6 Lindeberg-Stoyskjerm (Norway)**

Very expensive screen (twice the cost of an ordinary screen), with less difference in noise reducing effect then expected compared to the old screen.

Source: Brekke og Strand akustikk, ref number 2003 17610-7 (in Norwegian)

Figure 59: Example noise barrier E6 Lindeberg-Stoyskjerm (Norway)

5.5 Heights and prices

5.5.1 Heights

The QUESTIM survey results indicate that a wide range of barrier heights are used across the various NRA road networks, as shown in Figure 60. In terms of the minimum permissible height, these range from 1.0 m to 2.5 m. However the variation is more dramatic when considering the maximum permissible height, with a range from 4 m to 10 m or greater. In the case of the tallest barriers, it is considered that these are more likely to be in the form or partial covers, where the upper surfaces of the barrier extend out over some/all of the running lanes, rather than being plane vertical or tilted screens.

In terms of the most common barrier height, the survey results suggest that barriers are typically between 2 and 5 m high.

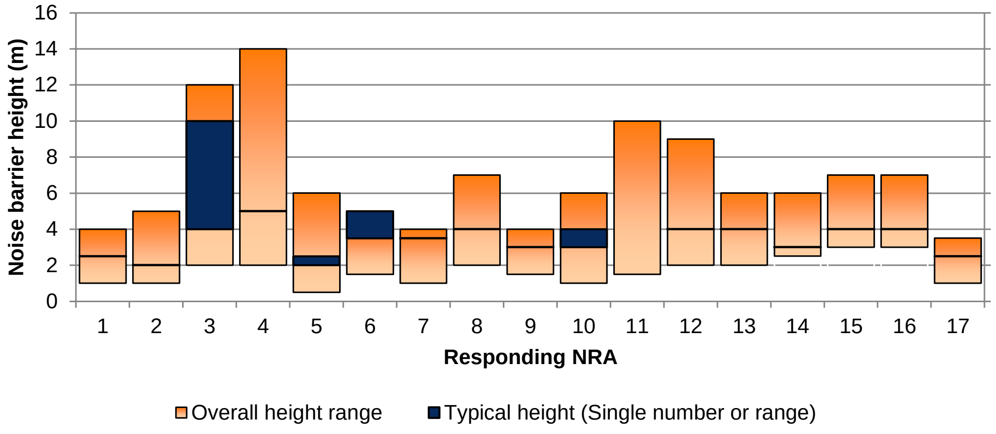

Figure 60: Noise barrier heights used on NRA roads

5.5.2 Prices

It is very difficult to compare prices of noise barriers between the different countries. In the Netherlands e.g. you find only all-in prices. That includes, beside the panels and posts, construction and VAT and also traffic measures and engineering costs. Engineering costs are all kinds of internal NRA costs, like preparing and administration. The all-in price of noise barrier with a height of four meter is EUR_{2013} 2053 per running m.

In Spain and Belgium the average price for a 4 m high barrier is between EUR 1000 and 1200 per m. These prices include panels, installation and posts, without VAT. The price for combined noise and safety barriers is almost the double. In Estonia noise barriers are much cheaper. There barriers are built with an average price (4 m high) of EUR 700 per m (panels, installation, posts and VAT included). For Italy the price for a 4 m high traditional barrier varies between EUR 850 and 1300 per m (panels, installation and posts and VAT included.

In the report 'Value for Money in Road Traffic Noise Abatement' of RN2, the reference price of 4 m high barriers is EUR 1600 per m.

5.6 Noise reducing devices and vegetation

Noise barriers are the architectural elements and should be designed to adapt to their local environments. In fact, if these barriers are not designed for each individual position they are likely to remain foreign and artificial visual elements that reduce the characteristics and the quality of the landscape.

From the point of view of the landscape, this means that the visual quality of a noise barrier should be considered on an equal footing with the noise problem. So, it is important to understand the aesthetic considerations in the design of these structures. This applies whether the noise barrier is a solid wall, a berm, a combination wall and berm, or a planted barrier.

Wherever possible, consideration should be given to accommodating existing vegetation in the design process. Often the removal of vegetation between houses and the road can trigger noise complaints, with residents experiencing a perceived increase in noise, rather than any actual increase. In general. the role of planting in reducing noise is mostly psychological. There is the perception that what is not visible is not audible. So, vegetation can act as a mitigation tool in itself. But it is hard to demonstrate their effectiveness, since they should be investigated through different seasons (full leaves, without leaf, falling leaves) and different plant types (swirl, tree, shrub, etc).

To obtain an extra noise reducing effect (approximately 3 to 5 dB(A)) a dense forest close to the road and with a depth of at least 100m is needed. This means a forest with a variety of high and low trees and bushes so the view is limited to a few meters.

There also some disadvantages using vegetation close to NRD's:

- More maintenance of the vegetation is needed
- It decreases the possibility of inspections
- Vegetation is a source of humidity which can affects the absorbing materials or even concrete barriers
- Vegetation close to a noise barrier deserve extra attention. Trees just in front or behind a barrier with the crest higher than the top of the screen reduce the efficiency of the barrier caused by reflections against the underside of the crest and the leaves so the sound waves reflect over the top of the barrier. The height of vegetation near to the barrier should therefore be limited to the top of the barrier

A number of 'green barrier' systems have been developed, which use living plant material in conjunction with soil-filled supporting structures. The toolbox contains some types:

- earth mounds;
- supported earth mounds;
- bio-barriers;
- vertical green walls.

