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QUESTIM

Assessing the acoustic durability of noise barriers on NRA road networks

Deliverable 4.1, March 2014

QUietness and Economics STimulate Infrastructure Management

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CEDR Call2012: Noise: Integrating strategic noise management into the operation and maintenance of national road networks

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Assessing the acoustic durability of noise barriers on NRA road networks

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Executive summary

Noise barriers are the most widely used form of noise mitigation on European roads managed by National Road Administrations (NRAs). Barriers are manufactured/constructed from a wide variety of materials and to different designs, but all serve the same basic purpose, namely to reduce noise levels at noise sensitive receivers away from the roadside, e.g. at residential properties, by acting upon the sound propagating away from the road by influencing the propagation path between the source and the receiver.

It is important for NRAs to have a robust understanding of noise barriers selected for use on their networks so that there is confidence that the barriers fulfil not only their acoustic function and structural design requirements in accordance with any NRA specifications, contact specifications, etc. but also maintain their acoustic performance characteristics for a reasonably long life with minimal maintenance wherever possible.

This report has been prepared within Work Package 4 of the QUESTIM project with the objective of providing information to NRAs on the acoustic durability of noise barriers and recommendations for the assessment and monitoring of performance.

Standardised tests have been developed for characterising the acoustic performance of noise barriers and other road traffic noise reducing devices and embedded into European standards and thereby the European harmonised specification standard that specifies the performance requirements and methods of evaluation for road traffic noise reducing devices. These test methods focus on **intrinsic** and not **extrinsic** characteristics of performance, i.e. the performance of the individual materials or components rather than on how the product is used, since extrinsic measurements will be dependent upon factors such as barrier geometry, topography and distance from the road/noise sensitive receivers.

This means that the definition of acoustic durability used in European standards and by noise barrier manufacturers and suppliers as part of a product's CE mark may differ from general NRA expectations of acoustic durability, which may be more aligned with whether or not a noise barrier maintains noise levels at the noise sensitive receivers screened by it over its working lifetime.

A review of data from noise barrier manufacturers/suppliers and research data has identified only minimal acoustic data exists related to changes in acoustic performance over the working lifetime of noise barriers, irrespective of whether laboratory or in situ test methods are considered.

Many types of noise barrier are considered to be acoustically durable over their full working lifetime and where manufacturers/suppliers do actually specify lifetime performance, this is typically in terms of absolute service life in years. What acoustic data is available is insufficient to allow time-dependant relationships between barrier age and acoustic performance to be derived.

It is recommended that visual inspections of noise barriers should be undertaken on an annual basis and key defects/failures that should be looked for have been identified.

In terms of acoustic assessments, where these are undertaken, it is recommended that the test methods defined in EN 1793-6 and the forthcoming EN 1793-5 should be used. This will allow assessment against the initial acoustic performance and lifetime performance values (if the latter exist) declared by a manufacturer as part of the CE mark for the noise barrier. However, it is recognised that there are practical issues that may prohibit the use of the technique at any location. Proposals have been set out for the frequency of monitoring using these methods. Where it is preferred to assess long-term performance in the far-field, at noise sensitive receivers screened by the barrier, then methods such as ISO 10847 or other standard methods for assessing environmental noise should be used.

It has been concluded that the addition of lifetime acoustic performance data within Pavement Management Systems (PMS) is not feasible or beneficial due to the lack of existing data and the difficulties of relating intrinsic characteristics to far-field noise levels in a manner that could be simply implemented without any noise mapping/modelling. However, the use of PMS as a broader data repository for noise barrier records, so that asset information is held within a common location is recommended and proposals set out for the type of data that could potentially be incorporated.

1 Introduction

Noise barriers are the most widely used form of noise mitigation on European roads managed by National Road Administrations (NRAs) and can therefore be considered as primary assets on their networks. Noise barriers are manufactured/constructed from a wide variety of materials and to different designs, but all serve the same basic purpose, namely to reduce noise levels at receivers away from the roadside, e.g. at residential properties, by obstructing the direct transmission of sound propagating away from the road and so influencing the propagation path between the source and the receiver.

As with any major NRA asset, e.g. pavements, signing structures, etc., these barriers require management and, in some cases, maintenance to ensure that they continue to serve their function. In practice, relatively little is known about the acoustic durability of the barriers and in many cases, maintenance is only undertaken in cases of structural failure or significant damage.

It is therefore beneficial for NRAs to have an understanding of noise barriers used on their networks so that there is confidence that

- existing barriers remain fit-for purpose or can be clearly identified when this is no longer the case, and

- new barriers, installed either as replacements or as part of new mitigation schemes, are fit-for-purpose, durable and cost-effective.

This means having data and assessment methods/procedures to allow NRAs the potential to ensure that noise barriers on their networks, particularly new and future installations

- fulfil their acoustic function and structural design requirements in accordance with any NRA specifications, contact specifications, etc., and

- maintain their acoustic performance characteristics for a reasonably long life with minimal maintenance wherever possible.

The key parameter in achieving this understanding is acoustic durability, i.e. how the acoustic performance of the noise barrier changes over time.

Common, standardised assessment methods and performance indices have been developed over time which better allow the specification of products on the part of both manufacturers/suppliers and those who procure/specify noise barriers for roadside noise mitigation, but the scale to which these are used has varied.

It is noted that these methods and indices relate to the performance of the products themselves rather than to the noise reductions at noise sensitive receivers being screened by the barriers.

This report has been prepared within Work Package 4 of the QUESTIM project with the objective of providing information to NRAs related to the acoustic durability of noise barriers

and recommendations for the assessment and monitoring of performance. A second objective was to establish the existence of data that could be used to allow noise barriers to be included within the concept proposals for a modified Pavement Management System (PMS) being developed within Work Package 5 of the QUESTIM project; such a system would better allow NRAs to address monitoring and maintenance of noise mitigation assets within their existing maintenance regimes.

1.1 The QUESTIM noise barrier survey

In order to assist in understanding current practices regarding the specification, manufacture, procurement, installation and monitoring/maintenance of noise barriers on NRA road networks and to gain real-world data where possible, a comprehensive survey consultation was proposed with both NRAs and industry. This information would serve to inform the recommendations produced within the Work Package.

The consultation was undertaken using specifically designed questionnaires (see Appendices A-C of this report for examples of the questionnaires), compiled through collaboration between TRL's Noise and Vibration Team and TRL's Psychology Team, the latter having long-standing experience in the development and undertaking of such surveys.

The survey was undertaken over a 4 month period from May-August 2013 and was conducted as follows:

- **National Road Administrations:** The NRAs in all 24 of the EU Member States comprising the CEDR membership were contacted (either directly by the QUESTIM consortium or indirectly via the Secretary of CEDR).

  Responses were received from 19 different NRAs.

- **Industry:** Industry contacts were identified from a range of sources, including

  - existing contacts within the QUESTIM consortium,
  - contacts identified via the QUIESST project (these were provided as a comprehensive list of email addresses, although it was not possible to clarify in advance of the survey as to whether all of these addresses were still valid), and
  - contact through the CEN (European Committee for Standardisation) standards Working Group CEN/TC226/WG6 (Noise Reducing Devices) of which one of the QUESTIM consortium members is the convenor.

  Since it was not always clear whether the contact company was a manufacturer, supplier or installer, no breakdown of the issued invites is possible.

  A total of 165 invites were issued (covering at least 132 companies in 10 EU Member States). Where contacts were found to be invalid, alternative contact points were sought where possible and reminders were sent out to all invitees well in advance of the closing date.

Disappointingly, the majority of those contacted chose not to respond to the survey; complete responses were received from 15 manufacturer/suppliers and 3 installers.

There were occurrences where either responses were partially completed but contained no data of benefit or where the questionnaire had been opened by the invited party but not completed at all. In both situations it was not possible to determine the identity of the individual opening the questionnaire.

However, the main barrier types used by NRAs were covered by the complete survey responses and, particularly in relation to declared acoustic durability characteristics, it is not expected that the reported findings would have been different with a greater level of response.

The information collated from the survey responses is presented, as appropriate, throughout the main body of the report.

1.2 Structure of the report

The report is structured as follows:

- Chapter 2 outlines the terminology that will be used throughout the report, describes the different mechanisms that affect the acoustic performance of a noise barrier and presents an overview of the types of noise barrier used on NRA road networks. In addition, information is presented on innovative noise barrier solutions that might offer alternatives to conventional noise barriers.

- Chapter 3 addresses methods for assessing the acoustic performance of noise barriers; the primary focus is on standardized methods, such as those included within European (EN) standards, although research-based methods are included. How NRAs specify noise barrier performance for procurement purposes and how manufacturers/suppliers declare the acoustic performance of their products are also discussed.

- Chapter 4 specifically addresses noise barrier durability with a particular focus on declared data. Causes for the loss of acoustic performance and mitigating measures are also discussed, together with findings on the monitoring and maintenance of noise barriers.

- Chapter 5 presents recommendations on methods/approaches for assessing in-service noise barrier performance and for monitoring performance over the working lifetime of barriers. The use of noise barrier-related data within PMS is also discussed.
- Chapter 6 presents a summary of the work and the conclusions reached within the study.

- Appendix A presents the QUESTIM noise barrier survey questionnaire that was disseminated to NRAs.

- Appendix B presents the QUESTIM noise barrier survey questionnaire that was disseminated to noise barrier manufacturers and suppliers.

- Appendix C presents the QUESTIM noise barrier survey questionnaire that was disseminated to noise barrier installers.

2 Noise barriers: An overview

This Chapter outlines the terminology that will be used throughout the report, describes the different mechanisms that affect the acoustic performance of a noise barrier and presents an overview of the types of noise barrier used on National Road Administration (NRA) road networks. In addition, information is presented on innovative noise barrier solutions that might offer alternatives to conventional noise barriers.

2.1 Standard terminology

For the purposes of this report, the terminology used will be consistent with that in the harmonised European standard for road traffic noise reducing devices, EN 14388 (CEN, 2005; see Section 3.1 of this report) and is as follows:

Noise Reducing Device (NRD): This is a device designed to reduce the propagation of traffic noise away from the road environment. This may be a noise barrier, cladding, road cover or added device. These devices may include both acoustic and structural elements.

Noise barrier: An NRD which obstructs the direct transmission of airborne sound emanating from road traffic. These are typically constructed from both acoustic elements and structural elements, where

- an **acoustic element** is an element whose primary function is to provide a noise reducing device with sound insulation, diffraction and/or sound absorption characteristics, and

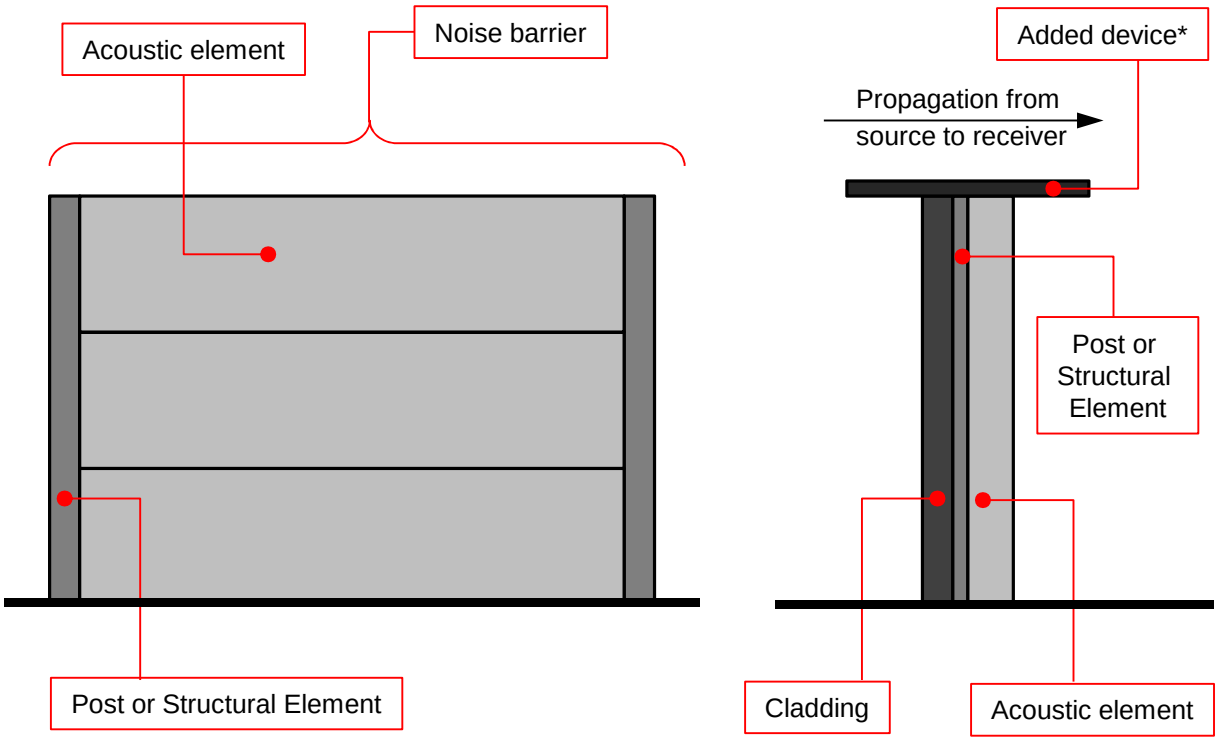
- a **structural element** is an element whose primary function is to support or hold in place the acoustic elements. Depending upon the design/materials used in the construction of the noise barrier, structural elements may not be required as the acoustic elements themselves have appropriate structural stability to be self-supporting.

Cladding: This is a noise-reducing device, which is attached to a wall or other structure and reduces the amount of sound reflected; claddings are made of both sound absorptive acoustic elements and elements that support those.

Cover: This is a noise-reducing device, which either spans or overhangs the highway, and obstructs the direct transmission of airborne sound emanating from road traffic. Covers will comprise both acoustic and structural elements:

Added device: This is an added component that influences the acoustic performance of the NRD to which it is fitted. Devices are generally fitted on the top and serve primarily to affect diffracted sound energy, typically by moving the position of the leading diffracting edge closer to the source. As such, they often change the cross-sectional profile of the overall NRD, e.g. from a plane vertical screen to a T-shape barrier.

Figure 2.1 on the following page illustrates how these different components are used for the construction of a roadside noise barrier.



* If the added device extends out over the road it becomes a cover

Figure 2.1: Noise reducing devices (NRDs) as defined in EN 14388:2005

2.2 Factors affecting acoustic performance

There are three mechanisms which influence the acoustic performance of any noise barrier. These are illustrated in Figure 2.2 and can be summarised as follows:

- **Sound diffraction:** 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 relative to the screening position is a significant characteristic.

  The use of added devices on the tops of barriers can help to reduce the diffracted sound propagating into the shadow zone. Depending upon the design, these can enhance the overall noise reduction with minimal increase in height and work by either moving the position of the leading diffracting edge relative to the source and/or may include surfaces treated with sound absorptive materials. The use of such devices is not widespread due to the difficulties of taking them into account in many noise prediction models.

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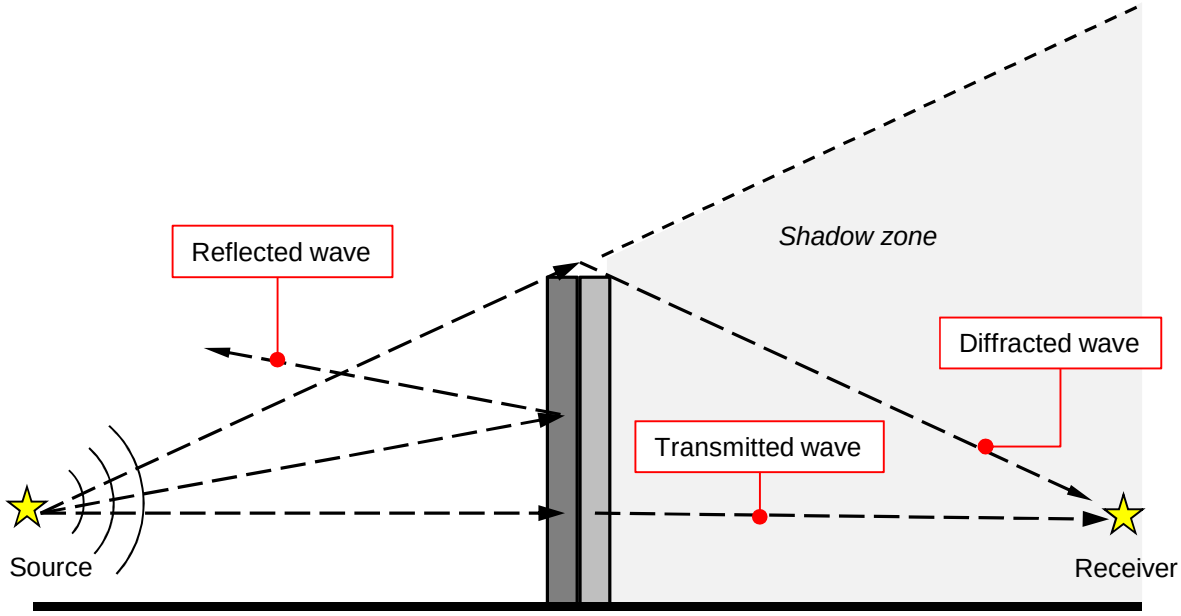

Figure 2.2: Mechanisms affecting noise barrier performance

- **Sound transmission:** This is where sound is transmitted through the noise barrier. Noise barriers should therefore be constructed from sufficiently dense material(s) to reduce propagation through the barrier; densities of the order of 15-20 kg/m^2 or greater appear to be sufficient for this purpose.

  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.

  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 3.2). Research has shown that there is potentially a good correlation between the two indices.

  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 2mm) to simulate leakage due to shrinkage of the wood. The board fence used 125 x 22mm boards with a 12mm 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 22mm 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 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 2.4-3.5m) installed at four roadside sites and included the effects of two or five 0.1m x 0.1m holes close to ground level and large gaps at/close to ground level ranging from 0.06m x 40m to 0.4m x 60m. At receivers close to the barrier (2m away, at a height of 1.5), the openings resulted in an increase in sound pressure level of up to 3 dB relative to the barrier without holes/gaps; at receivers up to approximately 7m away (at heights from 1.5-1.8m), the openings resulted in an increase in level of up to 1.3 dB; at receivers approximately 20m way, the openings resulted in an increase in level of up to 0.5dB. A further scenario, based around multiple vertical slits in a 2.5m high barrier constructed from vertical, overlapping wooden planks (where the slits were created every third plank by pulling the bottom of the plank 100mm outwards from the barrier), resulted in an increase in level of 2.3 dB at a distance of 7.5m from the barrier and a height of 1.8m.

A study reported by Watts (1999b) also investigated the effects of holes, focussing on an evaluation of timber noise barriers and comparing practical measurements with numerical model predictions. The results indicated that for noise barriers up to 3m high, the reduction in noise level behind the barrier due to the holes was not significant (less than 1dB) at distances greater than 20m from the barrier; this increased to 2 dB at larger distances for 6m high barriers. Watts derived an equation for predicting the reduction in screening performance, Δ, given by

$$\Delta = 10\log\left[1+\frac{2Gh}{\pi}\frac{(d_s+d_r)}{dsdr}10^{-B/10}\right] \qquad (2.1)$$

where d_s and d_r are the horizontal distances from source to barrier and from barrier to receiver respectively, G is the fraction of the barrier with air gaps, h is the height of the barrier and B is the potential barrier correction from the UK road traffic noise prediction model Calculation of Traffic Noise (CRTN; Department of Transport and Welsh Office, 1988).

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.

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 CEN/TS 1793-5 (see Section 3.2.2). 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 3.2.2) 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.

- **Sound reflection/absorption:** The reflection of sound from the face of a noise barrier will be heavily influenced by the geometrical shape of the barrier. As such, one way of reducing the effects of sound reflection is to use non-flat or inclined surfaces. The effects of using inclined noise barriers are well documented in the literature.

  An alternative and more common method for addressing the effects of sound reflection is to incorporate sound absorptive materials within the barrier design, either as claddings or integral components. Whilst sound absorptive materials can be found on both faces of a noise barrier, they are most commonly used on the traffic facing side of the barrier. The greatest benefits are achieved when there are noise barriers on both sides of the road, where the use of absorptive materials will reduce the impact of multiple reflections between the barriers.

  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 3.2); typically a good absorber would have a DL_{α} value of at least 8 dB(A). 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 (see Section 3.2).

  In order to ensure the acoustic performance of the materials over any declared acoustic lifetime, it is therefore important that these materials be durable with respect to the environmental conditions that may be experienced at the roadside e.g. moisture, salt used during winter maintenance, freezing temperatures, etc., protected as appropriate, and remain structurally intact, i.e. not collapse either under self-weight or due to the additional weight of moisture/dust, over their working lifetime. At the time of writing, no data have been identified which quantify any changes in the

acoustic performance of sound absorptive materials on noise barriers over lifetime due to factors such as clogging.