5.6.1 Earth mounds

An earth mound is an obvious solution to noise pollution in rural areas, because it fits (better) into the landscape more naturally than any vertical structure, especially as it supports planting which improves its appearance in rural contexts.

Earth berms can be a clever way to reduce noise. Berms appear environmentally friendly and may be designed aesthetically pleasant. Applying earth berms makes sense in rural areas where they fit well with the surroundings. They have advantages compared to conventional screens:

1. They have a natural appearance and they may not be perceived as noise barriers.
2. They create an more open area feeling compares to noise barriers.
3. They do not require extra security fence.
4. Costs are lower for construction and maintenance.
5. They have a higher perceived effectiveness.
6. They usually have an unlimited lifespan.

Figure 61 shows a comparison between vertical noise barriers and earth berms. A 4 m high earth berm corresponds, acoustically speaking, to a 3.25 m high noise barrier (H2).

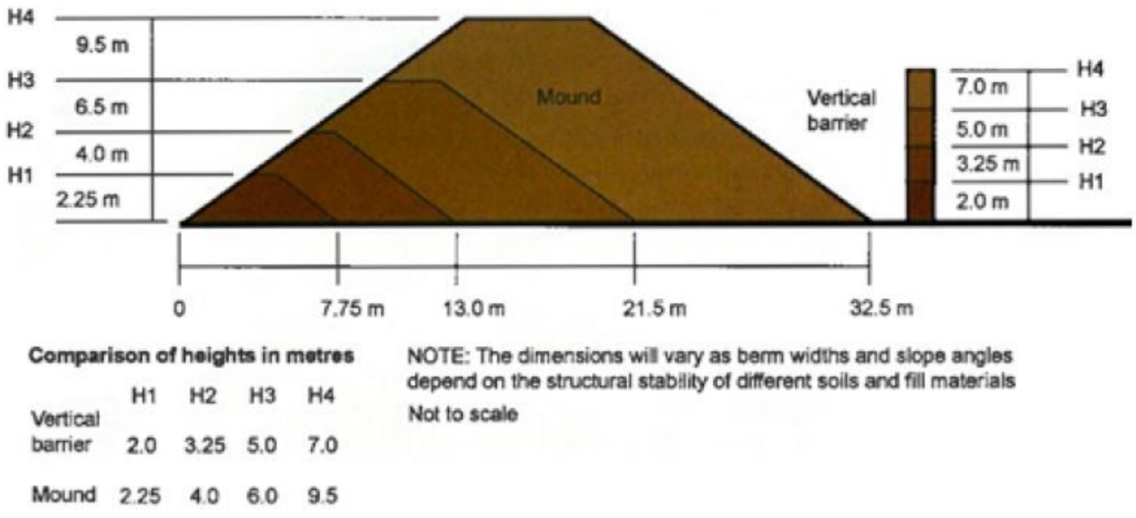

Figure 61: Comparison of the acoustic performance of a vertical noise barrier and an earth berm. A 4 m high earth berm is equivalent, acoustically speaking, to a 3.25 m high screen (H2).

Figure 61 also illustrates the major constraint of using earth berms: they need space. For a earth berm of 4 m high, there has to be at least 13 meter to build one. So, an earth berm will primarily be used in the countryside, where there is enough space to build these noise reducing devices. In the course of a few years, a manmade earth embankment with vegetation will appear to blend in with nature and enhance the natural character of the landscape. And, in the course of time, a planted earth embankment will become a small ecological system, in which various animal species and plants flourish.

Earth embankments advantages have a very long lifetime, limited maintenance cost, and almost no graffiti problems. Furthermore, excess material from other locations, such as soil and stones from construction work, can be recycled by constructing berms for noise reducing purposes.

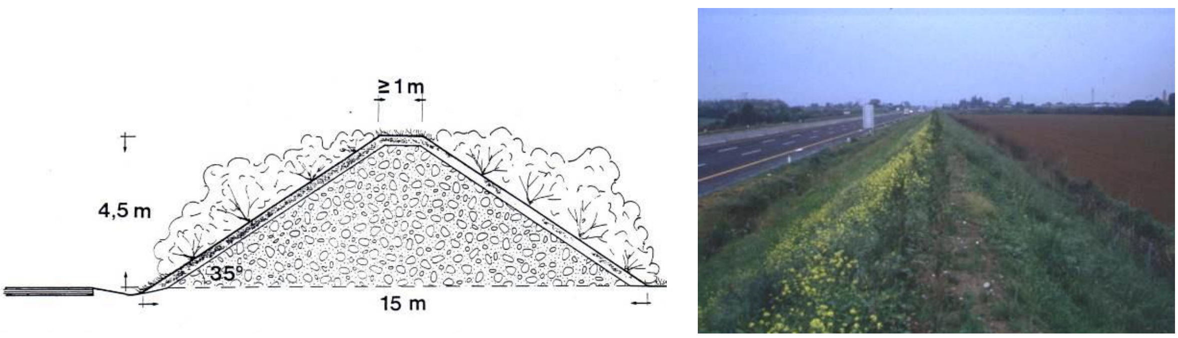

Figure 62: Natural earth embankment

5.6.2 Supported earth mounds

The embankments consist of trapezoidal-shaped soil embankments. In the majority of cases the embankment is made of reinforced soil, which has the advantage of keeping the embankment face almost vertical, with a consequent saving in construction material and reduction of overall size.

The supported earth mounds provide an effective solution to the problems of space mentioned above, while still providing the possibility of an effective revegetation. Also in these constructions, there are many materials employable (metal, synthetic and / or organic fibers).

In the rural context, it will appeal more natural than concrete, but may not be as durable.

Figure 63: Supported earth embankment during the construction and after fully vegetated

5.6.3 Bio barriers

Bio barriers, e.g. barriers designed, to incorporate planting within their structures, are used specifically where there is too little space to incorporate planted earth mounds (Figure 64). A 4 meter high bio barrier can be positioned in a space 2.5 metres wide, whilst a 4 meter mound requires a space of about 14 metres.

The minimal acoustical requirements for sound insulation (EN 1793-2) and absorption (EN 1793-2) are also valid for bio barriers in case they can be tested in an acoustic laboratory. In case they can't be tested, the bio barrier has to be hermetically and a voluminous mass of at least 15 kg/m². When the in-situ test methodology, set out in EN 1793-5 and 6, is used in the procurements bio barriers also have to fulfil.

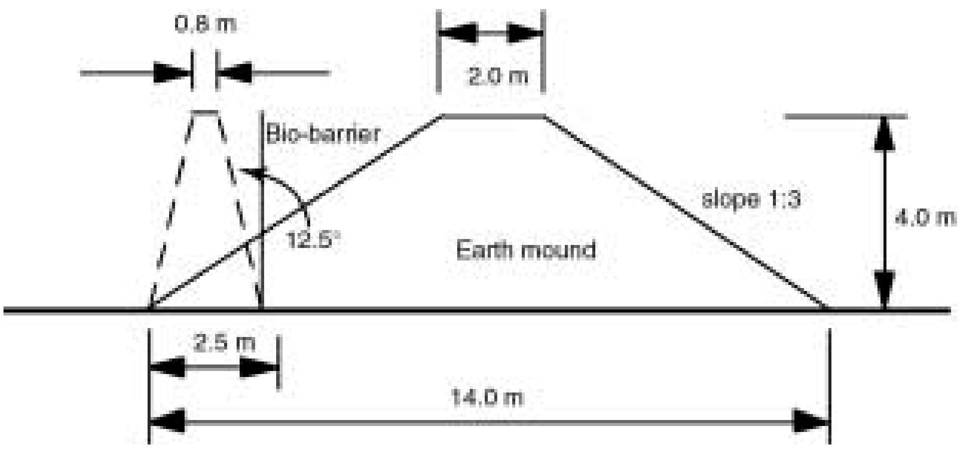

Figure 64 - Comparative land-take-for a 4 metre high earth mound and a 4 metre high bio barrier

They are interesting from the point of view of the use of structural spaces filled with inert and vegetation that allow for an effective sound insulation barrier heights of up to 5 m and with a need for space at the base of 2 - 3 m.

Reinforcement of support bodies earth metals can be in various materials: wood, concrete, steel, recycled plastic. Almost always, they require anchoring to the ground.

The constructive types are very diversified and the success of the green part is intimately connected with a number of conditions that allows vegetation to grown.

Applications of over 20 years in Italy and abroad allow to evaluate both duration and effectiveness of the structural part. It can be summarized as follows:

1. The wooden structures have the advantage of using a material which does not heat and provides open niches that allow a good development of the plants. The nature of the wooden material, however, has presented some problems of lifetime duration.

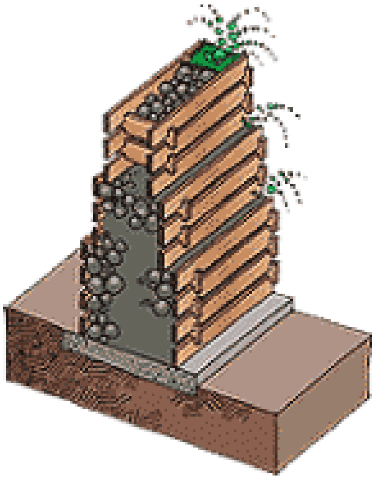

Figure 65 - Bio barrier with wooden structure

2. Concrete structures are optimal from the structural point of view, presenting some contraindication against the use of vegetation due to the heating of the material. This problem is overcome when the plants have developed providing coverage to the structure itself.

Figure 66 - Bio barrier with concrete structure (after the construction and after fully vegetated)

3. The structures in metal supports are valid both from the structural point of view and for the support of the growing plants.