When discussing the **overall performance** of noise barriers, particularly in relation to screening at the noise sensitive receivers protected by the barriers, the level of noise reduction is often referred to in terms of **insertion loss**; this is defined as being the difference in the noise level at the receiver with and without the barrier present.

2.3 Common types of noise barrier

The following descriptions provide a short overview of the different types of noise barrier that are most commonly found alongside NRA roads, as identified from the NRA responses to the QUESTIM noise barrier survey.

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, and the perception and acceptance of the structure by the general public.

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. Examples of this type of barrier are shown in Figure 2.3.

(a) Single-left reflective (b) Double-leaf reflective (c) Sound absorptive

Figure 2.3: Examples of timber noise barriers

Metal acoustic elements: Metal acoustic elements are typically cartridge/cassette-type panels constructed from aluminium or steel 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 2.4.

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Figure 2.4: Examples of metal noise barriers

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/photographs can be digitally printed onto the surfaces of the barriers, thereby offering the scope to completely change the appearance of the barrier and thereby 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 manufactures as a wood-fibre/cement composite. Such panels are frequently profiled to increase the surface area of the concrete and 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 2.5.

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Figure 2.5: 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, etc. Examples of this type of barrier are shown in Figure 2.6.

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Figure 2.6: 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 2.7 on the following page.

Figure 2.7: Examples of plastic/composite noise barriers
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Other types of acoustic elements: These include the following:

- **Soil structures:** Earth bunds are widely used at the sides of motorways to provide screening where there is sufficient space within the road corridor. Generally, for the same height as a simple noise barrier, earth mounds are less efficient at screening noise. This is because the base of the mound is relatively wide so the top cannot be placed as close to the traffic source as would be for the plane screen. Research on such structures has been reported, for example, by Watts (1999a) and Van Renterghem and Botteldooren (2012).

  Vegetative barriers: Such barriers are usually made from living vegetation, but are not hedges. Typically they are either manufactured from living willow or woven willow panels and may include an acoustic core. Such barriers enhance the aesthetics of the environment as they provide a contrast to conventional 'hard' man-made surfaces. Such barriers may require irrigation and regular maintenance to manage the vegetation growth. Other types of vegetative barriers include panels manufactured from coco-fibre where a noise insulating plate is mounted between the panels. Examples of this type of barrier are shown in Figure 2.8.

(a) living willow barrier
Reproduced with permission of Cheviot Trees Ltd

(b) living & woven willow barrier
Reproduced with permission of Cheviot Trees Ltd

(c) Coco-fibre barrier
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Figure 2.8: Examples of vegetative barriers

- **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. This type of structure will be self-supporting.

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Figure 2.9: Examples of stone gabion noise barriers

2.4 Application of noise barriers on NRA road networks

The QUESTIM survey for NRAs sought information on the use of noise barriers on NRA networks. Information was sought on the scale of use (including whether or not noise barriers are the primary choice of noise mitigation measure), as well as the type and dimensions of barriers used. Nineteen NRAs responded to the survey request. The findings are summarised below.

Noise barriers as a primary mitigation measure: Thirteen of the responding NRAs declared that noise barriers are used as the primary noise mitigation measure on their road networks and would remain as the primary mitigation measure in the future. In some instances, other mitigation measures are also implemented by these NRAs including different types of low-noise road surfaces (e.g. SMA (Stone Mastic Asphalt), single-layer porous asphalt and double-layer porous asphalt) and façade insulation.

Of the remaining NRAs, 5 declared low-noise road surfaces to be their primary measure and one declared façade insulation to be their primary measure. All 6 of these NRAs use barriers as an alternative mitigation option and will continue to do so. One of the 6 also reported the use of restrictions on the movement of heavy goods vehicles in order to minimise night-time noise disturbance.

Scale of application of noise barriers: The majority (18) of responding NRAs reported that they have installed barriers at some time within the period commencing 01 January 2008 – 31 December 2012 and 17 have installed barriers within the twelve months covering January-December 2012.

Where the scale of use on the network, i.e. the length of road screened by barriers, was quantified by the survey respondents, this was observed to vary considerably between Member States. For example, the lowest total distance screened on a network was 6km (in

Lithuania, equating to 0.03% of the network managed by the NRA), whereas the greatest total distance screened on a network was approximately 3,600 km (in Germany, equating to 6.7% of the network managed by the NRA). In terms of the percentage of the network screened, the widest use of noise barriers is in Switzerland where 15.5% of the road network (approximately 285km) has noise barriers installed.

Noise barrier type (acoustic property): Considering the general acoustic properties of the noise barriers used on NRA networks, i.e. whether barriers are fully sound reflective, fully sound absorptive comprising both reflective and absorptive elements, all 3 types are widely used. Thirteen of the NRAs use noise barriers comprised of only sound reflective elements on their network, 13 use barriers comprised of only sound absorptive elements and 12 use barriers comprised of both sound reflective and sound absorptive elements.

However, sound absorptive barriers are the most common type used (by 12 NRAs); 5 NRAs most commonly use barriers constructed from sound reflective elements and 2 NRAs did not respond to the question.

Any methodologies or procedures recommended within the QUESTIM project for acoustic durability monitoring (see Section 5.2 of this report) therefore need to be appropriate for assessing both airborne sound transmission (for all barrier types) and sound reflection (for sound absorptive barriers only).

Noise barrier type (materials): The survey results indicate that in terms of the generic (material) type of acoustic elements (see Section 2.3), a wide cross-section of types are used on the NRA networks (see Figure 2.10 on the following page): Timber acoustic elements are used by 15 NRAs, metal acoustic elements by 13 NRAs, concrete acoustic elements by 14 NRAs, plastic acoustic elements by eight NRAs, and transparent elements by 14 NRAs. Other material types (such as earth structures, willow/green barriers or stone gabions) are used by 6 of the NRAs. It is noted, that the range of acoustic elements covered in terms of responses to the QUESTIM survey by noise barrier manufacturers/suppliers addresses all of the different types used by NRAs.

In terms of the most common material, the survey results identified that no one type of acoustic element is especially prevalent (see Figure 2.11 on the following page); concrete acoustic elements are marginally the most popular (for 5 NRAs), followed by timber (for 4 NRAs) and metal elements (for 3 NRAs).

Where posts are required to support the elements, steel posts are the most commonly used, although timber posts are used in some instances.

Noise barrier dimensions: In terms of physical dimensions, the height of the barrier will be the main factor that determines the level of screening (noise reduction) offered at those noise sensitive receivers being protected by the barrier (assuming that the receivers are not located directly behind the noise barrier, and that the barriers are of sufficient density for sound transmission to not be a factor).

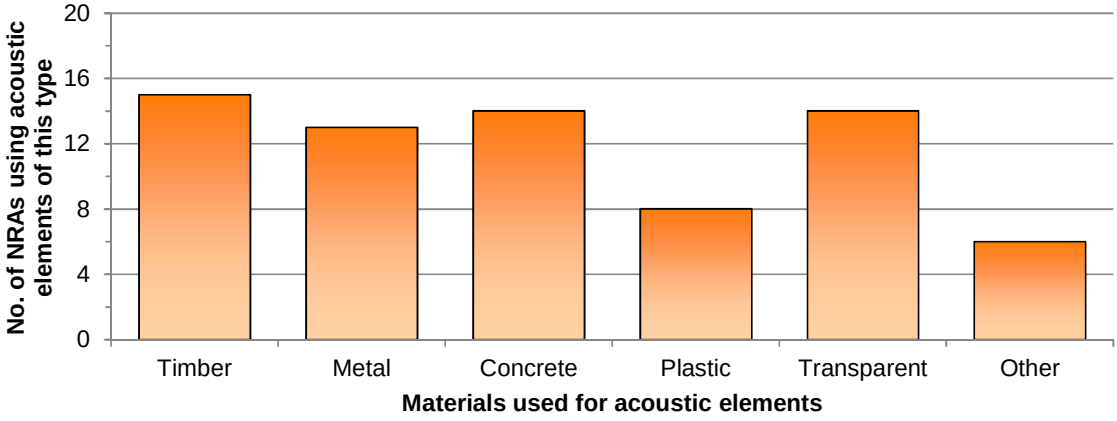

Figure 2.10: Types of acoustic element used by NRAs
(Total number of NRAs responding to survey: 19)

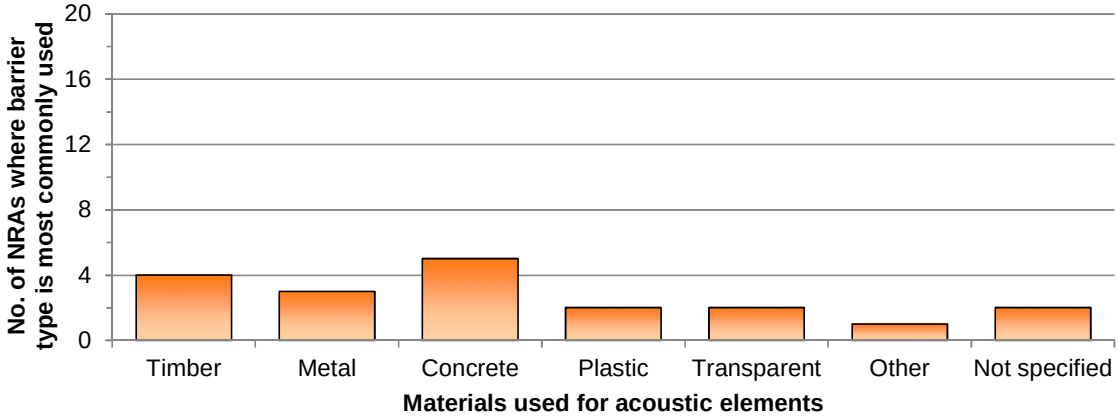

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Figure 2.11: Most common type of acoustic element used by NRAs
(Total number of NRAs responding to survey: 19)

The survey results indicate that a wide range of barrier heights are used across the various NRA road networks as shown in Figure 2.12 on the following page.

In terms of the minimum permissible height, these range from 1.0m (e.g. Ireland and Norway) to 2.5m (Lithuania); however the variation is more dramatic when considering the maximum permissible height, with a range from 4m (Belgium, Denmark, Estonia, Ireland and England/Wales) to 10m or greater (Italy, Germany and the Netherlands); 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.

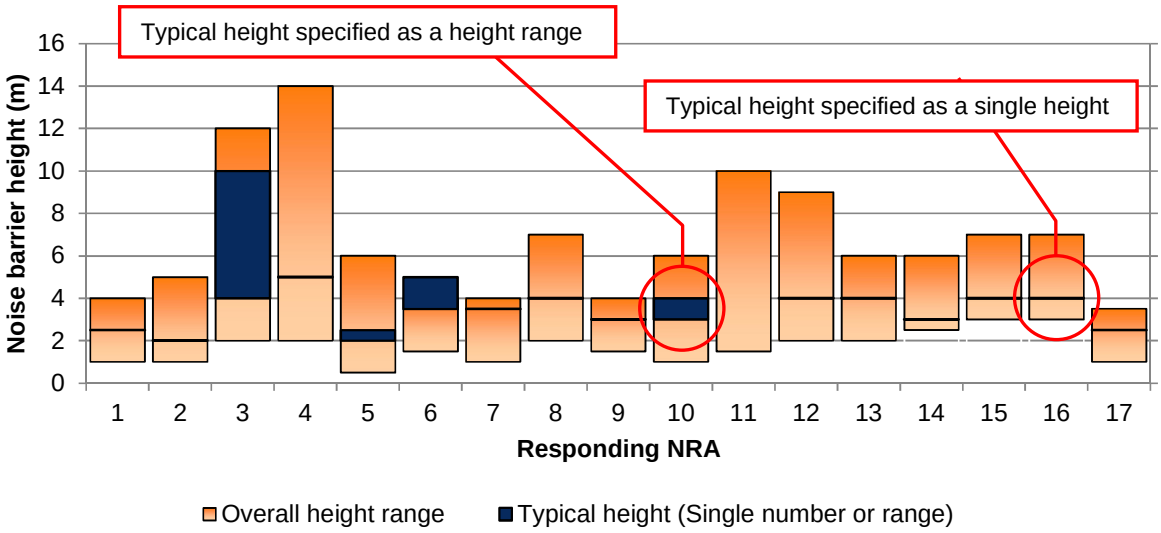

Figure 2.12: Noise barrier heights used on NRA roads where known
(Total number of NRAs responding to survey: 19)

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

Barrier position: 12 of the NRAs advised that in terms of position, barriers are most commonly sited at the edge of the hard shoulder or emergency lane. Two NRAs stated that the most common position is on the verge or at the top of cuttings/embankments and 5 NRAs did not provide a response. This means that in many cases, it is likely that some form of traffic management will be required for acoustic assessments and/or visual inspections (see Chapter 5) unless these are performed solely from the rear (non-traffic side) of the barrier.

Summary of noise barrier implementation by NRAs

Noise barriers are the most commonly used mitigation measure on NRA road networks, although the scale of implementation varies dramatically across Europe.

Sound absorptive noise barriers are the most commonly used, but no one material is especially prevalent for the construction of acoustic elements, with concrete, timber and metal being the most widely used.

The physical dimensions, particularly height, selected for noise barriers are primarily driven by the location of noise sensitive receivers relative to the barrier and the topography. However the range of heights used by the NRAs varies dramatically from as low as 0.5m to as much as 10m or greater although heights of 2-5m are the most common. The most common position relative to the carriageway is at the edge of the hard shoulder/emergency lane.

2.5 Innovative noise barrier solutions or concepts

Innovative noise barrier solutions can, broadly speaking, be considered as solutions which either use more innovative designs or materials for the construction of the acoustic elements or which perform additional functions, e.g. power generation, in addition to noise mitigation. Such solutions may already be commercially available but are not necessarily in widespread use or use at all by NRAs.

The following are examples of some of the different innovative solutions that have been identified; it is noted that a more comprehensive review of noise barriers with secondary functions will be prepared as part of the CEDR-funded project DISTANCE (Developing Innovative Solutions for TrAffic Noise Control in Europe).

Sonic crystal noise barriers: Sonic crystal barrier consist of periodic arrays of circular cylinders, which are most commonly in a vertical rather than horizontal alignment. They offer high noise attenuation at selected frequencies based on the spacing of the cylinders and the design of the cylinders themselves. Such barriers potentially offer a range of benefits: these include aesthetic benefits deriving from both the non-standard design and a level of transparency that falls between that of conventional opaque barriers and those constructed from or incorporating transparent element, reduced multiple acoustic reflections (if used where barriers are present on both sides of the road) and changes to barrier-induced wind turbulence.

While such barriers may be demonstrated to generate beneficial insertion losses at noise sensitive receivers away from the barrier, one of the fundamental issues in relation to sonic crystals most likely to affect their use by NRAs is whether or not they are capable of achieving sufficient acoustic performance levels in terms of the intrinsic characteristics specified in EN 14388.

Much of the published literature related to sonic crystal noise barriers relates either to numerical modelling or small scale testing in laboratory conditions, e.g. Chong et al (2009).

While the majority of practical applications appear to focus on their use for general improvement of soundscapes, one example has been identified which relates specifically to the use of the approach in full-scale use as a roadside traffic noise barrier (van Kemenade, 2010); a sonic crystal type noise barrier constructed from sound-absorptive aluminium cylinders was erected alongside the A2 near Eindhoven, the Netherlands. Assessments of the acoustic performance of the design in a reverberation chamber to EN 1793-2 and EN 1793-1 (see Section 3.2.1) demonstrated a single number rating of airborne sound transmission, DL_R, of 28 dB (Category B3) and a single number rating of sound reflection, DL_α, of 20 dB (Category A4). While no indication of the insertion loss at any noise sensitive receivers being screened is reported, these results demonstrate the barrier as being capable of complying with the acoustic performance specifications requested by many NRAs. The overall height of the barrier at the roadside appears to have been of the order of 6m and photographs (see Figure 2.13a on the following page) suggest that the heights of the cylinders varied along both the length and the cross-section of the barrier. Numerical modelling studies of low-height sonic crystal noise barriers using horizontal cylinders (Koussa et al, 2012) have also demonstrated the potential value of this type of barrier; the results showed that for receivers at a height between 1-2m , extending out to 40m behind the barrier, sonic crystal arrays with a depth (front to back) of 1 m and a height of 1m comprised

of different dimension cylinders offered an average insertion of up to 11 dB (depending upon the number and acoustic treatment of the cylinders), compared to an average insertion loss of 9.4 dB(A) for a solid barrier of the same dimensions.

(a) Sonic crystal barrier, A2 near Eindhoven, the Netherlands
(Reproduced with permission of Van Campen Industries)

(b) Sonic crystal type noise barrier
(Reproduced with permission of Sonobex Limited)

Figure 2.13: Examples of sonic crystal road traffic noise barriers

A further example of sonic crystal type noise barriers identified from literature and proposed as being suitable for use as a road traffic noise barrier is shown in Figure 2.13b; the device causes complex interference patterns between the scattered sound that passes through the barrier.

Photovoltaic (PV) noise barriers: These are noise barriers which are either constructed directly from PV cells or, more commonly, which integrate PV cells as a secondary (cladding) part of the barrier structure, and thereby produce electricity as a secondary benefit. PV noise barriers have been trialled 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). Commercially available systems have been identified during the QUESTIM noise barrier survey. Examples of this type of barrier are shown in Figure 2.14.

(a) Noise barrier constructed from PV cells
(from Carder and Barker, 2006)

(b) Noise barrier with integrated PV cells

Figure 2.14: Examples of photovoltaic noise barriers

An ongoing project in Sweden, NOISUN (Bengtsson and Persson, 2013) proposes to demonstrate the use of innovative PV barriers to generate power for distribution to local district heating systems; the PV barriers being used have been tested to EN 1793-2 and demonstrated to provide an airborne sound insulation performance of the barriers that falls within Category B3 (DL_R = 25-34 dB), which would comply with the acoustic performance specifications requested by many NRAs.

Barriers constructed from recycled materials: One of the main developments in this area is the use of rubber granulate from waste rubber products such as waste tyres. For example, the RUCONBAR project has investigated the use of recycle waste tyres to replace expanded clay or wood chips within sound absorptive cement concrete noise barriers (Lakušić et al, 2011); the design tested was found to have a single number rating of sound reflection DL_α of 6dB, corresponding to an A2 category noise barrier and was such that a 3m high, 1km long barrier contains recycled rubber from 7,800 vehicle tyres. The European project EKOPAN (www.ekopan.eu) is also looking at the use of recycled rubber from waste tyres for noise barriers.

A number of commercially available noise barriers constructed from these types of materials have been identified.

Added devices: 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.

Various research projects have, over the years studied the design of such added devices for use alongside roads and/or railways, 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). Examples of added devices are shown in Figure 2.15.

Figure 2.15: Examples of added devices (from Morgan, 2008)

Based on the responses from NRAs received as part of the QUESTIM noise barrier survey, such devices are not widely used across Europe; indeed, only two NRAs indicated any use of added devices (Italy and Poland), these typically being curved or octagonal-shaped devices. 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 forthcoming EN standard 1793-4 on diffraction performance (see Section 3.2.1 of this report) will provide a standard way of characterising performance and comparing the efficiency of different devices) and an inability to robustly take account of their effects within noise modelling software; costs were also seen as prohibitive relative to simply increasing the height of the screen.

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3 Assessment and specification of noise barrier acoustic performance

Variations in local conditions, in terms of, for example, the physical dimensions (height and length) of the noise barrier, its proximity to both source and receiver(s) and the local topography, affect the **extrinsic characteristics** of a noise barrier, i.e. how it performs in the far-field noise sensitive receivers such as residential properties.

Although methods exist for determining the extrinsic characteristics of a barrier in terms of insertion loss, i.e. the difference in noise level with and without a barrier present (see Section 3.3 of this report), the influencing factors mean that they are not well suited for the purposes of manufacturers; in this case, the need is to declare acoustic performance irrespective of the source/receiver positions and any other local factors.

Considerable progress has been made over the last 15 years in the development of methods for assessing the acoustic performance of road traffic noise barriers. These methods focus on the **intrinsic characteristics** of the noise barriers, i.e. the performance of the individual materials or components rather than on how the product is used.

Although much of the research has been undertaken through European-funded projects such as ADRIENNE (ADRIENNE, 1998), and QUIESST (QUIESST, 2013; www.quiesst.eu), the work has been largely driven by a desire for common, standardised procedures and is overseen at European level by the European Committee for Standardisation (CEN) and specifically for road traffic noise barriers by CEN/TC 226/WG6 (Noise protection barriers). Members of the QUESTIM consortium sit on this CEN Working Group.