Figure 67 – Different examples of Bio barrier with metal structure (after the construction and after fully vegetated)

4. Other examples of bio-barriers are constructed wholly from recycled materials or use recycled materials as a constituent material within their construction. Whilst most of these are still prototype systems or undergoing on-road trials, some are already commercially available. This type of barrier is constructed from panels or elements which have hollow sections which can be filled with earth/gravel or planted so as to allow vegetation to establish itself on the barrier façade.


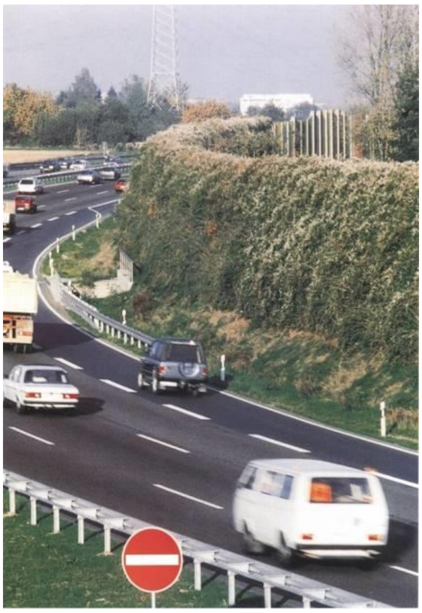

Figure 68 –Bio barrier with plastic structure (after the construction and after fully vegetated)

All types mentioned generally need drip irrigation and the success of the plant cover is linked to:

- ground substrate, use specific soils improved with fertilizer.
- the choice of plant species, preferably use indigenous bush species with pioneer character.

5.6.4 Vertical green wall

A green wall containing low-density soil provides an alternative to more conventional types of acoustic treatment, particularly in the low- and high-frequency ranges. The key concept is to provide a panel containing a stable porous granular medium, manufactured (from the textile, construction, and manufacturing industries), that supports plants that can provide acoustic absorption, water retention, and local climate modification via plant transpiration.

A natural green wall is a new vertical garden system, which saves large quantities of water, fertilizers, and energy. The system consists of small modules which are attached vertically, using a light aluminium frame and organic membranes richly filled with nutrients and favourable microorganisms. The system is highly efficient in terms of irrigation, meaning it does not require excessive care. The plants reach their visual impact within a few weeks after installation.

The construction of the natural green wall can be customised to every building situation and therefore offers a flexible and permanent landscaping solution. In addition, this solution offers the best effects regarding noise control, the retention of particulate matter and the improvement of air quality. Because of these properties, the system is suitable for applications in public places, in traffic route engineering and commercial construction.

They are supplied by an integrated irrigation and fertilization system. This allows for greening, regardless of the underground; even in places where conventional planting is otherwise not possible. Also, once installed in buildings or large surfaces, the system holds other extra advantages, such as:

- an increase of green in urban areas.
- thermal isolation of the building where it is installed.
- better air quality, due to its filtering action for air pollution.
- biodiversity.
- impact on the landscape and great(er) aesthetic and design value.

Concerning the acoustic quality the same remark as for the bio barriers (see section 5.6.3) is valid.

Figure 69 –Vertical green wall (during the construction and after fully vegetated)

6 Innovative barriers

6.1 Combined noise and safety barriers

Integrated noise barrier is a safety barrier and simultaneously serves the function of an acoustic barrier. Generally the vehicle restraint systems (safety barriers) are installed in front of noise barriers to prevent vehicles crashing into them and to prevent debris breaking away from the barrier, causing risks to road users and/or residents. Safety barriers are usually mounted at a distance sufficiently far from the noise barrier, to allow them to deform in case of impact without affecting the noise barrier. This approach requires space between the barrier and the edge of the carriageway which may not always be available.

So for new road schemes or road improvements, integration the noise barrier and the safety barrier into a single structure might be an options. Integrated noise and safety barriers, using both concrete and steel guard rails as the vehicle restraint component, have also shown positive response on safety issues by passing crash tests for safety barriers carried out according to EN 1317-1 (CEN, 2010a) and EN 1317-2 (CEN, 2010b). Even though the separation of the noise barrier and the vehicle restraint is limited; this means that the barriers would comply with the safety in collision requirements within EN 1794-1 (CEN, 2011a).

The noise barrier can be moved closer to the source of noise. This will increase the effectiveness of noise protection significantly. Therefore the height of noise barrier walls can be reduced to further improve the visual appearance at lower costs.

Potential advantages:

- The diffracting edge is moved closer to the road. For instance, a 4 m high noise barrier at 3 m from the source, can be lowered by about 0.5 m if positioned on the edge of the road.
- A lower operating width is needed for their installation.
- Are free-standing, no foundations or anchor to the soil are required needed.

This type of system also offers the potential for installing noise barriers into the central reservation or zones with cables in the soil.

Potential disadvantages:

- Maximum tested noise-safety barrier height is 5 m with metal guardrail and 4 m with concrete safety barriers.
- More expensive than an average noise barrier. When the total cost of safety and noise barriers are considered, combining both barriers is often more economical than two separate ones.

Technical feasibility:

- The concept has been proven in real-world applications and products are already commercially available.