The main focus of this Chapter is therefore on the standardised methods for the assessment of intrinsic characteristics since it is these which are most commonly used by noise barrier manufacturers/suppliers to specify product performance. Research based methods and methods for assessing extrinsic characteristics are included in Section 3.3. The Chapter also addresses how National Road Administrations (NRAs) specify noise barrier performance for procurement purposes (Section 3.4).

Standards related to non-acoustic performance are not addressed within this report.

3.1 European standards: General specification of performance characteristics

The overarching European Standard that specifies the performance characteristics against which 'road traffic noise reducing devices' should be assessed and the corresponding standards defining the test methods is EN 14388 (CEN, 2005). Within the standard, road traffic noise reducing devices include noise barriers, claddings, covers and added devices (as defined in Section 2.1 of this report).

The standard sets out requirements for acoustic performance, non-acoustic performance and long term performance characteristics as shown in Figure 3.1 on the following page. It covers products used for road traffic noise reduction made from any materials.

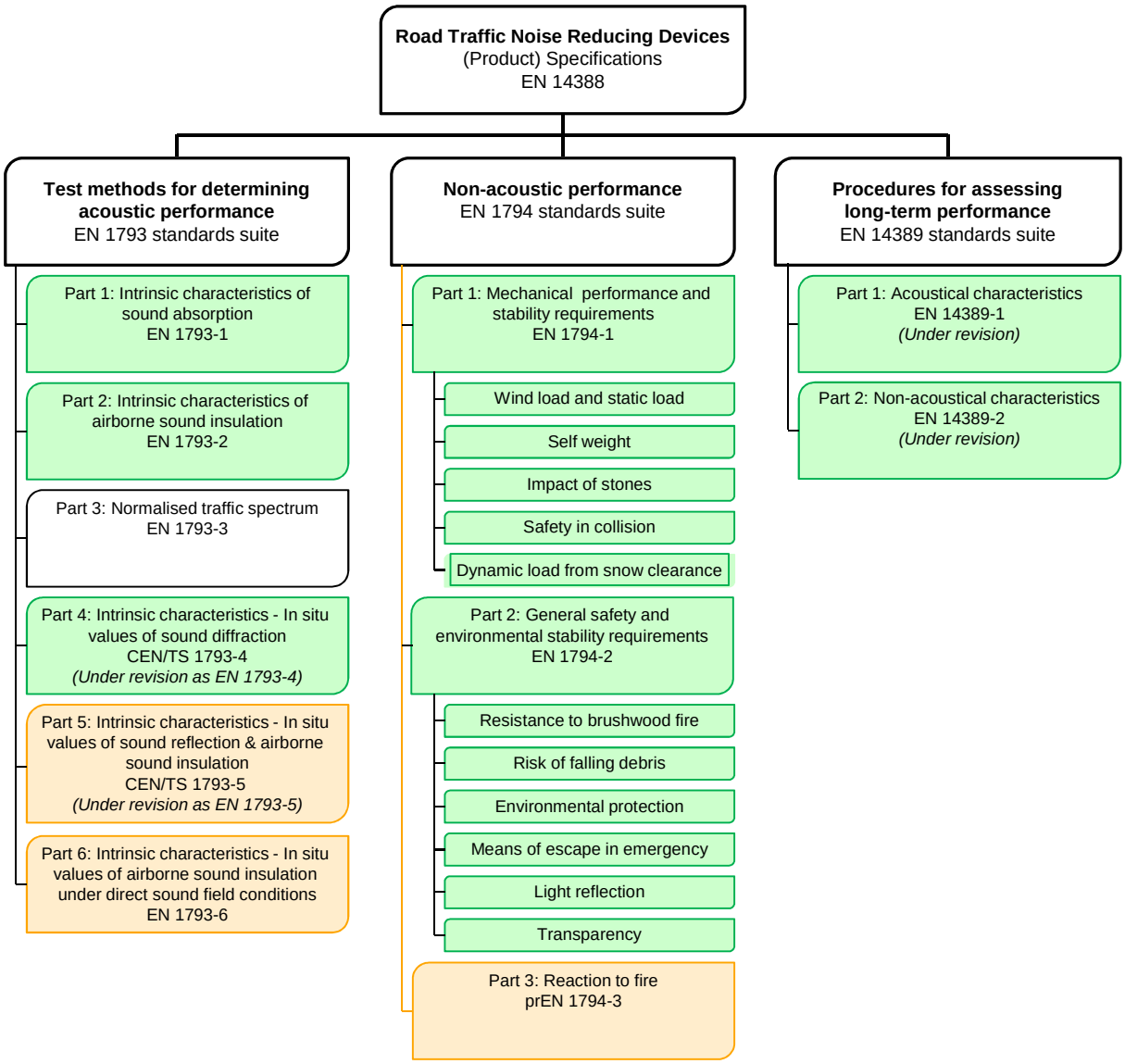


Figure 3.1: Framework of CEN noise barrier standards
(Green boxes denote standards currently within EN 14388:2005; Orange boxes denote standards to be introduced within the forthcoming revision)

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 relevant European Directives or Regulations. In the case of road traffic noise reducing devices, CE marking in accordance with the 2005 version of the Standard means that products meet the requirements of the Construction Products Directive (EU) No 89/106/EEC (European Commission, 1989).

As of 01 July 2013, this Directive is repealed and replaced by the Construction Products Regulation (EU) No. 305/2011 (European Commission, 2011) (see Section 3.1.1). EN 14388

is currently under revision to take account of not only the introduction of the Construction Products Regulation but also new methods that have been introduced since 2005 and associated revisions to the scope of other standards. The revision is expected to be published in late 2014 or early 2015.

3.1.1 Impact of the Construction Products Regulation, No. 305/2011

The level to which the standards covered within EN 14388 are implemented, both by the manufacturers themselves and those responsible for the specification and procurement of noise barriers has undergone a significant change in 2013.

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. This is a major change as the requirement for products to be CE marked under the previous Construction Products Directive (CPD) for products was voluntary in some countries, such as the UK.

CPR harmonises the methods of assessment and testing, the means of declaration of product performance and the system of conformity assessment of construction products. CE marking enables a product to be placed legally on the market in ANY EU Member State, although this does not necessarily mean that it is suitable for use in all Member States (e.g. due to differences in climatic conditions, etc.).

This means the following:

- Barrier manufacturers are required to declare performance for all characteristics addressed within EN 14388, or to declare the performance as NPD (No Performance Determined) where this is permitted.

  It is noted that of the manufacturers/suppliers who responded to the QUESTIM noise barrier survey, only seven manufacturers/suppliers stated that their products are CE marked. Additionally, it is noted from the survey findings that not all of the manufacturers were aware of the introduction of the CPR.

- Existing NRA specifications for noise barriers which specify the characteristics that must be satisfied may require revision to take account of CPR if such amendments have not already been undertaken.

It is noted that although some of the standards have been subsequently revised or had their scope of application changed (see particularly EN 1793-2 in Section 3.2.1), the declaration of performance and CE marking will be performed in accordance with the dated versions of the standard shown in EN 14388:2005 until the revision of EN 14388 is issued.

3.2 European standards: Standardised test methods

As noted above, standardised test methods for acoustic performance are covered by the EN 1793 suite of European standards. The standards describe the intrinsic characteristics for the

three performance mechanisms described previously, i.e. sound transmission, sound reflection and sound diffraction.

Historically, acoustic performance test methods have focused on assessments under laboratory conditions using a reverberation room. Such methods are suited for design/development purposes or the testing of samples in 'new condition', i.e. for the determination of initial performance, whereby the samples may require physical modification to satisfy the installation requirements in the reverberation room. However, the suitability of the methods for the assessment of 'in-service' barriers is significantly poorer, since this requires a section or sample to be removed from the in-situ location, thereby potentially disturbing the integrity of the test sample (in terms, for example, of the quality of joints and seals, the position of absorptive materials on/within the sample and the presence of dirt, detritus or other foreign bodies affecting performance). Furthermore, any physical modification of the sample for testing may render it unsuitable or unusable for re-installation on site. A need was therefore recognised for test methods that are suitable for testing barriers in conditions that are more representative of normal use or directly at their installed location at the roadside.

The options for alternative in-situ test methods were limited (see Section 3.3 of this report) and as a consequence, test methods developed specifically for the purpose of in-situ application within the EU-funded project ADRIENNE (ADRIENNE, 1998) have been adopted as the standard methods. Refinements and improvements have subsequently been undertaken within the EU-funded project QUIESST (QUIetening the Environment for a Sustainable Surface Transport; QUIESST, 2013; www.quiesst.eu).

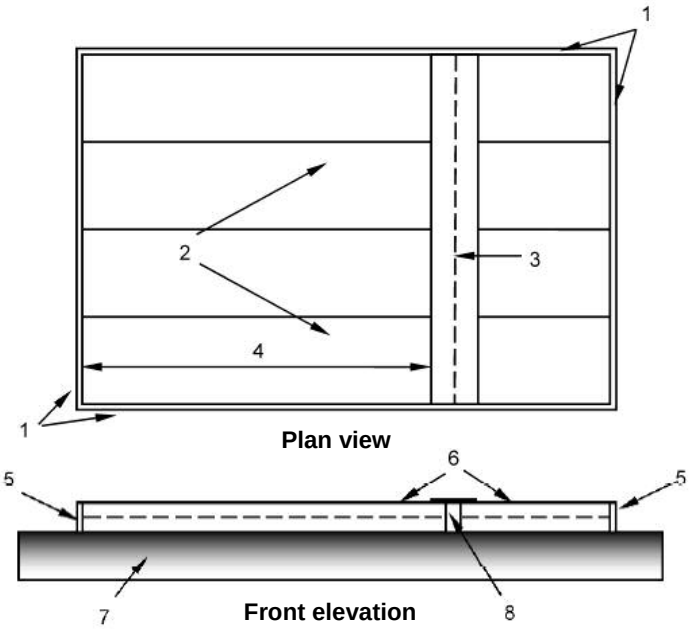
The following sections summarise the different test methods.

3.2.1 Laboratory-based test methods

EN 1793-1 (CEN, 2012a) sets out a test method for the determination of **sound reflection** characteristics. Measurements are performed under laboratory conditions using a reverberation chamber; Figure 3.2 on the following page illustrates the mounting conditions for the test specimen. The performance is expressed in terms of the single-number rating of sound absorption, DL_{α}. Where there is a need to categorise absorptive performance, the available categories range from A0-A5, where A0 is undetermined performance, A1 is the poorest performing category and A5 is the best performing category.

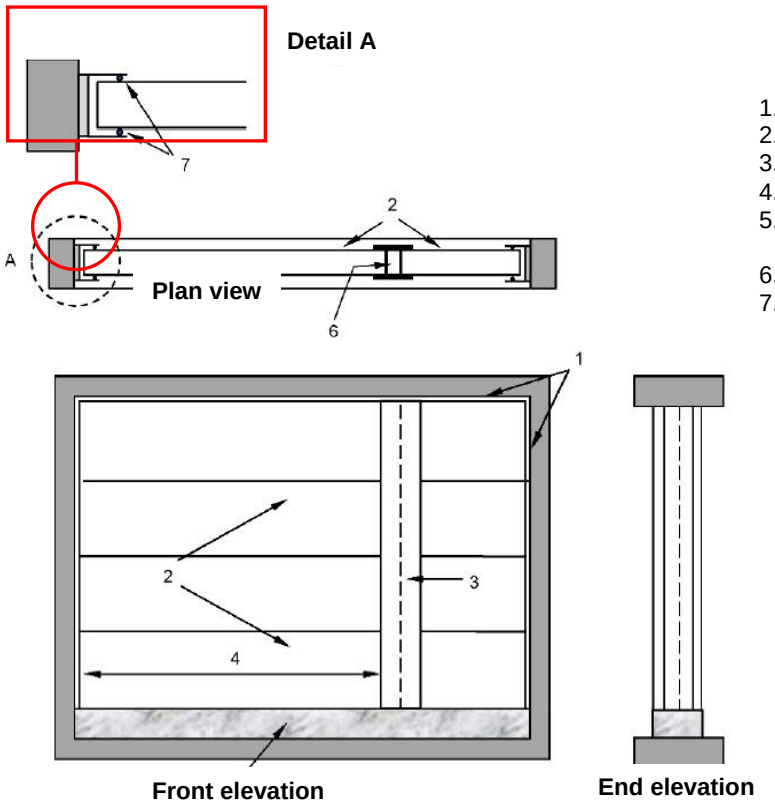
The scope and title of this standard will be similarly revised in the future to restrict the applicability of the test method to the assessment of devices used only "*under reverberant conditions*", as has already been done with EN 1793-2 (see below). The revised standard is expected to be published in late 2015. From that point, the method will no longer be considered applicable for the assessment of noise barriers and sound absorption properties shall be declared based on the in-situ test in EN 1793-5 (see Section 3.2.2 of this report).

EN 1793-2 (CEN, 1997; superseded by CEN, 2012b) sets out a test method for the determination of **airborne sound insulation** characteristics. Measurements are performed under laboratory conditions using a reverberation chamber; Figure 3.3 on the following page illustrates the mounting conditions for the test specimen).



1. Reflective frame
2. Panels (Sealed as in practice)
3. Post
4. L ≥ 2m
5. Reflective frame (sealed against sample)
6. Panels
7. Chamber surface (floor)
8. Post (Sealed as in practice)

Figure 3.2: Mounting conditions for test specimens tested to EN 1793-1



1. Sealing materials
2. Panels (Sealed as in practice)
3. Post
4. L ≥ 2m
5. Bricked-up plinth for levelling (if necessary)
6. Post (Sealed as in practice)
7. Sealing materials to prevent edge leakage

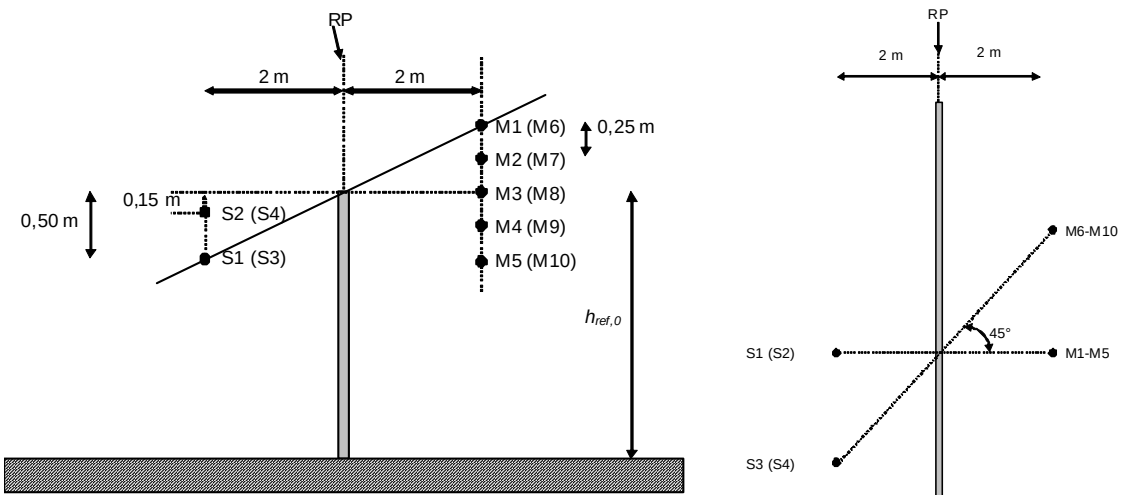
Figure 3.3: Mounting conditions for test specimens tested to EN 1793-2

The performance is expressed in terms of the single-number rating of airborne sound insulation, DL_R. Where there is a need to categorise insulation performance, the available categories range from B0-B4, where B0 is undetermined performance, B1 is the poorest performing category and B4 is the best performing category.

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. In practice, this change is unlikely to be enforced until the publication of the revision of EN 14388 in late 2014/early 2015, from which point the airborne sound insulation characteristics of noise barriers shall be declared based on the in-situ test in EN 1793-6 (see Section 3.2.2 of this report).

3.2.2 In-situ test methods

CEN/TS 1793-4 (CEN, 2003a) is a technical specification (TS) which sets out a test method for determination of the **sound diffraction** characteristics of added devices (see Section 2.5) installed on the top of traffic noise reducing devices. Figure 3.4 shows the basic test set-up used in the method.



(a) View from end of barrier (b) Plan view of barrier

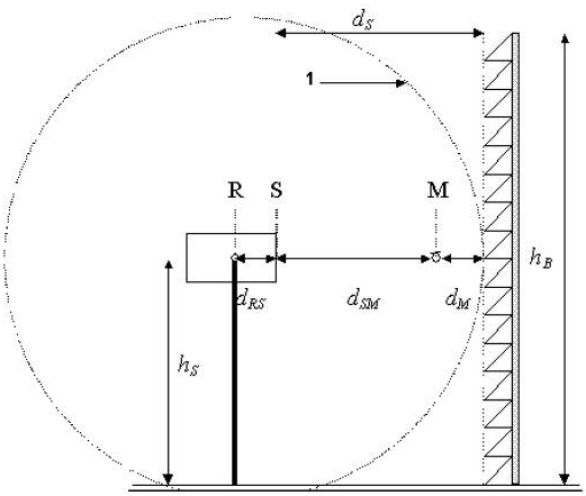
RP: Reference Plane; S1 – S4: Source positions; M1 – M10: Microphone positions

Figure 3.4: Test set-up for test specimens tested to the proposed revision of CEN/TS 1793-4

Measurements can be performed both on existing barriers in situ and on samples purposely built to be tested using the method described here; measurements can also be performed indoors or outdoors. The performance is expressed in terms of the single-number rating of sound diffraction, $DL_{\Delta DI}$.

This TS is currently under revision with the objective of converting it to a full EN standard. It is expected that the revision will be published in late 2014/early 2015.

CEN/TS 1793-5 (CEN, 2003b) is a technical specification which 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 on the same side of the barrier, the microphone being rotated through different positions around a reference circle. Figure 3.5 illustrates the basic test set-up shown in the current published version of the standard.



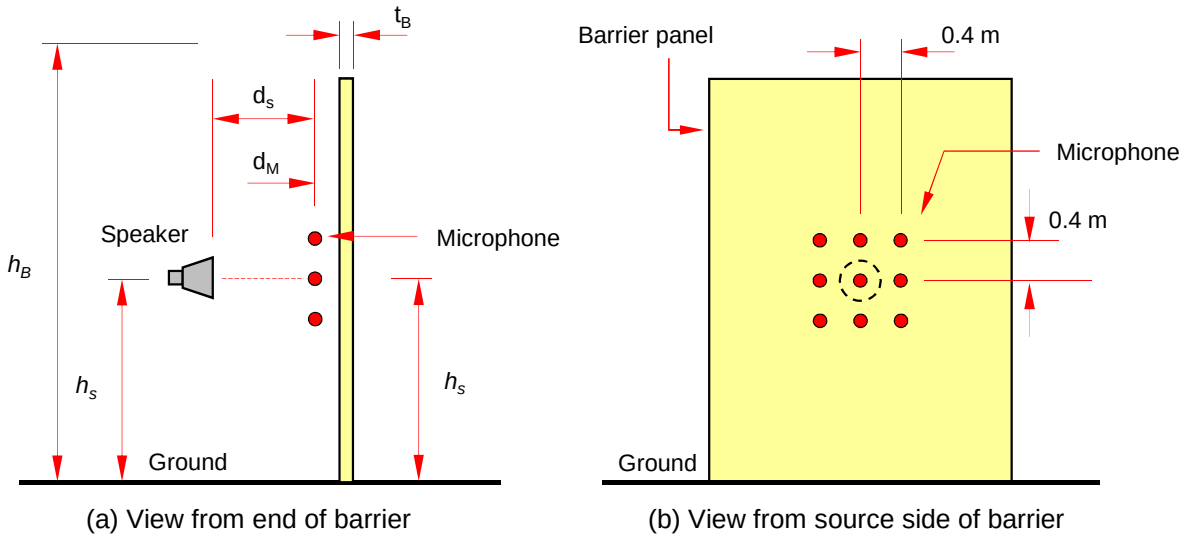
1: Reference circle
R: Axis of loudspeaker
S: Front of loudspeaker
M: Microphone
h_B: Barrier height
h_s: Reference height ($0.5 \times h_B$);
d_{RS}: horizontal distance from axis of loudspeaker to front of loudspeaker
d_{SM}: horizontal distance from front of loudspeaker to microphone M
d_M: horizontal distance from microphone to source reference plane at height h_s
d_S: $d_{RS} + d_{SM} + d_M$

Figure 3.5: Test set-up for test specimens tested to CEN/TS 1793-5

Following work undertaken within the QUIESST project to improve the test method, Figure 3.6 on the following page illustrates the proposed set-up that will be included in the forthcoming revision of the Standard (see below), whereby a static array of microphones replaces the use of a single microphone (Note that the measurements can be performed by using a single microphone which is physically moved to each position in the array). The performance is expressed in terms of the single-number rating of sound reflection, DL_{RI}. Where there is a need to categorise absorptive performance, the available categories range from A0-A5, where A0 is undetermined performance, A1 is the poorest performing category and A5 is the best performing category.