Figure 70: Example of integrated noise and safety metal barrier with steel guardrail

Figure 71: Example of integrated noise and safety concrete barrier with steel guardrail

Figure 72: Example of fully concrete self-standing barrier

The New Jersey profiled safety barrier sits on its traffic-facing footplate. If a small passenger car impacts the integrated noise barrier, the first chain will be active. The flexible New Jersey barrier redirects the car providing a soft impact behaviour. As soon as the impact energy exceeds a certain limit, the second chain becomes effective.

6.2 Photovoltaic noise barriers (PVNB)

Integration of technologies for reducing traffic noise and for generation of renewable energy, delivers several environmental benefits. 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 (PV) modules can be directly integrated in the surface of the barrier or retrofitted or mounted onto the barrier in the form of solar panels. The position of the photovoltaic modules on the barriers depends on the orientation and geometry of the barrier surfaces, which are defined by the sound abatement specifications. Vertical barriers are most commonly used, coupled with an additional tilted surface on the top of the barrier or with other anti-diffraction elements. Sometimes, in order to reach the requirements specified by the design, the road is partially or totally enclosed using a tunnel configuration.

PVNB have been trialled since 1989 (first installation along the A13 motorway in Switzerland) in a range of countries across Europe (pvresources.com, 2013) including Switzerland, Germany, Italy, the Netherlands (van der Borg and Jansen, 2001) and the UK (Carder and Barker, 2006). Germany and, to a lesser extent, Italy have installed the greatest quantity. Installation costs for large PV systems vary between EUR 1500 to EUR 2500 per kW. (Corfield, 2012), currently most likely lower as prices have dropped dramatically last years. A number of commercially produced systems are available. Several test sections and studies give variations in life cycle costs for PVNB. (e.g. Bellucci and La Monica, 2012) and state that PVNB can reduce the life cycle cost of noise reducing devices by up to 30%, based on current case histories, by selling the generated electricity. However this figure depends upon the price, level of public funding for renewable energies, the amount of mounted PV cells and on the PVNB being installed in appropriate climate conditions such as those in Southern Europe. In contrast, results from a pilot project in the UK on the M27 in 2004, resulted in a far less positive message (Carder and Barker, 2006; Carder et al 2007). No proof has been found that driver safety is affected by the presence of the PV cells, or that acoustic nuisance caused by sound reflection on installed PV cells is increased significantly. A feasibility study on PVNB in Belgium (De Schepper et al, 2012) monetized not only economical (including the subsidies for green energy), but also ecological benefits. Taking the latter into account is important to have a positive cost-benefit assessment. It stated that in the case of a decision for a noise barrier, PVNB could form an alternative to promote public-private partnership where government, private investors and residents could all benefit.

Potential Advantages:

Generally, the literature states that the overall gain of generating energy by PV cells mounted on noise barriers is limited with respect to the investment and maintenance cost. However subsidies could make PVNB worthwhile in some conditions, although the latter only means a cost reallocation. The remunerative nature of PVNB could result in a drain on private and public financial resources. Therefore, the costs of PVNB could potentially be shared funding the PV solution/part of the PVNB from the private sector and the basic noise barrier from public expenditure. The possibility of earning money from the production of renewable energy, makes it particularly interesting for the private sector. This is the case, for example, with PV noise barriers built in Italy, which have been constructed with the financial support of private investors. Another advantage of using PV cells mounted on noise barriers is that no supplementary land consumption is needed. Integrating this secondary function with noise barriers could also speed up the decision process for the provision of noise abatement measures, and so have a direct social benefit. The use of PVNB also increases awareness of renewable energy sources for all stakeholders. Last, but not least, the production of renewable energy reduces the amount of CO_2 in the atmosphere.

Potential Disadvantages:

- Maintenance needs and maintenance costs. Modules, inverter and other components should maintained, repaired or replaced, as far as is practicable and depending upon the design, without destroying/removing the noise barrier and with minimum traffic disruption. Cleaning of PV surfaces is a costly operation and as such, not often carried out.
- Theft and vandalism could be also a problem. These problems can be solved with appropriate design strategies (e.g. ensuring robustness, the use of anti-theft bolts, the use of materials which are easily cleaned, etc.) and protecting the barrier location through installation of security fences, cameras, et cetera. However, any requirement for such security measures may count against the use of PNVB in the design or selection phase.

Technical Feasibility:

The concept has been proven in real-world applications and products are already commercially available.

Indicative Cost Band:

PNVB are comparable to or less expensive than an average noise barrier, when considered in terms of lifecycle costs. Initial investment costs are high, but the sale of energy produced can drastically reduce the costs of the barrier, although this is likely to depend on the barriers being installed in locations where energy production is favourable. Experiences have demonstrated that in favourable conditions he cost of the photovoltaic modules is recouped within the service life of the modules.

Potential for use by NRAs:

The concept is proven and could therefore be readily implemented by road administrations. However, it will not be suited to all situations where noise barriers can be used, since the efficiency and scale of energy generated by the PV cells will be dependent upon the orientation of the barrier, number of PV 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 and transfer infrastructure.

Figure 73: Example of noise barrier with photovoltaic modules

6.3 Noise barriers with TiO_2 coating

Nitrogen oxides (NOx) emitted from vehicle exhaust are associated with negative health impacts and are a precursor to ozone. The noise barriers incorporating TiO_2 coatings employ photo catalysis, a chemical reaction in which titanium oxide acts as a catalyst to eliminate nitrogen oxides. When photo catalytic TiO_2 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. The amounts precipitated are minute compared to the limits defined for drinking water.

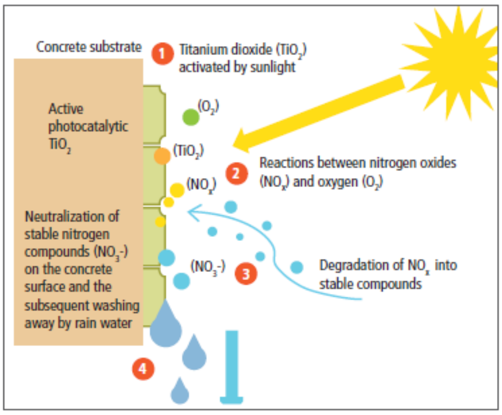

Figure 74: The photocatalytic process

Examples of practical trials on noise barriers incorporating TiO_2 coatings, e.g. the Dutch Air Quality Innovation Programme (Hooghwerff et al, 2009), UK trials on the M60 motorway and field trials in Wuppertal, Germany (Ifang, 2012) have met with limited success. The most likely explanations for the low rate of conversion in the Netherlands were the short contact time between the air and the barrier, relatively unfavourable meteorological conditions (wind direction, light intensity), the high relative humidity and the frequent low temperatures in the Netherlands.

Other studies have been undertaken in Germany (for example, on the A1 near Osnabruck-North and on Krohnstieg in Hamburg; BAST, 2014) although no results from these studies have been identified. A new study in the UK is shortly to commence, which will further investigate the issue using barriers installed specifically for air quality purposes (Highways Magazine, 2014). Trials in the Netherlands (Voogt, 2013) have demonstrated that proving that an air cleaning barrier works is very hard in real life circumstances.

The concept still requires further development and proof of effectiveness before it would be ready for use as a recognised 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.

TiO_2 is commonly used as a white pigment, photo catalytic coating. TiO_2 is mixed into the material used to construct the concrete wall in the noise barrier. In light equivalent to that of a sunny day, 75% of the pollutant gases that come into contact with the coating are eliminated. On a cloudy day, there is enough light to maintain the product's effectiveness. (Eurovia Vinci, 2013).

A important disadvantage is the manufacturing process of TiO_2 coating. It requires chemical procedures that generate pollutants that contribute to global warming and smog formation. Consequently, the expected benefits from the TiO_2 coating could not outweigh the environmental burdens incurred through the manufacturing process.


Figure 75: Example of noise barrier with TiO_2 coating

6.4 Inox/corten steel noise barriers

The use of noise barriers for the protection of housing from road traffic noise sets, beyond the acoustic problem to be solved, the need to harmonize the artefact with the local context, namely the residents and users of road infrastructure. The choice of a noise barrier so in addition to the fundamental motivation acoustics, is also affected by some requirements become essential as the aesthetic, mentioned above, and the performance.

Lately they are developing, especially in Italy, noise barriers made of stainless steel and Corten steel. 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 gray that reduces the visual impact in urban and suburban areas, while the Corten steel assumes a purple/brown colour that integrates more with the rural and suburban landscape.

The Corten steel presents a small advantage when it is exposed to the natural environment. This steel develops a beautiful patina, that serves as protective armour. The steel does not need to be galvanized or painted, reducing the cost. It weathers naturally, so there is very little need for ongoing maintenance after installation.

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

- Safety, connected to the intrinsic qualities of the materials used.
- The mechanical resistance and stability, according to the recent international standards for both static loads (weight of the structure, weight of the elements, snow) and dynamic loads (wind, pressure following the passage of vehicles, snow load, collision of vehicles).
- The durability of both materials of protective coatings, taking into account that the road environment is highly aggressive.
- Maintenance, meaning accessibility work, modularity of components, design and programming of maintenance activities, including the removal of graffiti.
- Environmental sustainability, including the possibility to reuse after the useful life.