The TS is currently under revision, for publication as a full EN standard. In addition to the changes to the measurement positions, the QUIESST research also resulted in improvements in the signal processing methodology. It is expected that the revision will be published in late 2015 (at the same time as the revision to EN 1793-1). Once the revision is published, this method will formally replace EN 1793-1 as the standard test method for assessing the sound absorption performance of noise barriers.

Note: CEN/TS 1793-5:2003 includes a test procedure for assessing airborne sound insulation performance; this procedure has now been superseded by EN 1793-6:2012 and will be deleted during the conversion to a full EN standard.



(a) View from end of barrier (b) View from source side of barrier

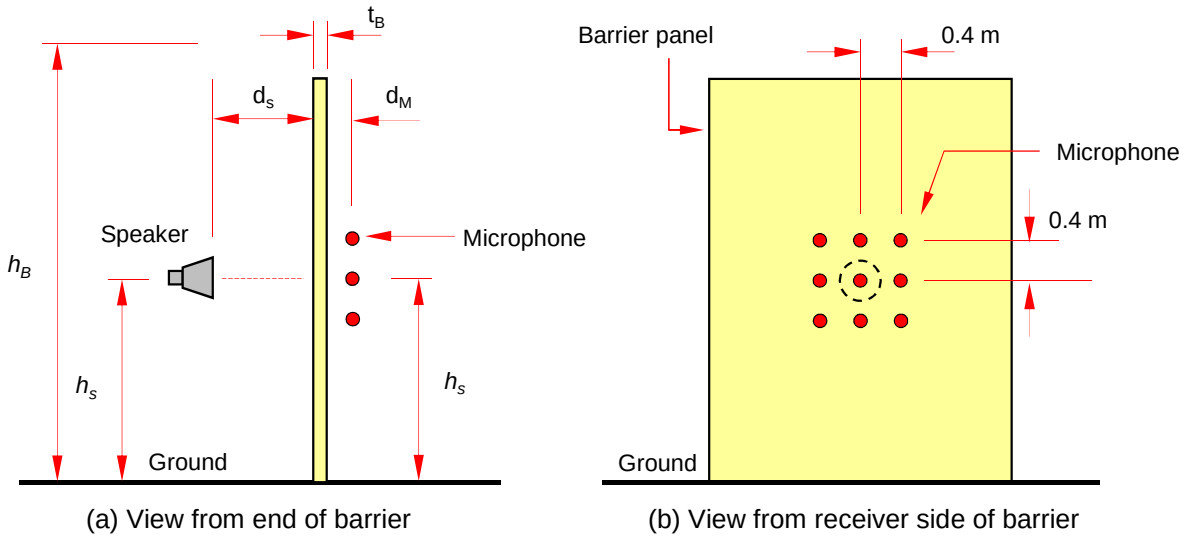
h_B: Barrier height; h_s: Reference height ($0.5 \times h_B$); t_B: barrier thickness at height h_s; ds: horizontal distance from loudspeaker to source reference plane at height h_s; dM horizontal distance from centre microphone to source reference plane at height h_s

Figure 3.6: Test set-up for test specimens tested to the forthcoming EN 1793-5

Research has shown that there is a moderate correlation between sound absorption results measured according to EN 1793-5 and EN 1793-1 (Conter, 2013), when all barrier types are considered as a single dataset, with the laboratory method dramatically over-estimating the sound absorption properties of a noise barrier compared to the in situ method. 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, 2012c) sets out a test method for the determination of **airborne sound insulation** 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 on one side of the test sample and a microphone array on the opposite side (Note that the measurements can be performed by using a single microphone which is physically moved to each position in the array). Figure 3.7 on the following page illustrates the basic test set-up.

The performance is expressed in terms of the single-number rating of airborne sound insulation, DL_{SI}. Where there is a need to categorise insulation performance, the available categories range from D0-D4, where D0 is undetermined performance, D1 is the poorest performing category and D4 is the best performing category.



(a) View from end of barrier (b) View from receiver side of barrier

h_B: Barrier height; h_s: Reference height (0.5 hB); t_B: barrier thickness at height h_s; d_s: horizontal distance from loudspeaker to source reference plane at height h_s; d_M horizontal distance from centre microphone to source reference plane at height h_s

Figure 3.7: Test set-up for test specimens tested to EN 1793-6

EN 1793-6 is specified as being suitable for the assessment of products used under "*direct sound field conditions*" and as noted above, following the change in scope to EN 1793-2, replaces that test method as the standard test method for assessing the airborne sound insulation of noise barriers. In practice, this change is unlikely to be enforced until the publication of the revision of EN 14388 in late 2014/early 2015. However since EN 1793-6 is already published, this offers the scope to manufacturers to already declare airborne sound insulation performance in terms of the indices in that standard, while still complying with EN 1793-2 (the responses to the QUESTIM noise barrier survey suggests some manufacturers/suppliers are already doing this).

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), when all barrier types are considered as a single dataset, with the laboratory method underestimating the sound absorption 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.

3.2.3 Long-term performance

It is recognised that the acoustic performance 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. As already noted, EN 1793-1 and EN 1793-2 are only appropriate for determining the performance of products in new condition. The introduction of CEN/TS 1793-5 provided methodologies suitable for assessing the acoustic performance characteristics of a barrier over its working lifetime and a new standard was introduced as follows:

EN 14389-1 (CEN, 2007a) sets out the procedure for determining long-term acoustic performance for a specified set of environmental classes, in terms of the estimated reduction in performance after 5, 10, 15 and 20 years, assuming that the product is maintained in accordance with the manufacturers recommendations or instructions. The change in airborne sound insulation DL_{SI} and (if applicable) sound absorption DL_{RI} should be stated for each time period.

Durability can be assessed using

- descriptive solutions based upon the estimated performance of the materials or by physical examination of the product, or

- comparative performance testing according to CEN/TS 1793-5 (this requires knowledge of the initial performance characteristics in accordance with CEN/TS 1793-5.

The standard is currently under revision. The revision will not only take into account the introduction of EN 1793-6, but also introduce durability for sound absorptive products in terms of EN 1793-1. The revision will also mark a significant change in the way that long-term performance should be characterised. This will see a move to declaring the expected performance, under specified environmental conditions, in terms of the expected lifetime of the product in years for each set of conditions and the expected acoustic performance at that time. It is expected that the revision will be published in some time during 2014.

3.2.4 Changes foreseen beyond the current standards

The work of CEN/TC226 WG6 is an on-going activity. With the introduction of a mandatory requirement for all European standards to include clauses on the uncertainty of the test methods, those standards that do not currently include such text will require over time to be revised or have the necessary text added through the inclusion of a Corrigendum.

It is noted that one of the key factors in the above acoustic standards that will be affected by these uncertainty requirements are the use of the categories of single number ratings, which are used by both manufacturers and for procurement specification purposes. These categories are not compatible with the principles of uncertainty, since the uncertainty associated with the test method may result in a barrier which performs close to the limits of a

particular category in terms of the absolute single number rating falling into a lower or higher category once the uncertainties are taken into account (Garai and Guidorzi, 2013). It has therefore been proposed by CEN/TC226 WG6 to remove the categories of single number ratings from the EN 1793 standards going forwards. No precise timescale is currently known for this action, however once introduced, procurement specifications will require to be based on absolute single number ratings.

Summary of European standardised noise barrier assessment techniques

Standardised tests have been developed for characterising the acoustic performance of noise barriers and other noise reducing devices. These test methods are embedded in European standards and thereby the harmonised specification standard that specifies the performance requirements and methods of evaluation for road traffic noise reducing devices.

As such, declarations of performance by noise barrier manufacturers/suppliers are based on measurements using these standardised tests.

It is important to note that these test methods focus on intrinsic and not extrinsic characteristics of performance, i.e. the performance of the individual materials or components rather than on how the product is used, since extrinsic measurements will be dependent upon factors such as barrier geometry, topography and distance from the road/noise sensitive receivers.

This is particularly relevant when considering how acoustic durability is defined. The link to intrinsic characteristics means that the definition may differ from general NRA expectations of acoustic durability, which are more likely to be aligned with whether or not a noise barrier maintains noise levels at the noise sensitive receivers screened by it over its working lifetime.

3.3 Other test methods for assessing acoustic performance

Away from the standardised methodologies described in the previous section, the following in-situ test methods have been identified.

Assessment of intrinsic performance characteristics

- A national method for performing in-situ assessments has been used in France (AFNOR, 1990); the approach follows similar principles to that used in EN 1793-6 but uses an explosive source, e.g. a starting pistol, to generate the noise signal rather than generate it from a signal generator or PC. The suitability of this method for standardised used was investigated during the ADRIENNE project (ADRIENNE, 1998) but was rejected due to its poor repeatability and its lower frequency limit of 400 Hz (a function of the analysis method).

- The use of *sound intensity measurements* to determine the airborne sound insulation characteristics of noise barriers has been demonstrated, for example, by Watts (1997) based on assessments of timber noise barriers. The method is another suited for in-situ application, but one where actual traffic is used as the noise source. The

method was found to give good agreement with assessments performed in a reverberation chamber using the EN 1793-2 method. However, it was noted that discrepancies may arise between in situ and laboratory measurements due to the differences in sound fields (direct in the former and reverberant in the latter). The method also requires relatively dense traffic flows to ensure a decent level and consistency of source noise.

- A method using an acoustic camera for the localisation of defects in noise barriers has been reported by Puš et al (2013). As with the sound intensity method this uses the actual traffic as the noise source. The data from the acoustic camera is used in conjunction with 3D noise modelling software to look at the effects on noise levels in the far-field.

Where these methods differ from the standardised tests, i.e. excluding the AFNOR method, while they are/may be appropriate for characterising/assessing intrinsic acoustic performance, no information is available as to whether the resultant data would correlate well with results obtained using the standardised tests. As such, it is not considered at this stage that these methods can be recommended by the QUESTIM project as the most appropriate technique for performance monitoring.

Assessment of extrinsic performance characteristics,

These tests/assessments focus on the effect of the noise barrier at the noise sensitive receivers being screened by it, and therefore, while these cannot be compared to the performance characteristics declared by manufacturers (see the previous Section), may be better suited to NRAs if the definition of acoustic durability is aligned with whether or not a noise barrier maintains noise levels at the noise sensitive receivers screened by it over its working lifetime.

However, they would require measurements to be taken when barriers are newly installed to provide appropriate baseline levels and the position of assessment locations would need to be carefully selected.

- The test method described in ISO 10847 (ISO, 1997) considers barrier performance in terms of insertion loss, i.e. the difference in noise levels with and without the barrier present. Two approaches are presented within the standard:
    - *The direct method:* This can only be used if the barrier is yet to be installed or can be removed for the "before" measurements. Sound pressure levels are measured at a reference position (a position where there is or will be minimal influence from the installed or proposed barrier) and the required receiver positions for both "before" and "after" the installation of the barrier.
    - *The indirect method:* If the barrier has already been installed and cannot be readily removed to allow direct measurement for the "before" condition, an estimated "before" level is obtained by measuring at a site equivalent to the main study site.

- The method specified in ANSI-S12.8 (ANSI, 1998) covers the methods adopted in ISO 10847 but also allows an 'indirect predicted' method where the "before" noise data is predicted from calculation schemes.

NRAs who responded to the QUESTIM noise barrier survey also reported performing far-field measurements to other national/international standards that address the measurement and assessment of environmental noise, e.g. the Nordtest Method (Nordtest, 2002) and ISO 1996-2 (ISO, 2007). These standards are not addressed here since they are not specifically designed for the assessment of noise barriers.

Summary of other noise barrier assessment techniques

A number of other test methods have been identified for characterising the acoustic performance of noise barriers. Some of these focus on intrinsic performance, others on extrinsic performance.

While the results from the extrinsic tests cannot be compared to the performance characteristics declared by manufacturers, such approaches may be better suited to NRAs if the definition of acoustic durability is aligned with whether or not a noise barrier maintains noise levels at the noise sensitive receivers screened by it over its working lifetime.

3.4 NRA specification of noise barrier performance for procurement purposes

The QUESTIM noise barrier survey of NRAs identified that the majority of the NRAs have some form of national specification documents and/or guidance documents related to noise barriers; see for example GCW-2012 in the Netherlands (CROW, 2012), ZTV-Lsw 06 in Germany (FGSV, 2006) and *Tien meluesteiden suunnittelu* (Design of road traffic noise reducing devices) in Finland (Liikennevirasto, 2010).

The range of information specified in these documents varies and may address topics including basic principles of noise barrier design, options for acoustic and structural elements, specifications/quality requirements related to materials and any associated treatments, acoustic performance and non-acoustic performance and guidance on inspection/monitoring and maintenance. In terms of requirements on materials used for both acoustic and structural elements, compliance can be required with either national and/or international standards/regulations.

These documents may also cover performance characteristics/issues not addressed by EN 14388 and its supporting standards, e.g. resistance to vandalism (see, for example, Irish specifications (National Roads Authority, 2011) for noise barriers) or requirements in terms of visual appearance, etc.; however, such issues fall outside of the scope of this report.

Where the documents relate to specification, requirements may also be in place that must be satisfied by noise barrier suppliers or installers in order for them to work on a particular NRA network. Such requirements will typically require for the supplier/installer to demonstrate the

existence of internal quality systems/controls regarding their noise barrier products; see, for example, Sector Scheme 2C in England/Wales (UKAS, 2012).

Figure 3.8 summarises the survey results regarding the **acoustic standards** that NRAs require noise barriers to have been tested against in order for them to be used on their networks.

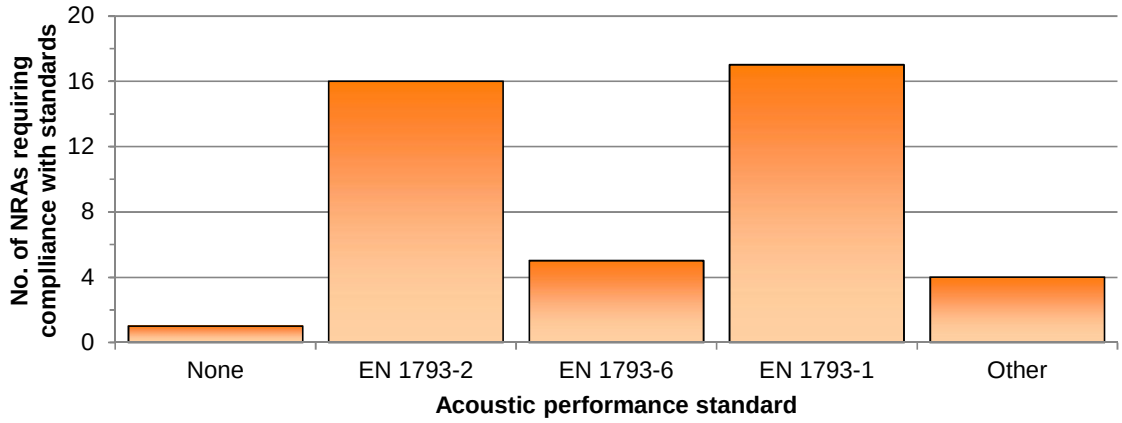


Figure 3.8: Specification of requirements for acoustic performance of barriers
(Total number of NRAs responding to survey: 19)

It is observed that the majority of the responding NRAs (16 or greater) require that any noise barriers used on their networks to have been tested in accordance with EN 1793-2 and, if appropriate, EN1793-1. This ensures that the NRA is aware of the quality and expected performance of the barrier being procured. The survey results only indicate a limited adoption to date of the EN 1793-6 in situ airborne sound insulation test. It is noted that Norway was the only responding NRA not to require testing to any of the EN standards. Other standards used by NRAs included national regulations or standards such as ISO 11654 (sound absorbers for use in buildings; ISO, 1997).

In terms of minimum levels of initial acoustic performance, only 6 NRAs were found to not specify requirements for barriers to meet. Where minimum requirements exist, these are most commonly category B3 (DL_R > 24 dB) for airborne sound insulation performance and category A3 ($DL\alpha$ = 8-11 dB) for sound reflection performance. It is noted that Danish specifications have been updated to take account of the most recent revisions to EN 1793-2 and EN 1793-1, requiring, as a minimum category B4 and A4 performance.

In terms of lifetime acoustic performance, only eight of the responding NRAs specify any form of **requirements** for barriers on their networks, with the majority opting for a time-dependant requirement for barriers to maintain acoustic performance (ranging from 10-30 years) rather than specifications in terms of an absolute change in acoustic performance (see also Chapter 4). As such, compliance with EN 14389-1 has largely not been a requirement to date.

Requirements for additional criteria beyond standardised acoustic and non-acoustic characteristics vary among the NRAs who responded to the QUESTIM survey in this regard. Nine of the NRAs had no additional requirements but where these are in place, they are related to non-acoustic performance, such as resistance to vandalism and/or graffiti, endurance in abnormal climate conditions, aesthetic requirements, etc. and as such, are outside of the scope of this report.

Summary regarding NRA noise barrier specifications

The majority of NRAs require that the acoustic performance of barriers to be used on their networks have been determined in accordance with the standardised tests in EN 14388.

More than half of the NRAs who responded specify a minimum acceptable level of initial acoustic performance based on these test methods. Where lifetime performance is specified, this is usually in terms of years rather than any changes in acoustic performance.

In addition to the characteristics addressed within EN 14388, other performance requirements are sometimes specified, but these are typically related to non-acoustic characteristics.

3.5 Manufacturer/supplier specification of noise barrier performance

All of the manufacturers/suppliers who responded to the QUESTIM noise barrier survey declared that the acoustic performance of their products is tested against the EN 1793-2 and, if appropriate, the EN 1793-1 standards. Following the introduction of the Construction Products Regulation (see Section 3.1.1), declaration of performance against these standards is mandatory, unless a product is declared NPD. Six of the manufacturers declared that they already assess the airborne sound insulation performance of their products using the in-situ test method set out in EN 1793-6.

Six manufacturers/suppliers stated they do not declare any kind of long-term performance; five state performance as a lifetime in years and 4 manufacturers/suppliers stated that they declare long-performance in accordance with the requirements of EN 14389-1, i.e. using changes in acoustic performance; however follow-up communications identified that only one manufacturer declares acoustic lifetime in this manner and that the other 3 actually declare performance in years.

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4 Acoustic durability of noise barriers

A key requirement for noise barriers used by National Road Administration (NRAs) is for them to maintain an appropriate level of acoustic durability over their working life to ensure that noise levels at noise sensitive receivers behind the barriers remain at an appropriate level. It is important therefore that the acoustic elements within a barrier are capable, as far as is practicable, of resisting the effects of agents encountered within the roadside environment that might have a negative impact on their acoustic performance. Loss of performance can also result through damage caused by impact, vandalism, etc.

The use of good quality raw materials, good quality design/manufacture including the adoption of appropriate protective measures within that process, selection of the appropriate type of barrier for the location, and installation/maintenance according to the manufacturer's instructions are all key factors in ensuring a long and robust service life. Failure to adhere to these principles is may result in any physical degradation of the barrier being potentially accelerated. Degradation will most commonly manifest in terms of changes in the structural integrity of the barrier and its physical condition/aesthetics.

It is important to note that any change in actual acoustic performance that results from physical degradation or the failure of acoustic elements will, for the most part be restricted to changes in the intrinsic characteristics determined using the EN 1793 suite of tests (see Section 3.2); unless the result is the physical loss of acoustic elements, the research studies on holes and gaps in barriers summarised in Section 2.2 of this report indicates that at distances beyond 20m, the effects of holes and gaps are likely to relatively small (less than 1dB) unless the barriers are high.

Degradation of sound absorptive materials may result in some increase in reflected sound, the magnitude depending on the degradation of the materials, as follows:

- In cases where there is a barrier only on one side of the road, this may increase levels on the opposite side of the road to the barrier.
- In cases where there is a barrier on both sides of the road, this may increase noise levels behind one or both of the barriers due to the reduced absorption of sound reflected between the two barriers.
- In both cases, levels behind the barriers may be adversely affected due to the increased effects of reflections between the barrier and high-sided vehicles.

For example Watts (1996) compared noise levels behind a 2 m high reflective barrier when sound reflective and sound absorptive barriers were installed on the opposite side of the road and found that the use of the sound absorptive barrier reduced average noise levels behind the barrier by almost 3 dB(A); such an example obviously represents a complete loss of sound absorption performance on the non-reflective barrier.

In order for manufacturers/suppliers to declare changes in long-term acoustic performance, if such changes occur, they must be ideally be expressed in terms of characteristics that the manufacturer/supplier readily measure or specify, which are independent of local conditions

(including topography, barrier height and length) and which, ideally, can be assessed once a product is in service. This means focussing on the intrinsic characteristics of the noise barrier, i.e. the performance of the individual materials/components (see Chapter 3) and not the noise levels at noise sensitive receivers. As discussed in Chapter 2, changes in the intrinsic characteristics may not affect noise levels in the far-field.

Therefore, this means that the definition and specification of acoustic durability used in European standards and by noise barrier manufacturers/suppliers as part of a noise barrier's CE mark may differ from general NRA expectations of acoustic durability which may be more aligned with whether or not a noise barrier maintains noise levels at the noise sensitive receivers screened by it over its working lifetime.

Acoustic durability is currently addressed within the long-term performance standard EN 14389-1 (see Section 3.2.3 of this report), which allows the declaration of changes in long-term performance after 5, 10, 15 and 20 years using either expert judgement (a descriptive approach based on the estimated performance of the materials used) or testing (based on application of the in-situ test methods described in CEN/TS 1793-5[1]), i.e. based on measurements of the single number ratings of airborne sound insulation, DL_{SI} and, if applicable, and sound absorption, DL_{RI}.

The forthcoming revision of EN 14389-1 will instead specify the method in EN 1793-6 for airborne sound insulation but will also allow declaration of durability for sound absorptive barriers using the forthcoming EN 1793-5. Additionally, it replaces the above declaration by a statement, for defined environmental exposure classes, of the working life of the product in years and the expected acoustic performance at the end of the working life only. It is expected that a further, later revision will amend the declaration of changes in sound reflection performance to use EN 1793-5.

It is note that whilst this simplifies the assessment for the manufacturer, in principle it offers a reduced level of information for end-users, such as NRAs, as there is no indication as to the rate of change of acoustic performance if such degradation occurs.

However, the most significant problem facing manufacturers is how to determine acoustic intrinsic performance in the long term, if physical measurements rather than expert judgements are the preferred route. There are a number of options that could potentially be used, examples of which, where identified are presented in Section 4.2.

- **Artificial ageing of test samples in a climatic chamber:** The success of this approach is dependent upon being to reproduce appropriate climatic conditions. Aged samples could then be tested using either the laboratory or in situ tests in the EN 1793 standards. Performance would be compared with that for a sample in new condition tested under the same methods.

- **Artificial reproduction of physical defects:** Such a technique would use information from visual inspections of in-service barriers to identify the magnitude and dimensions of defects such as gaps between boards on a timber noise barrier, which

[1] It is noted that whilst the standard refers to CEN/TS 1793-5, the airborne sound insulation measurement method within that standard has been superseded by the method in EN 1793-6 (see Chapter 3).

would then be artificially reproduced on a test sample. The 'defective' samples could then be tested using either the laboratory or in situ tests in the EN 1793 standards. Performance would be compared with that for a sample in new condition tested under the same methods. It is considered that such an approach may have limited applicability, e.g. restricted to timber barriers, and could only be applied to assess existing barrier designs/constructions unless there was confidence that the same defects would result in a new, untested design/concept; however, it is considered that one of the potential objectives of the new design/concept might actually be to eliminate the occurrence of such defects.

- **Comparison of products in new condition with equivalent products that have already been in-service for a number of years:** Such tests would ideally be undertaken using the in situ test methods, since test samples removed from the roadside could not be reconstructed within a laboratory exactly as they were in situ; this issue will be less of an issue where the barrier is a modular structure, e.g. constructed from metal cartridge elements.

- **Assessment of new barrier products:** In this instance there is no historical data and no product already in service. Performance data would therefore only be determinable in real time. Such tests would ideally be undertaken using the in situ test methods, since test samples removed from the roadside could not be reconstructed within a laboratory exactly as they were in situ; this will be less of an issue where the barrier is a modular structure, e.g. constructed from metal cartridge elements.

4.1 Causes for loss of intrinsic acoustic characteristics and mitigating measures

Based on published literature and the feedback from manufacturers responding to the QUESTIM noise barrier survey, many of the noise barrier products on the market are not considered to degrade acoustically over their working lifetime; only 5 of the manufacturers/suppliers who responded stated that the acoustic elements within their noise barriers deteriorate acoustically over time.

This section provides a short overview of natural factors affecting the loss of intrinsic acoustic performance characteristics. The effects of poor quality installation, etc. are discussed in Section 4.3.

Timber: Timber barriers are susceptible to acoustic degradation (e.g. Morgan, 2010) since the planks/boards making up the barrier will warp or shrink resulting in gaps between planks, are susceptible to knots and, particularly in the case of gravel boards, are susceptible to rotting. To address these issues, manufacturers use good quality timber and pressure treat all elements with appropriate preservatives which are resistant to fungi, boring insects and other wood destroying organisms; this protects against the effects of moisture, thereby helping to reduce the effects of warping/shrinking and may help to protect against damage from de-icing salts and chemicals.

The occurrence of gaps is most frequently addressed by either overlapping planks/boards or use of a tongue and groove construction. It is noted that where the acoustic elements are

constructed on site from component planks/boards/timbers, then care should be taken to ensure that any cut surfaces are treated with an appropriate preservative.

Sound absorptive materials: The acoustic performance of sound absorptive materials will also be adversely affected if the materials are allowed to delaminate or sink/compress to the bottom of the acoustic element due to the effects of vibration, the presence of moisture or if dirt/dust is allowed to accumulate (although in the case of the latter, sound insulation performance of the barrier may increase). At the writing, no data has been identified to quantify these effects. Many commercially absorptive materials such as mineral wools are designed to be moisture repellent; compression can to a large extent be avoided through the use of denser materials (although this may affect the absorption characteristics) and ensuring that the materials are well supported or retained.

In the case of cartridge-type systems such as metal barriers, where the sound absorptive materials is mounted behind the perforated facing of the cartridge, evidence of settling or delamination is not readily visible. In such instances, it is necessary to allow a drainage path for the absorptive material; this can be achieved by supporting the material away from the walls of the cartridge.

For barriers where the absorber is mounted on the front of the barrier structure, as is typically the case with sound absorptive timber barriers, the absorber should be protected by an appropriate protective membrane that must itself be resistant to UV degradation and the effects of agents such as de-icing/salt sprays, etc. and similarly supported to prevent settling over time.

Concrete: Factors affecting **concrete barriers** such as freeze/thaw cycles UV degradation and exposure to de-icing salts and chemicals will primarily affect the structural integrity of a barrier rather than its acoustic performance; however this is potentially an issue for porous concrete or wood cement concrete barriers, since they can result in the physical loss of the porous surface from the structure of the barrier.

As with other sound absorptive materials, porous concrete barriers will also be affected by the accumulation of dirt/dust and other materials in the pores. Conversely, it was noted by one manufacturer/supplier that the absorption properties of concrete barriers may actually increase as the surface of the barrier undergoes abrasion.

4.2 Practical data on acoustic durability

It has been established from the QUESTIM noise barrier survey that declaration of acoustic durability by manufacturers/suppliers in terms of absolute changes in intrinsic performance is not widespread. This has been supported by a subsequent separate review of a random sample of manufacturer/supplier technical data sheets. This is driven by the combination of acoustically robust products, a lack of long-term performance data for those barriers where performance does degrade and no mandatory requirement to specify acoustic performance over the working lifetime of noise reducing devices (declaration of the product performance as NPD is sufficient for the purposes of CE marking).

After taking account of follow-up investigations with respondents to the QUESTIM survey (see Section 3.5), it was found that 8 of the manufacturers/suppliers who responded to the

survey declare acoustic performance in terms of years that the performance is expected to last. Only a single respondent to the survey declares absolute changes in acoustic performance after 5, 10, 15 and 20 years; in that case, the noise barrier in question is constructed from aluminium cartridge elements and the associated performance values are summarised in Table 4.1.

Table 4.1: Acoustic durability data, in terms of change in intrinsic characteristics, as identified from the QUESTIM noise barrier survey

Barrier type	Characteristic	Years of exposure			
		5 years	10 years	15 years	20 years
Aluminium barrier	Change in airborne sound insulation	0	0	0	0
	Change in sound absorption	0	0	0	-1

The figures in the Table are based primarily on measurements rather than expert judgement, being in part a comparison between a new barrier and a 23 year old barrier constructed from the identical design of acoustic elements. The results from the assessment showed that the sound absorption performance of the acoustic elements changed by only 1 dB, which was considered to be due to dust and detritus collecting in the fibres of the sound absorptive material. It was suggested that after 20 years the sound absorption properties would still be such that the barrier would be category A3.

Moving forwards, of the 15 manufacturers who responded to the QUESTIM noise barrier survey, 6 declared that they already test the initial sound insulation properties of their products using the in-situ test method in EN 1793-6. This number will increase with the revision of EN 14388, as that test method will become the recognised standard for airborne sound insulation of noise barriers. This means that even if manufacturers do not declare long-term acoustic durability performance, there will be the scope for NRAs to investigate this independently if so required using the declared performance as a benchmark (again this is only for intrinsic performance and not for levels at noise sensitive receivers screened by the barrier).

Based on the lack of durability data reported by manufacturers, the remainder of this Section focuses on a review of available data identified from research studies.

The QUIESST project (QUIESST, 2012a) collated a comprehensive dataset of performance data from both research projects and manufacturers for a range of different types of noise barrier, broadly categorised as timber, metal, concrete, and other (the latter encompassing plastic, transparent, photovoltaic and earth/green barriers). This data is published in a publicly accessible database (QUIESST, 2012b) and includes results for sound reflective and sound absorptive barriers obtained from laboratory tests (to EN 1793-2 and EN 1793-1 respectively) and in-situ tests (to EN 1793-6 and CEN/TS 1793-5 respectively and also sound insulation to NFS 31089 (AFNOR, 1990)).

However, consultation with the QUIESST database manager has established that the data within the QUIESST database relates solely to noise barriers in new condition; no data is included on barriers in aged condition or from any time-based studies that can be used within QUESTIM to examine acoustic durability

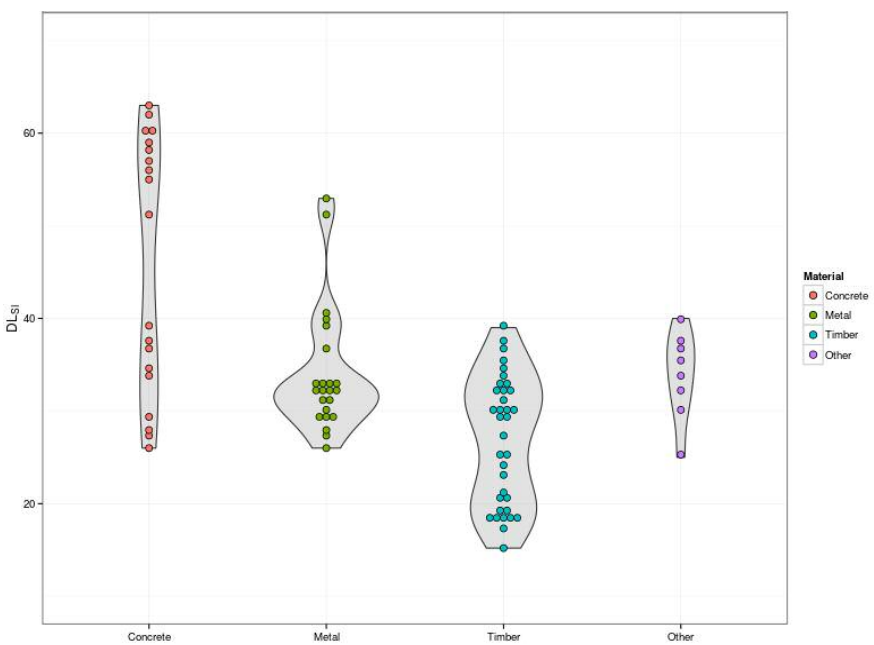
However, for illustrative purposes, Figure 4.1(a) on the following page reproduces an analysis of the database which shows the distribution of new-condition performance data obtained from EN 1793-6 tests. Similarly, Figure 4.1(b) on the following page suggests that there is a good correlation between data measured using the laboratory test in EN 1793-2 and the in-situ test in EN 1793-6, with the laboratory test underestimating performance compared to the in situ test.

The two methods give different results because the Part 2 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. It is noted that Figure 4.1(b) correlates all barrier types as a single dataset. Due to the relatively small number of cases where results were available from both laboratory tests and in situ tests on the same barrier, it was not possible to determine a robust relationship for individual barrier materials. Relationships between laboratory and in situ results presented by other authors, e.g. Watts and Morgan (2005) and Garai and Guidorzi (2000), were similarly affected by the availability of relatively small datasets.

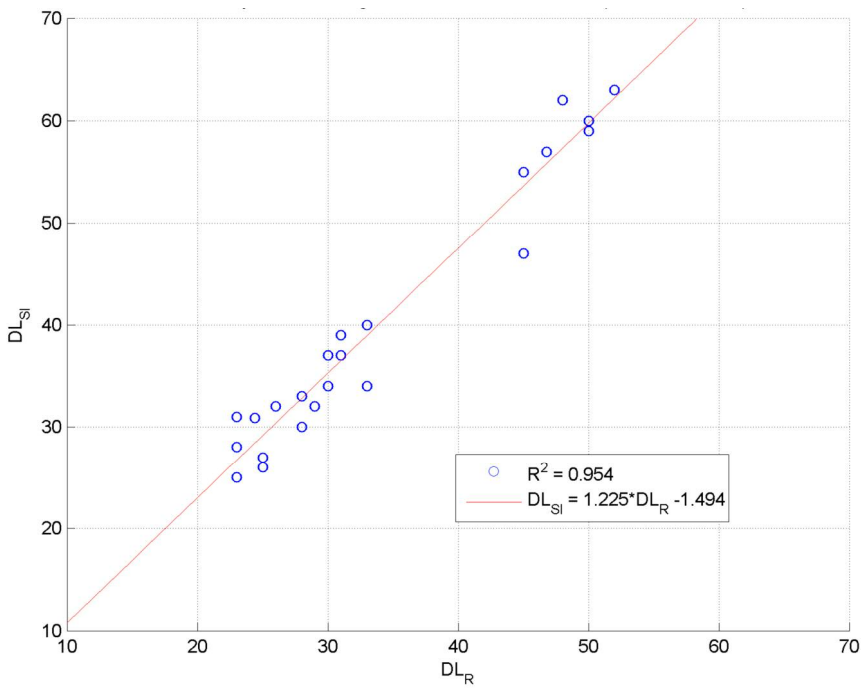
With regard to assessments of noise barriers that have been artificially aged, Bochen (2013) reported tests of sound absorptive panels that had been subjected to ageing lasting 150 cycles (based on a simulated environment representative of Upper Silesia, where 100 cycles corresponds to 2-2.5 years). The performance of the panels was assessed in new condition and then after every 50 cycles. The sound absorption properties of the samples were found to deteriorate by 4 dB, from $DL\alpha$ = 14dB (Category A4) in new condition to $DL\alpha$ = 10dB (Category A3) after 150 cycles. An equation for predicting the time-dependant $DL\alpha$ was derived for these climatic conditions, which predicted that the panels would be rated as upper-limit category A2 after 7 years and lower-limit category A2 after 12 years and A1 rated after 36 years.

Only two research studies have been identified whereby the acoustic performance of noise barriers has been investigated over an extended period without the use of accelerated ageing techniques. Both of these studies used the EN 1793-6 test methods and are summarised as follows:

- A research project undertaken in the UK to investigate the acoustic durability of timber noise barriers on the English strategic road network (Morgan, 2010) has presented data from EN 1793-6 roadside tests for three different types of timber barrier (single-leaf reflective, double-leaf reflective and sound absorptive). Due to site logistics and the low height of many barriers found on the UK network at the time, only a limited number of barriers were tested. Additionally, in the majority of cases it was not possible to determine the expected initial performance (in terms of either DL_{SI} or D_{LR} for sound reflective barriers and DL_{RI} or DL_{α} for sound absorptive barriers); this was a particular issue where the tested acoustic elements were known to have been constructed on site, i.e. not prefabricated. These factors resulted in datasets that were either too small or too scattered to allow the derivation of even indicative acoustic degradation curves.



(a) In-situ sound insulation performance for different noise barriers
(the grey area represents a so-called violin plot which shows a kernel density estimation of the probability density of the data)



(b) Relationship between results from EN 1793-2 and EN 1793-6 tests
(all barrier types)

Figure 4.1: In-situ sound insulation performance data as collated within the QUIESST project database on noise reducing devices (from http://viona.ait.ac.at/~quiesst/)

Figure 4.2 shows the data collated for single-leaf reflective noise barriers. The DL_{SI} values of 32 dB at 0 years correspond to roadside barriers where the initial performance was assumed, based on discussions with industry experts, to have been rated Category B2 (to EN 1793-2); however these barriers were all in-situ constructions (rather than pre-fabricated) meaning that the actual performance of the new construction, if it could have been tested, could have been significantly less than the assumed value and as such, these datapoints should be considered as outliers.

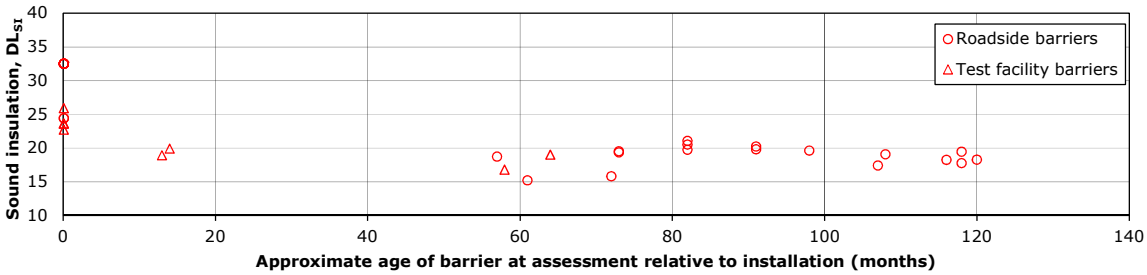


Figure 4.2: Airborne sound insulation performance of single-leaf reflective timber barriers as a function of age (from Morgan, 2010)
(0 months: Point of installation)

For this type of barrier, it was concluded that any degradation in acoustic performance occurs during the first 5 years after construction. Depending upon the initial performance, this decrease appeared to be of the order of 4-7 dB. These effects may unavoidable due to the behaviour of timber as it is exposed to the elements; however to minimise these effects as far as is practicable, good quality raw timber should be used, suitably treated and where possible the acoustic elements pre-fabricated.

- A study by Conter et al (2007) looked at the long-term performance of sound absorptive aluminium barriers; the study was performed using the in-situ test method in EN 1793-6 and tested two roadside barriers of the same design, one constructed in 1994 and one constructed in 2005. The results showed that the sound absorption performance, DL_{RI}, of the new barrier was 0.3-0.8 dB greater than that of the old barrier.

Summary of acoustic performance data

A review of data from manufacturers and research data has identified only minimal data related to changes in acoustic performance over the working lifetime of noise barriers, irrespective of whether laboratory or in situ test methods are considered.

Many types of barrier are considered to be acoustically durable over their working lifetime. Where manufacturers specify lifetime performance, this is typically in terms of service life in years.

What acoustic data is available is insufficient to allow relationships between barrier age and acoustic performance to be derived.

4.3 Other factors affecting acoustic durability

In addition to exposure to environmental conditions and any natural degradation due to the type of materials used, there are a number of other issues that can affect intrinsic acoustic durability and potentially the working lifetime of the barrier.

Installation: Poor quality installation through failure to adhere to manufacturers installation instructions immediately increases the risk of performance degradation. Poor quality installation frequently manifests in the form of clearly visible defects such as misaligned or non-vertical posts, poor fitting of seals between acoustic elements or between acoustic elements and posts, and gaps between panels or between the lowest barrier element and the ground.

The use of prefabricated acoustic elements rather than elements constructed on site from component materials, as can be the case with timber barriers, can play an important role in determining the quality of the installation, since there will be a far greater level of quality control under factory conditions and there is a far greater likelihood that the product will provide a level of intrinsic acoustic performance equivalent to the declared performance used during procurement. Only one of the responding NRAs (Ireland) was found to prohibit the installation of any non-prefabricated products**.**

The use of experienced installers, who are familiar with the products, combined with visual inspections of the newly installed barrier, either on completion or during the installation are perhaps the most significant factors in ensuring a correctly installed noise barrier.