Figure 76: Examples of Inox steel noise barriers

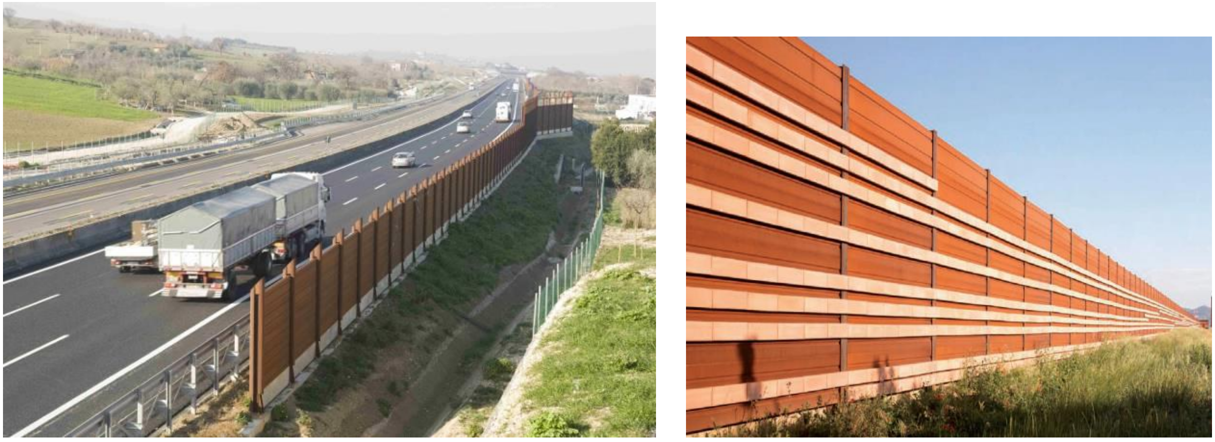

Figure 77: Examples of Corten steel noise barriers

6.5 Sonic crystals

One of the major impulses to work on sonic crystals as noise barriers was the discovery that a sculpture consisting of periodically arranged arrays of cylinders of same radius but different lengths had been capable of complying with the acoustic performance specifications requested by many NRAs. These barriers are structures of circular cylinders scatters periodically arranged in a lattice with a vertical and horizontal alignment. They forbid sound propagation for some frequency bands, named bandgaps, in a manner similar as semiconductors forbid the transmission of electronic waves of some energy bands. The physical mechanism behind the formation of bandgaps is the interference between sound waves. These barriers are made of rigid cylinders and show a strong attenuation of the transmitted sound only at bandgap frequencies. The sound attenuation characteristics of a sonic crystal can be tuned by appropriate selection of the lattice constant and cylinder radius.

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

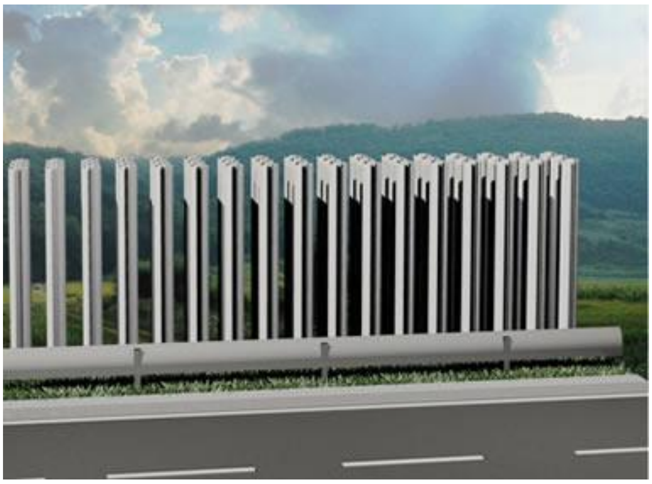

Figure 78: Example of Sonic crystals noise barrier

6.6 Other measures of noise abatement

The following represents different kind of measures of noise abatement that can be applied along existing.

6.6.1 Buildings as noise barriers

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.

In Denmark a new district of row houses constructed along an existing highway using secondary buildings like garages, carports, bicycle sheds, laundry buildings et cetera as parts of noise barriers facing the road.

Figure 79: In Denmark a common carport facility was constructed as a two storey high noise barrier

6.6.2 Coverage or tunnels

The effectiveness of a barrier is limited to buildings in shadow relative to the source. In practice, this means that the effectiveness of the barriers is limited to those housing to which the barrier takes away the view of the vehicles in transit.

If it becomes necessary to increase the effectiveness of shielding structures, it is possible to create closed configurations (artificial tunnels, coverage). A cover is a noise reducing device, which either spans or overhangs the highway, and obstruct the direct transmission of airborne sound emanating from road traffic. Covers will comprise both acoustic and structural elements. However, covers are very impactful solutions, expensive and hard landscaping. They are applies only in extreme cases, for example, a critical area extended constituted by tall buildings close to the infrastructure.

Application of these noise reducing devices could be found in Italy and the Netherlands. The acoustic cover created with baffles permits to reduce the sound reflected by the walls, ensures a ventilation of exhaust fumes and requires no internal lighting or ventilation system.

Figure 80: Examples of coverage created with baffles, the right photo shows an integrated road safety barrier

6.7 Conclusion innovative barriers

Table 3 summarizes the different innovative barriers looking at the technical feasibility (ready for implementation by NRAs), the financial impact (estimated supplementary cost compared to a conventional noise barrier), the advantages and disadvantages and the potential use for a NRA (colour green, yellow or red).

Description of the innovative barrier	**Technical feasibility**	**Financial impact**	**Positive**	**Negative**	**Potential use for NRA**
Combined noise and safety barriers	Now	-	space-saving free-standing	Higher cost	
Photovoltaic noise barriers	Now	= to -	generation of renewable energy	Maintenance and overall cost	
Noise barriers with TiO_2 coating	Near	--	Health issues	Efficiency and higher cost	
Inox/corten steel noise barriers	Now	--	Good material and positive perception by the population	Higher cost	
Sonic crystals	Future	?	Open barrier and visually attractive	Further research is needed	
Buildings as noise barriers	Now	= to -	Good solution	/	
Coverage/tunnels	Now	---	Impactful solution	Very expensive and hard landscaping	

Green means 'suitable for widespread use on an NRA road network'
Yellow means 'suitable for restricted use on an NRA road network'
Red means 'not ready for implementation'

Table 3: Conclusions innovatie barriers (based on the results of the report DISTANCE D3.1)

7 Summary

The subgroup report on noise barriers presents a general overview of the domain of noise barriers used along European roads. It primarily focuses on the collation, dispersion, implementation and use of results from research and development of noise barriers from:

- recent innovative research projects undertaken within specific CEDR member countries;
- the reports QUESTIM and DISTANCE from the CEDR Noise Call 2012.