Regarding the installation of noise barriers, of the 18 NRAs who responded to question in the QUESTIM noise barrier survey, 9 stated that they use highway maintenance teams/contractors to install barriers, whilst the other 9 all use specialist installers (or manufacturers/suppliers who also install their own products). Of the 15 manufacturers/ suppliers who responded to the question in the survey, 10 declared that they install their own products, whilst 14 also supply products for installation by third parties. All three of the installers who responded to the QUESTIM noise barrier survey declared that they install barriers using prefabricated acoustic elements but only two install barriers where the acoustic elements are manufactured on site. Installation of the full range of barrier types used on NRA networks was addressed across the responding group. In terms of manufacturer/supplier instructions, the response was split between components being accompanied by installation instructions and installers using their own knowledge and experience.

Access gates: An additional factor affecting the performance of a noise barrier that is not always correctly considered is the inclusion of access gates in noise barriers, which may be required to allow emergency escape from/access to the carriageway or to allow maintenance workers to access other roadside assets. It is important that the gates are of the same acoustic quality as the barrier and constructed in such a manner to eliminate or at least minimise the effect of sound leakage through gaps around the gate frame. It is observed that in many cases, access gates are not properly designed, if not installed as an afterthought, and are therefore of poor quality/poorly fitted; this can therefore affect not only the integrity of the gate but the barrier itself. An alternative solution (Parker, 2006) would be to create an absorptive overlap in the barrier at the point of access, such that a gate would not be required, where the inner faces of the walkway would be sound absorptive. Most of the noise

from the road would be trapped within the walkway zone, thereby maintaining the acoustic integrity of the barrier.

4.4 Monitoring and maintenance of noise barriers

Quality control monitoring for new installations: The undertaking of visual inspections during installation can ensure that any defects identified can be potentially corrected or prevented from being repeated elsewhere in the installation.

Of the 18 NRAs who responded to the related question in the survey, 14 stated that they undertake some form of assessment; where no assessments are performed, this was due to the small-scale/limited use of noise barriers. Fourteen NRAs stated that visual inspections of the barrier are undertaken, whilst nine stated that acoustic assessments of some kind are used. A range of different approaches are used for acoustic assessments, including ISO 10847 measurements or similar (a standard position behind the barrier is sometime adopted, although measurements are most commonly taken in the far-field), EN 1793-6 and CEN/TS 1793-5 measurements or measurements using other standard approaches for environmental noise measurements (i.e. methods not specifically designed for the assessment of noise barrier performance). This means that the purpose is not necessarily to assess relative to the manufacturer's declared performance but often to compare with predicted noise levels at positions behind the barrier.

Of the 15 manufacturers who responded to the question in the survey, 3 declared that they undertake acoustic tests, 8 declared that they undertake visual inspections. The installers who responded to the survey also confirmed that they undertake visual inspections of completed installations.

Monitoring of in-service barriers: Of the 18 NRAs who responded to questions in the QUESTIM noise barrier survey on monitoring of noise barriers, only one NRA reported that no monitoring of any kind is undertaken.

The majority of NRAs (15) reported that they already undertake visual inspections, whilst four (Finland, Poland, Lithuania and Greece) reported that they undertake monitoring of acoustic performance although this is not necessarily a regular occurrence.

In terms of *in-situ acoustic testing* of barriers on the network, it was noted that 8 NRAs currently undertake such monitoring (Slovenia, Netherlands, Norway, Malta, Estonia, Poland, Switzerland and Greece). However, further investigations have revealed that these are not necessarily routine measurements but may be taken for a variety of reasons, e.g. for to validate/compare with modelled/predicted noise levels, for research investigations regarding barrier efficiency or durability, or to resolve disputes over the perceived performance of the barrier. A range of different approaches are used, including ISO 10847 measurements or similar (a standard position behind the barrier is sometime adopted although measurements are most commonly taken in the far-field), EN 1793-6 and CEN/TS 1793-5 measurements or measurements using other standard approaches for environmental noise measurements (i.e. methods not specifically designed for the assessment of noise barrier performance).

The main reason given for not performing such acoustic tests was stated as being budget constraints.

In terms or special precautions required for monitoring or inspection of barriers, eight of the NRAs who responded to the survey indicated that some form of traffic management is necessary; two NRAs gave no form of response. In terms of any logistical or practical problems that affect the monitoring and/or inspection of noise barriers on NRA networks, the primary problems reported by NRAs was the presence of excess vegetation and restricted access. Such issues are highlighted within Section 5.4 of the report as being key factors affecting monitoring and maintenance; however these cannot always be easily addressed.

Maintenance/repair of noise barriers: The general approach adopted by NRAs regarding maintenance is that barriers should require minimal maintenance over their working life.

Of the 18 NRAs who responded to questions on maintenance and replacement, only five NRAs stated that they have specific maintenance procedures in relation to noise barriers, while only four NRAs stated that they have specific policies in place regarding noise barrier replacement – these policies generally related to replacement only when the barriers are damaged or after very significant time; some NRAs stated that the noise barriers on their network are up to 40 years old. It is expected that these policies are largely driven by a combination of cost and practicality, since maintenance will in many cases require some form of traffic management to be undertaken.

The responses received from noise barrier manufacturers indicate that maintenance requirements vary depending upon the design and materials from which the noise barrier is constructed. Where maintenance guidelines have been obtained, these focus largely on maintaining aesthetic characteristics and may have relatively little impact upon intrinsic acoustic characteristics. However, the one maintenance area where care must be taken not to damage or adversely affect intrinsic acoustic performance is in the cleaning of noise barriers; this is particularly the case when cleaning sound absorptive barriers using high-pressure washer systems; in such instances, water pressure should be reduced or the panels sprayed from a greater distance. Similarly, care should also be taken if solvents or similar are used to clean acoustic elements or to remove graffiti, etc.

Vegetative or green barriers are likely to require regular maintenance since they will require regular trimming to ensure that growth is kept under control.

Replacement of noise barriers: Where NRAs responded to the questions regarding replacement of barriers, only four NRAs stated the existence of specific policies; the most common criteria for replacement, even for those NRAs without specific policies, is when barriers are physically damaged or structurally unsound; as such, there was generally no specific timescale associated with replacement. Where timescales were quoted, these were typically in excess of 20 years. Some NRAs stated that the noise barriers on their network are up to 40 years old. Only 4 NRAs use degraded acoustic performance as a criteria for replacement.

Repair of barriers is eased considerably when the barriers is constructed from modular elements such as cartridge type sections, since it is possible to only replace the damaged elements and works can be undertaken far more efficiently than if entire sections of a barrier need to be replaced.

Summary of monitoring and maintenance

The survey suggests that the use of some form of inspection to ensure the quality control of newly installed noise barrier products is commonplace, with visual assessments being the most common approach adopted by NRAs. Where acoustic assessments are undertaken, these may use a wide range of methods since the purpose is not necessarily to assess relative to the manufacturer's declared performance but may be to compare with predicted noise levels at positions behind the barrier.

Monitoring of noise barriers over their lifetime is also commonplace, again with visual inspections being the prevalent method. It is noted that the undertaking of either visual or acoustic assessments can be hindered or even completely prohibited by the need for traffic management to protect the assessors or by restricted access to the barrier.

In most cases, maintenance and replacement of noise barriers is only undertaken when barriers are damaged or structurally unstable.

5 Recommendations for assessment, monitoring and use of noise data

For the purposes of recommendations put forward as part of the QUESTIM project, two types of monitoring/assessment are defined:

- **Acoustic assessment:** These assessments focus on the noise reduction performance offered by a noise barrier, in terms of its **intrinsic characteristics,** i.e. those determined in accordance with the EN 1793 suite of standards and EN 14389-1 for long-term acoustic durability (see Section 3.2 of this report).

  The justification for this focus is that these are the characteristics declared by the manufacturer/supplier as part of the CE Mark/Declaration of Performance (unless the product is declared as NPD (No Performance Determined)) and the characteristics most commonly used by National Road Administrations (NRAs) for when specifying the type of noise barrier to be implemented on a scheme.

  The use of intrinsic performance characteristics means that values cannot be easily translated to performance in the far-field at noise sensitive receivers being screened by the barrier; indeed, unless the receivers are in close proximity to the barrier or the barrier is high then the physical geometry of the barrier will be the dominant factor in defining its far-field performance. This means that the definition of acoustic durability derived from intrinsic characteristics may differ from general NRA expectations of acoustic durability, which may be more aligned with whether or not a noise barrier maintains noise levels at the noise sensitive receivers screened by it over its working lifetime. That expectation will be linked more closely to the structural integrity of the barrier. In such instances, the use of test methods such as that set out in ISO 10847 or other standards related to the measurement of environmental noise levels should be used to determine noise levels at selected positions behind the barrier; this would require an initial measurement following installation to provide the baseline level of screening performance.

- **Visual assessments:** These assessments focus on the physical condition of the installed product in terms of defects/faults (which arise either because the barrier components are incorrectly installed or because the barrier has become damaged), overall structural/physical integrity and aesthetic condition; any judgement on acoustic performance is therefore inferred from the observations. The actual extent to which any identified defects will affect intrinsic acoustic performance will vary; it is expected that unless the noise sensitive receivers protected by a noise barrier are in close proximity to it, only major failures, e.g. missing acoustic elements, are likely to adversely affect noise levels at the receivers to an extent that will be detectable by members of the public.

5.1 General recommendations

From the perspective of NRAs, it is recommended that assessments of some type should be performed both when a noise barrier is newly installed as well as at stages over the working

lifetime of the barrier. The QUESTIM noise barrier survey identified that the assessment of newly installed barriers by some method is commonplace amongst NRAs. Monitoring over the lifetime of the barrier is based primarily on visual inspection and the frequency of inspection also varies widely.

5.1.1 Newly installed barriers

It is recommended that some form of assessment is undertaken as a form of project sign-off, compliance with contract requirements or conformity-of-production of the barrier. This will serve to primarily provide an indication as to whether the product has been installed in accordance with any manufacturer/supplier instructions or in line with the intended design.

As a minimum requirement, this should be a **visual inspection** of randomly selected sections of the noise barrier. Depending upon the type of barrier and the expertise of the assessor, this will mainly identify obvious physical defects in the installed product that may require to be corrected before the installation can be accepted or is deemed fit-for-purpose.

However, it is noted that visual assessments cannot ensure that the intrinsic acoustic performance characteristics of the installed product are as stated by the manufacturer/ supplier; **acoustic assessments** should be performed if such a check is required by the NRA.

The collection of initial in-situ acoustic performance data is also relevant if an NRA wishes to monitor the acoustic performance of the installed barrier over its working lifetime of the noise barrier. This avoids reliance on any declared initial performance characteristics, which may be particularly relevant in situations where the acoustic elements of the barrier are fabricated on-site rather than off-site under factory conditions, e.g. wooden noise barriers; in such circumstances, the actual intrinsic acoustic characteristics may differ significantly from those related to the CE marked product, resulting in an installation that does not comply with that expected.

Timing of assessments: Where the assessment is to be used for project sign-off/acceptance of the final installation, the point at which they are undertaken will most likely be determined by the NRA. Otherwise, it is recommended that the assessments for initial condition, either visual or acoustic, be undertaken either during the construction/installation phase or within 1-2 months of the installation being completed. The former offers several benefits in that

- it allows defects/faults arising through poor quality workmanship to be addressed (e.g. incorrectly fitted seals, misaligned elements, etc.) so that they can be corrected before a scheme is signed off or so that the problems are not carried through across the whole scheme, and

- it may overcome restrictions regarding traffic management and access to the rear of the barrier (see Section 5.4 for further discussion of this point).

Scale of assessments: The scale of any initial assessment is likely to influenced by the length of noise barrier being installed, the time at which the inspection is undertaken (i.e. during or following completion of installation) and the available access (as discussed later in Section 5.4). The following general comments are noted:

- *Visual inspections:* These may be achievable along the full length of the barrier, unless the extent of the barrier is particularly great. If direct access to the barrier façade is not possible this means that the level of detail of the inspection will be reduced; in such instances, a drive-by inspection may still allow the most visible flaws/defects (if any) to be identified.

- *Acoustic assessments of intrinsic performance:* The scale of such measurements will be at the discretion of an individual NRA and may be influenced by the proposed end use of the information gathered.

  Barriers constructed in-situ from component materials, e.g. as is sometimes the case with timber barriers, may require a more in-depth assessment (i.e. more measurements along the installed length) than those assembled from pre-fabricated elements.

  It may be deemed sufficient to use only limited acoustic assessments *in parallel with* a visual assessment. This would require only one or two measurements on an installation at random locations (although preferably where the barrier is highest if the height varies along the length) unless visual inspection identifies specific locations along the barrier where it is suspected that the actual in-situ performance of the barrier may be less than that declared by the manufacturer as part of the product's CE mark; additional measurements at these positions would be compared with those measurements on 'good' sections of the barrier to demonstrate the effect of the defects.

  Where a more detailed assessment is required, it is suggested that these should be performed at regular intervals along the length of the barrier, e.g. every 100m, covering sections of the barrier spanning between 2 or 3 adjacent posts.

- *Acoustic assessments to determine the initial noise levels at noise sensitive receivers:* Where ISO 10847 type measurements are taken following the installation of a noise barrier, then these should ideally be at the same positions used for any pre-installation measurements. If such measurements were not performed, then the number and location of measurement positions should be determined on a case-by-case basis.

5.1.2 Monitoring noise barriers over their working lifetime

It is expected that the type and frequency of in-service monitoring/assessment will, in reality, be driven by a combination of costs, logistics and the maintenance/replacement strategies adopted by individual NRAs.

However, it is important to note that the types of materials used for the acoustic elements and the likelihood of any physical/acoustic degradation may mean that a common policy cannot be readily adopted. Manufacturers may provide guidance on the measures that should be undertaken to maintain their products in order to achieve the maximum possible working life and to maintain performance which may also influence the frequency of any monitoring.

Visual assessments are expected to be the preferred option based on the likely logistical and practical criteria that require to be satisfied for performing acoustic assessments; these are discussed in the following sections. It is, however, noted that in the absence of manufacturer/supplier data on long-term acoustic durability, NRAs may wish to perform at least occasional acoustic assessments to collate their own data.

Frequency of monitoring: Based upon the information identified on acoustic durability of the types of noise barriers used on NRA networks, the following recommendations are put forward:

- **Visual inspections:** It is recommended that visual inspections of noise barriers on NRA networks should be undertaken on an annual basis. If such inspections highlight damage to/defects in the noise barrier that are considered likely to adversely affect it's screening performance then measurements of acoustic performance may be required to supplement the inspections.

- **Acoustic monitoring:** Based on the findings reported elsewhere in this report, many barrier types are considered not to degrade acoustically over their working lifetime. Investigations by Morgan (2010) into timber barriers suggest that intrinsic characteristics of screening performance may degrade within the early service years before stabilising; for timber barriers or other barriers where performance might be expected to degrade, acoustic performance 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.

Scale of monitoring: The extent to which in-service monitoring is achievable for a noise barrier installation will be largely dominated by access to the barrier (see Section 5.4). The following general comments are noted.

- *Visual inspections:* These may be achievable along the full length of the barrier, unless the extent of the barrier is particularly great. If direct access to the barrier façade is not possible this means that the level of detail of the inspection will be reduced; in such instances, a drive-by inspection may still allow the most visible flaws/defects (if any) to be identified.

- *Acoustic assessments of intrinsic performance:* These measurements will be strongly determined by access to the rear of the barrier. If access to the rear is only available by means of emergency access gates, these might be some distance apart, depending upon local requirements for the spacing of such gates. In instances where access is not a constraining factor, monitoring should ideally be carried out at the same positions used for any initial assessment or focus on sections of the barrier

where performance is anticipated to be below expected levels, e.g. due to visible damage to acoustic elements or reduced structural integrity.

- *Acoustic assessments to determine the noise levels at noise sensitive receivers:* Where ISO 10847 type measurements are taken, then these should ideally be at the same positions used for any pre-installation or initial performance measurements. If such measurements were not performed, then the number and location of measurement positions should be determined on a case-by-case basis.

5.2 Acoustic performance monitoring

For the specification and procurement of noise barriers to be used in road traffic noise mitigation schemes, the QUESTIM noise barrier survey indicated that the majority of NRAs currently specify acoustic performance requirements in terms of the single number ratings and/or categories used within EN 1793-2 and, for sound absorptive barriers, also within EN 1793-1.

With the forthcoming revision of EN 14388, manufacturers will declare airborne sound insulation performance to EN 1793-6 and, in the longer term, sound reflection performance to EN 1793-5. It is therefore expected that current NRA approaches for specifying noise barriers will continue, albeit using instead the single number ratings and/or categories from these in-situ test standards. It is noted that going forwards (see Section 3.2.4 of this report) there are proposals to withdraw the categorisation of acoustic performance from the standards, meaning that any declaration would be done based upon the specification of absolute values.

It is therefore recommended that all acoustic performance monitoring of installed noise barriers be performed using the in-situ test methodology set out in EN 1793-6. Similarly, in the case of sound absorptive barriers, it is proposed that monitoring should be done using the revised in-situ method (with a 9-point receiver array) once it is published in the forthcoming revision of EN 1793-5. This will allow performance of intrinsic characteristics to be assessed against declared values.

Although other test methods have been identified which focus on intrinsic performance (e.g. using sound intensity measurements; see Section 3.3), no robust correlation necessarily exists between results from these methods and the in-situ EN standard tests.

One potential concept for identifying the location of specific defect points within a noise barrier has been demonstrated by Puš et al (2013), based on the use of acoustic cameras. The principle behind the research is not to correlate results with those from the EN test methods but rather to use the data in combination with 3D calculation models to determine the impacts of the defects on noise levels at sensitive receiver positions in the far field. In light of the potential complexity of input data into the 3D model in terms of geometry, etc. it remains to be seen in the longer term whether such a technique could be readily applied (in terms of both the acoustic camera and the modelling), or whether they can be used to produce generic guidelines on the impacts of defects in noise barriers.

There are a number of considerations, discussed below, that must be taken into account when determining whether the in-situ test methods set out in EN 1793-6 and EN 1793-5 can

be routinely applied by NRAs, or whether their use will be restricted based on site and logistical considerations.

Noise barrier height: The height of the noise barrier is one of the most important characteristics and will vary based on the local site geometry, the location of the noise sensitive receivers to be screened and the level of noise reduction required screening required. The QUESTIM noise barrier survey indicated that the lowest barriers used by NRAs range from 0.5-2.5m in height.

The type of method used within EN 1793-6 and EN 1793-5, which uses windowing operations in the time domain and a defined-profile temporal window, means that the lower frequency limit of sound insulation and sound reflection measurements respectively depend on the smallest dimension (most commonly the height rather than the length) of the noise barrier under assessment.

Within the EN 1793-6 Standard, Figure 13 shows how the low frequency noise limit changes with the height of the noise barrier; as the barrier height decreases, so the lower frequency limit changes. For product certification purposes, and thereby for the declaration of single number ratings according to the standard, the dimensions of the test sample (a height of 4.0m and a width of at least 6m) mean that the single number ratings of performance are calculated for a frequency range 200 – 5,000Hz.

Figure 13 in the standard shows that for a 2m high barrier, the lowest usable frequency is approximately 600 Hz, whilst for a 2.5m high barrier the lowest usable frequency is approximately 315Hz; this means that when comparing barriers of identical design/construction with differing heights, the difference in the lower frequency limit, and therefore valid one-third octave bands, will result in different values of single number rating. This has been illustrated, for example by Morgan (2010), where comparisons between 4m and 2m high timber barriers of identical design (using lower frequency limits of 315 and 800Hz respectively) resulted in a difference in single number rating of 1.7 dB, whilst Bull et al (2013) showed a 3 dB variation in single number rating when using lower frequency limits of 200 and 500Hz.

Considering application of the method at the roadside, then for barriers in excess of 4m high, acoustic assessments can most likely be carried out by performing the measurement as if the barrier height was only 4m, i.e. with the loudspeaker and the centre of the microphone array at 2.0m above ground. However, for barriers where the height is lower than 4m, it may be more appropriate to compare valid one-third octave band sound insulation indices (based on the lower barrier height) rather than the single number ratings. Alternatively, it may be possible to recalculate the declared single number rating using a lower one-third octave band limit applicable to the height of the roadside barrier; such an approach was also shown to be feasible by Morgan (2010).

Similar issues will arise when considering the test method for sound reflection in EN 1793-5.

Monitoring equipment requirements: The EN 1793-6 and EN 1793-5 standards include specifications for the monitoring equipment. In particular, they specify the use of the following

- Type 2 microphones in accordance with IEC 61672-1 (2013) with a maximum diameter of ½".

- A loudspeaker with a single driver, constructed without any ports (such as those which would enhance low frequency response), any electrically active or passive components affecting the frequency response and a smooth magnitude of the frequency response resulting in an impulse response under free-field conditions with a length not greater than 3ms.

Additionally, the standard requires the use of an input signal to the loudspeaker that is deterministic, exactly repeatable and set to avoid any non-linearity of the loudspeaker; it states that "*this European Standard recommends the use of a MLS* (Maximum Length Sequence[2]) *signal as test signal*", but acknowledges that other types of signal, e.g. a swept sine[3], can be used providing that "*results can be shown to be exactly the same*" (see Section 4.4.3 of EN 1793-6).

There are concerns that the cost of measurement systems that are fully compliant with the standard can be prohibitive. The following reports on studies that have been undertaken to investigate whether equipment that is not compliant with the standard can be used.

- **Choice of input signal:** Mahon et al (2012) compared measurements on an acrylic, reflective noise barrier using an MLS signal with those using a swept sine signal. It was observed, as expected, that there was no appreciable difference between the measured sound insulation indices, confirming the suitability of both types of input signal.

  However, it is known that in some conditions, e.g. excessive background noise, differences can be observed in the acoustical characteristics of a noise barrier assessed using the two different input signals. Measurements performed by Guidorzi and Garai (2013) to examine the effects of background noise and time variance (due to wind and temperature changes over a long measurement session) showed advantages in using a swept-sine for assessing the intrinsic acoustic characteristics of a noise barrier due to its higher dynamic range, its improved signal-to-noise ratio and its good resistance to time variance; however, in the presence of short impulsive noises, the use of an MLS signal is recommended.

  The use of a swept sine input also offers benefits in terms of the loudspeakers used for the measurements, as discussed below.

- **Choice of loudspeakers:** Careful selection is required when procuring loudspeakers for performing the EN 1793 tests to ensure that they conform to the above requirements; it is known that there are loudspeakers on the market specifically designed for performing tests to the EN standards. However, Mahon et al (2012) investigated using a non-compliant loudspeaker to perform EN 1793-6 measurements; the commercial speaker selected was rated at 20W (compared to the purpose-built ADRIENNE speaker normally used which was rated at 225W) and included a cross over and a low frequency enhancement. When tested using an MLS

[2] A maximum-length sequence (MLS) is a type of pseudo-random binary sequence.
[3] Use of a swept sine signal allows higher loudspeaker output levels to be used, because the energy is concentrated at single frequencies for a short duration within the signal rather than at all frequencies over the full duration of the signal.

signal as the input, the loudspeaker had insufficient power to provide an adequate signal-to-noise ratio; however, this was not the case when using a swept sine input signal. The single number ratings obtained using the swept sine input signal were within ± 2dB repeatability. This suggests that it may be possible to use speakers that do not comply with the requirements of the standard, providing they are capable of outputting a sufficient level of the frequency range of interest. The measurements performed by Bull et al (2013) used a 600W loudspeaker.

Tests by Mahon et al (2012) suggested that using such a speaker in non-linear range[4], with a swept sine signal and appropriate processing of the data (Farina, 2000) is plausible, although operating the speaker in this way has the potential to damage the speaker.

Mahon et al (2012) also conducted tests to examine the suitability of using a non-compliant loudspeaker for sound reflection tests to CEN/TS 1793-5. Based on preliminary findings using the same speaker as for the sound insulation tests, the results suggested potential for the use of a non-compliant speaker.

- **Number of microphones:** The EN 1793-6 method requires measurements at nine positions arranged in a 3 x 3 array.

  In order to minimise the time spent by operators on the roadside, particularly if working in close proximity to passing traffic, it is desirable to minimise the duration of the measurements. To achieve this whilst complying with the standard therefore requires, as a minimum, 9 microphones (thereby reducing time spent repositioning/moving around the array) and ideally to be able to measure at all nine positions simultaneously. Many commercial systems provide less than the 9 required channels; systems with more channels are available but costs may be prohibitive.

  Mahon et al (2012) therefore undertook a test to investigate whether measurements could be undertaken with an array of fewer microphones, in this case using a hexagonal 7-point array, such that there were three measurement positions common to both the 9-point and 7-point array. The differences between the arrays were less than 1 dB and suggest that use of a reduced microphone array is potentially feasible.

  Cost aside, it is noted that the time required to undertake the measurements is the primary factor for reducing the number of microphones used. If measurements cannot be performed at all microphone positions simultaneously, it is considered that unless the technique can be used to give robust results using only one or two microphones, there is no significant benefit to deviating from the nine-point array used in the standard. Further investigations are required to determine whether this is the case.

[4] Non-linear distortion refers to the generation of different frequencies measured in a loudspeaker response that are not present in the original stimulus.

Summary of monitoring and maintenance

The EN 1793 standards for in-situ testing include specifications for the measurement equipment and the input signal. Recent research suggests that

- there are potential benefits to using a swept sine input signal rather than an MLS signal;
- loudspeakers that are non-complaint with the standard may be feasible, providing that they are capable of outputting a sufficient level of the frequency range of interest and are used with a swept sine signal; and
- that use of a reduced microphone array with 7 positions may be feasible. However, the limiting constraint is considered primarily to be whether the measurements can be performed at all microphone positions simultaneously. Further investigations are required to determine whether reliable results can be obtained using a significantly reduced number of microphones, if not then, cost aside, it is not considered that there is significant benefit to deviating from the nine-point microphone array.

5.3 Visual inspections

Whilst NRAs typically require that noise barriers installed on their network should require minimal maintenance over their working lifetime, regular visual inspections will still be required to ensure the integrity of the structures. Some defects will be detectable merely as a result of drive-by inspections, particularly where there is significant damage to acoustic elements, e.g. missing/broken acoustic elements, exposed sound absorptive claddings, etc. However more comprehensive inspections may be required to detect other defects.

The aesthetics 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. Visual inspections are therefore as important to ensure that physical appearance as structural integrity.

Wherever possible, and particularly for new installations, visual assessments should be performed using the manufacturers' installation instructions as a guideline for defect detection.

The following is an overview of the types of defects/failures which might affect intrinsic acoustic characteristics that should be looked for during these inspections. Where these failures result in the occurrence of physically visible gaps, then approaches such as that shown by equation (2.1) may be used to give an indication of changes in noise level in the far-field. At the time of writing, no data has been identified to quantify such effects in terms of changes to the intrinsic characteristics. The effects of other factors which result in damaged materials can also not be quantified.

Acoustic elements: Timber acoustic elements should be inspected for the occurrence of splits and knots and to see whether individual planks/boards have warped or shrunk. Where elements have been modified on site, e.g. timbers have been cut to fit the structure, then

attention should be paid to whether the cut surfaces have been treated in order to prevent decay/rotting of the wood. Where metal, cartridge type elements are used, ensure where possible that end caps are fitted; this will help to ensure that any materials within the cartridge remain protected. In the case of porous concrete surfaces, checks should be made for cracking/spalling, as this may result in a loss of the sound absorptive component of the barrier. Alignment of all acoustic elements should also be checked to ensure that no gaps have opened up or that joints have failed.

Seals between acoustic elements or between acoustic elements and posts: The assessment should check for evidence of incorrectly fitted, missing or damaged seals as these will affect the intrinsic acoustic performance of the noise barrier by exposing joints or creating gaps between the barrier components.

Posts and fastenings: Posts should be checked to ensure that they are stable and upright; any movement of the posts may results in misalignment of or damage to acoustic elements, resulting in gaps and ill-fitting joints. The quality of any fastenings or other elements used to secure acoustic elements should also be checked.

Protective membranes for sound absorptive materials: Damage to protective membranes will expose the sound absorptive materials to the elements and potentially solutions/substances used for winter maintenance, which may affect their durability and performance. Vandalism may be a particular issue for protective membranes on sound absorptive timber barriers.

Sound absorptive materials: Aside from problems caused by damage to protective membranes, assessments should where feasible assess the stability of the sound absorptive materials on/within the acoustic elements to ensure that they have not settled/slumped. Depending upon the barrier design, this may involve dismantling acoustic elements.

Gravel boards/ground level seals. The assessments should ensure that, where used, gravel boards are in good condition and, if timber, have not rotted. Where gravel boards are not used, the assessments should ensure that there is good fitment between the ground and the bottom element of the noise barrier. Gaps at the foot of the barrier will affect the intrinsic characteristics of the barrier and in many cases, the size of these gaps will be far greater than any occurring in between acoustic elements or between elements and posts. It is not uncommon to find significant gaps beneath gravel boards caused by animals burying beneath the structure.

Drainage slits: In some instances, gaps may be deliberately left at the foot of a noise barrier to allow water drainage away from the carriageway; these gaps should be checked to see that they are not blocked/obstructed. *Note: It will be necessary to be aware in advance of the inspection that such any observed gaps are a deliberate design feature and not a result of poor quality installation.*

Doors, access gates, etc.: Check that the doors still close, the alignment and fitment of the door/gate within its frame and the presence/quality of any seals.

Vegetation: The assessment should ensure that, unless intended by design, growth of vegetation should be kept clear of both acoustic and structural elements. Depending upon

the design of the barrier, vegetation growth can result in joints between acoustic elements being opened up and damage to materials.

5.4 Factors affecting both acoustic and visual assessments

The factors set out below affect the ability of NRA staff or appointed contractors to safely undertake either visual or acoustic assessments. While solutions can generally be found, there may be cost implications which prohibit the work being undertaken.

Site access: Unless acoustic monitoring equipment can be suspended robustly over the top of a noise barrier and accurately positioned, then having readily available access to both sides of the noise barrier is necessary to be able to apply the EN 1793-6 method for airborne sound insulation. This is because the loudspeaker and microphone array are positioned on opposite sides of the noise barrier.

Access to the rear (non-traffic) side of the barrier is therefore required either around the ends of the barrier or through the barrier, e.g. via access gates installed for emergency escape from/access to the carriageway or for maintenance workers to access other roadside assets. This was observed by Morgan (2010) to be a key issue affecting the availability of test sites. It is expected that health and safety restrictions will most likely prevent access to the rear over the top of the barrier in many cases.

In the absence of suitable access points, it is considered that the use of the in-situ test methods will likely be restricted to application during barrier construction for conformity-of-production assessments.

Access to the rear of the barriers, even in the presence of access gates or direct access, can frequently be obstructed by the presence of dense vegetation either in close proximity to or directly up against the façade of the barrier. It is noted that the presence of vegetation may be deliberate, e.g. incorporated to improve the visual appearance of the barrier or to screen the presence of the barrier when viewed from noise sensitive receivers.

If regular assessments are to be undertaken, vegetation growth needs to be well managed/ controlled; this will also serve to ensure that unwanted vegetation growth over the facade of the barrier does not adversely affect its physical condition and thereby its intrinsic acoustic performance characteristics. Poor management can, in extreme circumstances (such as experienced by Morgan (2010)), mean that an environmental assessment may be necessary to determine whether vegetation can be cleared sufficiently to provide access.

The position of barriers relative to the roadside can also be a restricting factor. Examples of this include sites where barriers are located at the top of embankments and either the slope of the embankment or the available space at its crest (on either side of the barrier) are sufficiently prohibitive to allow safe access/working. This is a factor that cannot easily be addressed because the position of the barrier will be dictated by the location of the noise sensitive receivers and the topography in the immediate vicinity. It is accepted that there are likely to be locations of this type where acoustic assessments particularly cannot be performed.

Traffic Management/Health and Safety: Ensuring the health and safety of assessors working on their network is a key requirement for NRAs. Provision of a safe and appropriate working environment is just one factor to be considered.

Where barriers are located at the edge of the carriageway, then the ability to undertake either visual or acoustic assessments may be dictated by whether or not a hard shoulder/ emergency lane is present.

- Where no hard shoulder is present or the width of the hard shoulder is insufficient to allow vehicular access when it is closed with traffic cones, the use of at least a single lane closure will be a minimum requirement. Similarly, on roads, typically motorways, where the hard shoulder is made available to traffic either by hard shoulder running (the hard shoulder is opened to traffic *at busy times* in conjunction with a reduced speed limit) or all lane running (where the hard shoulder is *permanently open* to traffic), lane closures may also be required.

- Where a hard shoulder is present it may be sufficient for those individuals performing the assessment to operate from within some form of hard shoulder closure only unless local NRA policy dictates the closure of the nearest running lane as a minimum requirement. Where this is possible, then in the case of visual inspections, the use of an impact protection vehicle (IPV) may be sufficient. However in the case of acoustic assessments to EN 1793-6 and EN 1793-5, this is likely to involve the individuals performing the tests to be located at a single position for a duration that exceeds acceptable limits for use of an IPV and/or the erection of monitoring equipment in the hard shoulder. Examples of on-road testing using the EN 1793-6 method where different levels of traffic management were required have been reported by Morgan (2010) and Bull et al (2013).

This need for traffic management clearly has scheduling and cost implications for NRAs and may impact on any NRA reliability performance indicators related to traffic efficiency, e.g. 'journey time reliability' which measures the percentage of journeys between two fixed points, such as adjacent junctions on the network, that are 'on time', i.e. completed within a set reference time (Department for Transport, 2013) It may therefore determine if, when and with what frequency monitoring can be undertaken, particularly if there are extensive sections of noise barrier on an NRA network to be monitored.

One approach to overcoming this is for assessments to be undertaken simultaneously with other works on the carriageway, thereby utilising existing traffic management. However, the necessity for and frequency of such works, e.g. surfacing repairs, is likely to prohibit the monitoring of noise barriers at regular intervals. Such an approach may potentially be more easily applied during barrier construction for conformity of production assessments.

5.5 Use of noise data in PMS systems

The QUESTIM noise barrier survey of manufacturers and the literature review of published data have identified that relatively little data is available on the acoustic durability of the different types of noise barriers used by NRAs on their road networks.

This is in part due to many barrier types maintaining their acoustic performance over their typical working lifetime and, for those barriers that do not, a lack of declared/measured performance data conforming to the requirements of EN 14389-1. This will begin to be addressed, to some extent, by the forthcoming revision of EN 14388 expected, at the earliest, by the end of 2014.

It is therefore concluded, depending upon the type of barrier, that it is either unnecessary or, at the present time, not possible to derive robust relationships for the acoustic degradation of noise barriers over time. Furthermore, changes in the intrinsic acoustic characteristics used to describe acoustic performance in accordance with EN 14388 cannot be readily related to changes in noise level at noise sensitive receivers in the far-field.

Within the QUESTIM project, it was initially proposed to demonstrate the concept of including acoustic degradation data for both low-noise pavements and noise barriers within PMS systems, with the aim of informing maintenance practices and allowing top-level cost-benefit analysis.

This approach, which will be reported in the final deliverable from Work Package 5 of the project, will most likely apply the effects of acoustic degradation in broad terms, e.g. as a fixed change applied to a baseline noise level at all noise sensitive receivers within a defined road corridor, as it is not practical to perform propagation calculations for individual receivers within the corridor; such an approach would essentially be equivalent to a full noise mapping exercise.

The baseline noise levels are expected to be derived from the strategic noise maps that are prepared to meet the requirements of the Environmental Noise Directive, 2002/49/EC (European Commission, 2002). These levels are likely to already have taken into account corrections for the presence of (non-aged) low-noise surfaces and the presence of existing noise barriers. The accuracy with which the latter will have been modelled will be dependent upon the quality of input data and the noise prediction model forming the basis of the noise mapping software; this may also render any inclusion of acoustic degradation factors redundant if input data is unreliable.

Taking into account manufacturer feedback on acoustic degradation, the available performance data for noise barriers, the issues noted above and noting that NRAs undertake relatively little maintenance on noise barriers unless structures are severely damaged or are structurally unsound, it is not considered feasible or beneficial to include the acoustic performance of noise barriers within PMS systems for the purposes proposed within QUESTIM.

However, it is considered that there are still benefits for the inclusion of noise barrier data within PMS systems from the perspective of more general asset awareness. It is known that not all NRAs currently hold accurate or detailed records of the noise mitigation measures on their networks; this may mean that asset condition surveys/inspections may not be being carried out in accordance with NRA requirements. The inclusion of data within a PMS system would address such short-comings.

In addition to the centralised storage of asset data (rather than multiple databases held/maintained, in some instances by different parties), the collation of key data on noise barriers would offer a number of potential benefits to NRAs including:

- A comprehensive data record of the noise mitigation measures installed on an NRA network which could be consulted to inform the choice of barrier when, for example, implementing new barriers, by providing an indication of barriers which have been successfully/unsuccessfully used on the network, or upgrading/replacing barriers as a result of road improvement schemes, e.g. road widening.

- A comprehensive data record of noise barriers for strategic noise mapping, e.g. as required under the Environmental Noise Directive, 2002/49/EC (Insert reference), thereby improving the accuracy of strategic noise maps and potentially allowing the generation of more informed action plans.

- Recording and schedule asset inspections/monitoring and, whilst not necessarily used specifically for scheduling routine maintenance, could provide a record of if maintenance is carried out and what was done.

Based on the potential uses for the data, the following is therefore presented as an indicator of the type of data that could be recorded.

Barrier type and construction data

- Date of installation, contract ID and details of installation scheme (this could include details of why the barrier is installed/what noise sensitive receivers are being screened).

- Acoustic type, e.g. sound reflective or sound absorptive.

- Construction type, e.g. single-leaf or double-leaf, modular or continuous, single element or multi-element.

- Acoustic element composition, e.g. timber, metal, concrete; Details of any secondary construction materials, posts, etc.

- Date of acoustic element manufacture (only applicable to prefabricated acoustic elements where the manufacture date differs significantly from the date of installation).

- Height, length and, if relevant, post spacing (treating the barrier as a contiguous serious of fixed height sections).

- Name of manufacturer and/or installer.

Location data

- Road name, nearest junction numbers (where relevant) and approximate geographical location.

- GPS coordinates by fixed height section.

- Distance from the edge of the carriageway and, for barriers located on embankments, height above edge of carriageway.
- Generalised details of the noise sensitive receivers being screened by the barrier.
- Distance to the nearest residential property.

Manufacturer-declared performance characteristics

- Details of product CE mark.
- Initial acoustic performance characteristics.
    - For all barriers: Sound insulation category, corresponding single number rating of airborne sound insulation and one-third octave band sound insulation indices determined in accordance with EN 1793-6 (or, in the interim, EN 1793-2).
    - For sound absorptive barriers: Sound absorption category, corresponding single number rating of sound absorption and one-third octave band sound absorption coefficients determined in accordance with EN 1793-1.
- Long-term performance characteristics.

NRA-determined performance characteristics

- Date of last inspection/monitoring.
- Monitored acoustic performance characteristics.
    - Sound insulation and, for sound absorptive barriers, sound absorption data as determined following installation and from routine monitoring.
- Physical condition reports.
- Next scheduled inspection/monitoring (if any).

Other data

- Details of complaints lodged regarding the barrier; these may be related to performance, condition, etc.

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6 Summary and conclusions

This report has been prepared within Work Package 4 of the QUESTIM project with the objective of providing information to National Road Administrations (NRAs) on the acoustic durability of noise barriers and recommendations for the assessment and monitoring of performance.

Noise barriers are the most commonly used mitigation measure on NRA road networks, although the scale of implementation varies dramatically across Europe. Sound absorptive noise barriers are the most commonly used, but no one material is especially prevalent for the construction of acoustic elements, with concrete, timber and metal being the most widely used. The physical dimensions, particularly height, selected for noise barriers are primarily driven by the location of noise sensitive receivers relative to the barrier and the topography. However the range of heights used by the NRAs varies dramatically from as low as 0.5m to as much as 10m or greater although heights.

Standardised tests have been developed for characterising the acoustic performance of noise barriers and other road traffic noise reducing devices. These test methods are embedded in European standards and thereby the European harmonised specification standard that specifies the performance requirements and methods of evaluation for road traffic noise reducing devices. As such, declarations of performance by noise barrier manufacturers/suppliers are based on measurements using these standardised tests. It is important to note that these test methods focus on **intrinsic** and not **extrinsic** characteristics of performance, i.e. the performance of the individual materials or components rather than on how the product is used, since extrinsic measurements will be dependent upon factors such as barrier geometry, topography and distance from the road/noise sensitive receivers.

This is particularly relevant when considering how acoustic durability is defined. The link to intrinsic characteristics means that the definition used in European standards and by manufacturers/suppliers as part of a products CE mark may differ from general NRA expectations of acoustic durability, which may be more aligned with whether or not a noise barrier maintains noise levels at the noise sensitive receivers screened by it over its working lifetime.

A review of data from manufacturers and research data has identified that only minimal acoustic data related to changes in acoustic performance over the working lifetime of noise barriers, irrespective of whether laboratory or in situ test methods are considered.

Many types of barrier are considered to be acoustically durable over their full working lifetime and where manufacturers do actually specify lifetime performance, this is typically in terms of absolute service life in years. What acoustic data is available is insufficient to allow time-dependent relationships between barrier age and acoustic performance to be derived.