The main purpose of the report is to make such results available and known to all the CEDR member countries. The report intends to assist each NRA in the planning, building and maintaining processes of noise barriers for new and existing road infrastructure. The following summarizes what the subgroup considers as the main findings of the report and describes also the main recommendations.

7.1 Conclusions

- *clarification of the noise level reduction achievable with a noise barrier*

Barriers are constructed from a wide variety of materials and designs, but all serve the same basic purpose: to reduce noise levels at noise sensitive receivers by influencing the propagation path between the source and the receiver. The noise reduction of 10 dB(A) is obtainable at ground level in the area closely behind a barrier of considerable height with sufficiently insulation value and absorption value. Noise barriers are relatively ineffective at more than 250 m distance from the road, the L_{Aeq} reduction is limited to a few dB(A). Informing the citizens about the reducing effect of a new noise barrier, with information meetings, brochures, noise maps, audiotape, et cetera, is important to avoid misunderstandings afterwards. People 'behind' new noise barriers do get (much) lower noise levels, but it will not become silent.

- *check the acoustic characteristics of a noise barrier*

The aim of NRAs is to build durable noise barriers with sufficient noise reduction, low costs and almost no maintenance. Using the acoustical requirements listed below in tenders or public procurements, helps in achieving this. Noise barriers should have:

- product specifications, like acoustic performance and CE markings, based on the European standard EN 14388;
- a minimum absorption value DL_{α} of at least 10 dB, based on the European standard EN 1793-1;
- a minimum minimum sound insulation DL_R value of at least 25 dB, based on the European standard EN 1793-2;

Currently, the sound transmission and absorption characteristics of a noise barrier are determined using laboratory based tests (EN 1793-1 and 2). In the future, the in-situ test methods (EN 1793-5 and EN-1793-6) will be the reference.

- *check the conformity and the correct installation of a new noise barrier in situ*

Despite good results in laboratory, the problems often arise during and after installation. The weakest points are the joints between panels, foundation and posts.

To ensure that the noise barrier is fit for purpose and to avoid problems later on, it is necessary to undertake some form of assessment, like a form of project sign off or a declaration of conformity and completed installation, to check compliance with the contract specifications of the new noise barrier. Visual and audible inspections are the minimum. When the in-situ test methods EN 1793-5 and EN 1793-6 will be the reference, they can be supplemented by acoustic assessments if necessary.

- *monitor the condition of the noise barriers*

It is also important that the barriers fulfil not only the acoustic requirements after installation, but also maintain their acoustic performance characteristics for a reasonably long lifetime. It has identified that there is a lack of published data on the long-term acoustic in-situ performance of noise barriers. Further noise measurement data are required, even though acoustic degradation over time is not an issue yet.

Besides the long-term acoustic performance, it is also important to monitor the actual condition of the noise barriers. So, undertake regular monitoring programmes for the barriers on your network, in order to get basic information on the future maintenance cost. Do regular visual surveys with appropriate acoustic and/or structural test methods.

NRAs must be represented in the CEN standardization working group “TC226 (road equipment) / WG6 (noise reducing devices)” to have an adequate knowledge and to follow-up the developments of the standards and test methods. Also to indicate the advantages (mainly safety reasons) if test methods could be implemented without the need for operators and/or equipment to be static on the carriageway side of the barrier.

- *take into account the possibility to use a innovative noise barrier*

in addition to noise mitigation, innovative noise barriers use innovative designs or materials for the construction of the acoustic elements or have additional functions, like power generation. Suitable for widespread use on an NRA road network are buildings as noise barriers. Suitable for restricted use are the combination of noise and safety barriers, photovoltaic noise barriers, inox/corten steel noise barriers and the partial or full covering of a road.

- *possible topics for the CEDR Call 2018*

Based on the conclusions of this subgroup report, the following topics are possible for research in the CEDR Call 2018:

- how to improve the long-term quality of noise barriers;
- how to combine in-situ measurements with inspections to improve the quality of noise reducing devices;
- how to improve in-situ test methods, without the need to use the carriageway side of the barrier for operators and/or equipment (for safety reasons);
- how to ameliorate the correlation between the in-situ test methods EN 1793-5 and -6 and the laboratory based methods;
- how to solve the lack of published data on the long-term acoustic in-situ performance of noise barriers.

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Ref: CEDR Technical Report 2017-01 State of the art in managing road traffic noise: noise barriers
ISBN: 979-10-93321-27-1

Conférence Européenne des Directeurs des Routes
Conference of European Directors of Roads

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ISBN 979-10-93321-27-1
9 791093 321271