It has been established that visual inspections are the most common form or monitoring undertaken by NRAs both for newly installed barriers and for routine inspections. Where acoustic measurements are taken, these are not necessarily at regular intervals and a variety of methods are used as the objective is often to investigate disputes or to compare performance against predicted levels, rather to compare performance against manufacturer

declared values. Key issues affecting monitoring work, whether by visual inspection or acoustic measurement include traffic management requirements, access to the barriers and the presence of excess vegetation.

It is recommended that visual inspections should be undertaken on an annual basis and key defects/failures that should be looked for have been identified.

In terms of acoustic assessments, where these are undertaken, it is recommended that the test methods defined in EN 1793-6 and the forthcoming EN 1793-5 should be used. This will allow assessment against the initial intrinsic acoustic performance and lifetime performance values (if the latter exist) declared by a manufacturer as part of the CE mark for the noise barrier. However, it is recognised that there are practical issues that may prohibit the use of the technique at any location. The frequency of monitoring recommended will depend upon the type of barrier being assessed: for timber barriers or other barriers where performance might be expected to degrade, acoustic performance 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.

Where it is preferred to assess long-term performance in the far-field, at noise sensitive receivers screened by the barrier, then methods such as ISO 10847 or other standard methods for assessing environmental noise should be used.

It has been concluded that the addition of lifetime acoustic performance data within Pavement Management Systems (PMS) is not feasible or beneficial due to the lack of existing data and the difficulties of relating intrinsic characteristics to far-field noise levels in a manner that could be simply implemented without any noise mapping/modelling. However, the use of PMS as a broader data repository for noise barrier records, so that asset information is held within a common location is recommended and proposals set out for the type of data that could potentially be incorporated.

Glossary of terms and abbreviations

CEDR	Conference of European Directors of Roads
CEN	Comité Européen de Normalisation (European Committee for Standardisation)
CPD	Construction Products Directive
CPR	Construction Products Regulation
CRTN	Calculation of Road Traffic Noise
DISTANCE	Developing Innovative Solutions for TrAffic Noise Control in Europe (Project Title)
$DL\alpha$	Single number rating of sound reflection assessed to EN 1793-1
$DL_{\Delta DI}$	Single-number rating of sound diffraction assessed to CEN/TS 1793-4
DL_R	Single number rating of airborne sound insulation assessed to EN 1793-2.
DL_{RI}	Single number rating of sound reflection assessed to CEN/TS 1793-5 and EN 1793-5
DL_{SI}	Single number rating of airborne sound insulation assessed to EN 1793-6
IPV	Impact Protection Vehicle
ISO	International Organisation for Standardisation
NRA	National Road Authority
NPD	No performance declared
NRD	Noise reducing device
PMS	Pavement Management System
QUESTIM	QUietness and Economics STimulate Infrastructure Management (Project title)
QUIESST	QUIetening the Environment for a Sustainable Surface Transport (Project Title)

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Appendix A: QUESTIM noise barrier survey for National Road Administrations

Introduction

The QUESTIM project (QUietness and Economics STimulate Infrastructure Management) is funded by the National Road Administrations (NRAs) of Belgium/Flanders, Germany, Ireland, Norway, Sweden and the United Kingdom. The QUESTIM consortium comprises M+P Consulting Engineers, TRL (Transport Research Laboratory), Müller-BBM Schweiz AG and Aalto University, representing a cross-section of industry and academic expertise.

The objective of the project is to generate information on issues that inhibit the wider application of low-noise road surfaces and noise barriers across road networks in Europe, in order to allow NRAs the opportunity to better include these measures in the planning, construction, management and maintenance of their road networks.

You have been identified as the contact within the NRA for your country.

We would like to invite you to complete this questionnaire about noise barriers/screens used to mitigate road traffic noise.

It includes questions on noise barrier specifications, procedures/processes for procurement, monitoring and maintenance, and long-term performance (including the use of 'added' devices or cladding materials to enhance performance).

We would be most grateful if you could assist us by completing the questionnaire. You may be directly contacted by the QUESTIM project team if further details or clarification are required.

We will not share your personal contact details with anyone else. We will also not name specific companies, individuals or products when reporting the survey outcomes.

Your answers will be used to help develop common best practice guidance on noise barriers.

Your organisation

1) What is the name of your organisation? *

2) In what country is your organisation based? *

3) Please provide your contact details. Your information will be kept confidential and will only be used in case we need to contact you to clarify any of your responses. *

* Your name

* Your position/job title

* Email address

* Telephone number

Use of noise barriers on your road network

4) Are noise barriers the primary measure used to mitigate noise on your road network? *

- [ ] Yes
- [ ] No (please specify the primary noise mitigation measure used on your road network)

Specify alternative noise mitigation measures here:

Use of noise barriers on your road network

5) Will you continue to use noise barriers on your road network?

- [ ] Yes
- [ ] No

Use of noise barriers on your road network

6) Do you plan to use noise barriers on your road network in the future? *

- [ ] Yes
- [ ] No

Use of noise barriers on your road network

7) Have noise barriers been installed on your road network during any of the following periods?
(Please tick all that apply) *

- [ ] 01 January 2012 – 31 December 2012 (Please specify quantity in km)
- [ ] 01 January 2011 – 31 December 2011 (Please specify quantity in km)
- [ ] 01 January 2008 – 31 December 2010 (Please specify quantity in km)
- [ ] No barriers have been commissioned in the 5-year period 2008-2012

Please provide length of roads equipped with noise barriers for each of the time periods selected above:

8) How much of your road network has noise barriers installed? *

- [ ] There are no noise barriers installed on our road network

- [ ] There are noise barriers on our road network, but the quantity (in km) IS NOT known
- [ ] There are noise barriers on our road network and the quantity (in km) IS known

Use of noise barriers on your road network

9) Please specify the length of road on your network (in km) that has noise barriers and the percentage of your network that this represents.

	Length of road (km)	Percentage of network (%)
Barriers on the road network (overall)		
Barriers on one side of the road (if known)		
Barriers on both sides of the road (if known)		

If your road network uses more than one type of material or acoustic type for noise barriers, please provide the length and percentage of the network on which each type of noise barrier is installed:

Selecting noise barriers: requirements for use

10) Under what conditions are noise barriers considered necessary for your network? Please consider what environmental noise limits or standards, road infrastructure requirements, or budget conditions may apply.

Selecting noise barriers: barrier characteristics

11) What type of acoustic elements (in terms of acoustic behaviour) do you use in noise barriers on your road network? (Please tick all that apply)

- [ ] Barriers with sound reflective acoustic elements only
- [ ] Barriers with sound absorptive acoustic elements only
- [ ] Barriers with sound reflective elements and sound absorptive elements in the same barrier

12) What types of acoustic elements (in terms of materials) do you use in noise barriers on your road network? (Please tick all that apply)

- [ ] Timber
- [ ] Metal
- [ ] Concrete or cement bound
- [ ] Plastic (not recycled)

☐ Transparent materials (please specify in the box below, e.g. glass, acrylic)

☐ Other (please specify, e.g. recycled tyres):

Please specify which transparent materials are used:

Selecting noise barriers: barrier characteristics

13) What is the most common type of noise barrier used on your network?

	Select acoustic behaviour	Select material
Select most common type and material		

Selecting noise barriers: barrier characteristics

14) What is the height range of noise barriers installed on your road network, and what is the most common height used?

Lowest barrier (metres):

Highest barrier (metres):

Most common barrier height (metres):

15) What is the typical position for noise barriers relative to the road?

☐ At the edge of the hard shoulder/emergency lane

☐ Other (please specify):

16) What road surface type is predominant in areas where noise barriers are installed? (For example, hot rolled asphalt (HRA), stone mastic asphalt (SMA), single layer porous asphalt, two layer porous asphalt, cement concrete)

Enhancing noise barrier performance

17) Are you aware of commercially available added devices (tops, caps, etc.) that can be used to enhance the performance of conventional noise barriers?

☐ Yes

☐ No

18) Do you use added devices to enhance the performance of conventional noise barriers on your network?

- [ ] Yes (Please provide details in the box below)
- [ ] No (Please explain why you do not in the box below)

Comments:

Requirements for noise barrier manufacturers/suppliers and/or installers

19) Are there special requirements that barrier manufacturers/suppliers must meet as a company/organisation (e.g. ISO 9001 certification) in order to be able to supply noise barriers for use alongside your road network? *

- [ ] No
- [ ] Yes (Please specify in the box below)

20) Are there special requirements that barrier manufacturers/suppliers and installers must meet as a company/organisation (e.g. ISO 9001 certification) in order to be able to install noise barriers for use alongside your road network? *

- [ ] No
- [ ] Yes (Please specify in the box below)

Noise barrier specifications: NRA requirements

21) Please provide reference details for any specification documents relating to noise barriers prepared by your NRA (and indicate whether they are accessible online). If you would prefer to email any documents, please send to Dr Phil Morgan, in the Noise and Vibration team at TRL (Email: pmorgan@trl.co.uk)

Noise barrier specifications: acoustic characteristics

22) What acoustic standards must noise barriers have been tested to for them to be used on your road network?
(Please tick all that apply) *

- ☐ None
- ☐ EN 1793-2 (Airborne sound transmission)
- ☐ EN 1793-6 (Airborne sound transmission)
- ☐ EN 1793-1 (Sound reflection; for sound absorptive products only)
- ☐ Other (please specify):

23) Do you specify a minimum acoustic performance for noise barriers? *

- ☐ No
- ☐ Yes (please specify in the box below)

24) Do you specify any lifetime acoustic performance for noise barriers? *

- ☐ No
- ☐ Yes (please specify in the box below)

Noise barrier specifications: non-acoustic characteristics

25) What non-acoustic standards must noise barriers have been tested to for them to be used on your network?
(Please tick all that apply)

- ☐ None
- ☐ EN 1794-1 (Please specify which tests you require)
- ☐ EN 1794-2 (Please specify which tests you require)
- ☐ Other (please specify):

Please specify which tests you require for EN 1794-1 and/or EN 1794-2:

26) Do you specify any lifetime structural (or materials) performance for noise barriers? *

- [ ] No
- [ ] Yes (please specify in the box below):

Noise barrier specifications: additional criteria

27) Do noise barriers have to meet any other criteria/standards before they are installed on your network? *

- [ ] No
- [ ] Yes (Please specify in the box below - e.g. resistance to vandalism)

28) Do you only permit the use of prefabricated (factory built) acoustic elements for noise barriers? *

- [ ] No
- [ ] Yes (Please specify why only prefabricated elements are permitted - e.g. quality, cost)

Installation of noise barriers

29) Who is responsible for the physical installation of noise barriers on your network? (Please tick all that apply)

- [ ] Highway maintenance teams/contractors
- [ ] Specialist installers (including barrier manufacturers who also install)
- [ ] Other (please specify):

30) Do you use any of the following quality control methods to assess newly installed noise barriers for:
a) conformity of production and/or
b) compliance with contract specifications?
(Please tick all that apply)

- [ ] Measurements of acoustic performance (Please specify in the box below)
- [ ] Visual inspection (Please specify inspection criteria in the box below)

- [ ] No (Please explain why in the box below)
- [ ] Other (please specify types of check/procedures):

Please provide additional details here:

Monitoring noise barrier performance and/or condition

31) Do you use any of the following methods to monitor noise barriers over their lifetime? (Please tick all that apply)

- [ ] Monitoring of acoustic performance (Please specify type and frequency in the box below)
- [ ] Visual inspection (Please specify inspection criteria and frequency in the box below)
- [ ] No (Please explain why in the box below)
- [ ] Other (please specify type of monitoring/inspection and frequency):

Please provide additional details here:

32) Does your road network require special precautions when monitoring and inspecting noise barriers?

- [ ] No
- [ ] Yes (Please specify in the box below, e.g. hard shoulder closures, traffic management)

Monitoring noise barriers

33) Are there any logistical or practical problems on your network (e.g. limited access to rear of noise barriers, excess vegetation) that affect or prohibit monitoring and inspecting noise barriers?

- [ ] No
- [ ] Yes (please specify):

34) Is in-situ testing of the acoustic performance of noise barriers currently undertaken on your road network?

- [ ] Yes
- [ ] No

Monitoring noise barrier performance and/or condition

35) Are there any reasons why in-situ testing of the acoustic performance of noise barriers cannot/would not be undertaken (e.g. budget constraints, proven acoustic durability of noise barriers)?

Maintaining noise barriers

36) Do you have a specific maintenance policy for noise barriers on your network?

- [ ] Yes (Please specify details of your maintenance policy in the box below)
- [ ] No (Please explain why you do not have a maintenance policy in the box below)

Please provide details in the box below:

Replacing noise barriers

37) Do you have a specific replacement policy for noise barriers on your road network?

- [ ] Yes (Please specify details of your replacement policy in the box below)
- [ ] No (Please explain why you do not have a replacement policy in the box below)

Please provide details in the box below:

38) Approximately, how often are the noise barriers on your road network replaced?

39) What criteria are used to determine if noise barriers need replacing?

Noise barrier manufacturers

40) Please provide the names of the noise barrier manufacturers/suppliers and installers that you have had contact with (and their contact details if you have permission to share these).

The future of noise barriers

41) How do you think the way in which noise barriers are procured, manufactured, installed and maintained will change in the future?
Consider, for example, changes in the types of materials used with regard to performance and sustainability, restrictions on the use of non-prefabricated products, etc.

Further comments

42) Please provide any further comments in the box below.

Appendix B: QUESTIM noise barrier survey for noise barrier manufacturers/suppliers

Introduction

The QUESTIM project (QUietness and Economics STimulate Infrastructure Management) is funded by the National Road Administrations (NRAs) of Belgium/Flanders, Germany, Ireland, Norway, Sweden and the United Kingdom. The QUESTIM consortium comprises M+P Consulting Engineers, TRL (Transport Research Laboratory), Müller-BBM Schweiz AG and Aalto University, representing a cross-section of industry and academic expertise.

The objective of the project is to generate information on issues that inhibit the wider application of low-noise road surfaces and noise barriers across road networks in Europe, in order to allow NRAs the opportunity to better include these measures in the planning, construction, management and maintenance of their road networks.

You have been identified as a contact for a noise barrier manufacturer/supplier.

We would like to invite you to complete this questionnaire about the noise barriers/screens you manufacture/supply for road networks.

It includes questions on your company's noise barrier specifications, quality management systems, manufacturing, installation and post-installation quality control, performance (including the use of 'added' devices or cladding materials to enhance performance), and product durability over lifetime.

We would be most grateful if you could assist us by completing the questionnaire. You may be directly contacted by the QUESTIM project team if further details or clarification are required.

We will not share your personal contact details with anyone else. We will also not name specific companies, individuals or products when reporting the survey outcomes.

Your answers will be used to help develop common best practice guidance on noise barriers.

Your organisation

1) What is the name of your company? *

2) In what country is your company based? *

3) Please provide your contact details. Your information will be kept confidential and will only be used in case we need to contact you to clarify any of your responses. *

* Your name

* Your position/job title

* Email address

* Telephone number

Noise barrier products

4) What noise barrier products do you manufacture?
(Please tick all that apply)

- [ ] Complete barrier systems
- [ ] Components, e.g. acoustic panels (Please specify in the box below)
- [ ] Materials (Please specify in the box below)

Please provide details of your products in the box below:

Noise barrier products

5) What type of acoustic elements do you manufacture?

- [ ] Sound reflective elements only
- [ ] Sound absorptive elements only
- [ ] Both sound reflective and sound absorptive elements

6) What types of materials do you use in the manufacture of acoustic elements for noise barriers?
(Please tick all that apply)

- [ ] Timber
- [ ] Metal
- [ ] Concrete or cement bound
- [ ] Plastic (not recycled)
- [ ] Transparent materials (please specify in the box below, e.g. glass, acrylic)
- [ ] Other (please specify, e.g. recycled tyres):

Please specify which transparent materials are used:

7) What types of posts are used for supporting the acoustic elements that you manufacture?

(Please tick all that apply)

- ☐ None (acoustic elements are self-supporting)
- ☐ Timber
- ☐ Steel
- ☐ Other (please specify):

Retail of noise barriers

8) Where do you retail your products?
(Please tick all that apply)

- ☐ Nationally
- ☐ Internationally – Europe (Please specify where in the box below)
- ☐ Internationally – Rest of the world (Please specify where in the box below)

Please specify which countries:

9) In what areas are your products typically used?
(Please tick all that apply)

- ☐ Roads operated by National Road Authorities (NRAs)
- ☐ Roads operated by Local Road Authorities (LRAs)
- ☐ Railways
- ☐ Screening industrial/retail premises or equipment
- ☐ Other (please specify):

Quality management requirements

10) Do you operate a standardised quality system(s), e.g. ISO 9001 type, in your company?

- ☐ Yes (Please specify in the box below)
- ☐ No (Please explain in the box below why you have no such systems in place)

Please provide details in the box below:

11) Are there additional requirements set out by the National Road Administrations that your company must comply with in order to supply and/or install noise barriers on roads operated by those administrations?

- ☐ No
- ☐ Yes (please specify in the box below):

12) Are there additional requirements that your company must comply with in order to supply and/or install noise barriers for *other customers*?

- ☐ No
- ☐ Yes (please specify in the box below):

Quality management requirements: subcontractors

13) Do you use subcontractors during the installation of noise barriers?

- ☐ No
- ☐ Yes – Whole subcontract (please specify in the box below)
- ☐ Yes – Elements, e.g. concrete, posts, etc. (please specify in the box below)

Please provide details in the box below:

14) If you do use subcontractors, are there special requirements that their company must comply with, e.g. ISO 9001 certification, etc., in order to undertake works for you?

- ☐ Yes (Please specify in the box below)
- ☐ No (Please explain in the box below why you have no such systems in place)

Please provide details in the box below:

Product manufacture

15) How do you manufacture your products?
(Please tick all that apply)

- [ ] Prefabricate acoustic elements in a factory for subsequent mounting on/in between posts on site
- [ ] Prefabricate complete barrier system in a factory for subsequent installation on site (applicable to products with integrated posts or no posts)
- [ ] Supply component materials for manufacture/construction of acoustic elements on site
- [ ] Other (please specify):

16) How do your clients specify the required performance criteria when procuring your products (e.g. in terms of classes/single number ratings from EN 1793, in terms of spectral performance, etc.)?

Product performance: acoustic characteristics

17) What standards do you test your products against to determine initial performance? (Please tick all that apply)

- [ ] None
- [ ] EN 1793-2 (Airborne sound transmission)
- [ ] EN 1793-6 (Airborne sound transmission)
- [ ] EN 1793-1 (Sound reflection; for sound absorptive products only)
- [ ] Other (please specify):

18) If products are tested to determine acoustic characteristics, in which country/countries is this testing undertaken?

Product performance: acoustic characteristics

19) Do you declare long-term acoustic performance for your products?

- [ ] No
- [ ] Yes (To EN 14389-1 – Change in performance after 5, 10, 15 and 20 yrs)
- [ ] Yes (As change in performance over life time)
- [ ] Yes (As absolute performance at end of life time)
- [ ] Yes (As lifetime in years only)

If 'Yes', please specify how numbers are determined (e.g. based on historical data, expert judgement)

Product performance: non-acoustic characteristics

20) What standards do you test your products against to determine initial performance? (Please tick all that apply)

- ☐ None
- ☐ EN 1794-1 (Please specify which tests in the box below)
- ☐ EN 1794-2 (Please specify which tests in the box below)

Please specify which tests:

21) If products are tested for non-acoustic characteristics, in which country/countries is this testing undertaken?

Product performance: non-acoustic characteristics

22) Do you declare long-term materials performance for your products?

- ☐ Yes
- ☐ No

23) Do you declare long-term structural performance for your products?

- ☐ Yes
- ☐ No

Product performance: general

24) Are your products currently CE marked?

- ☐ No
- ☐ Yes (please specify):

25) Are your aware of the forthcoming impact on 01 July 2013 of the Construction Products Regulations (CPR) 2011? From this date, it will become mandatory for manufacturers to apply CE marking to any construction products which are covered by a harmonised European standard (hEN).

- ☐ No
- ☐ Yes (please provide details of how you became aware of CPR):

Installation of noise barriers

26) Who is responsible for the installation of your products?
(Please tick all that apply)

- ☐ We install our own products
- ☐ We supply products for installation by third parties

27) Do you undertake any of the following quality control checks after installation to ensure that noise barrier products are correctly installed?

- ☐ Measurements of acoustic performance (Please specify in the box below)
- ☐ Visual inspection (Please specify inspection criteria in the box below)
- ☐ No, but the installer is required to check performance (Please specify type of checks in the box below)
- ☐ No checks are undertaken by any party
- ☐ Other (please specify types of check/procedures):

Please provide additional details here:

Monitoring noise barriers

28) Do you use any of the following methods to monitor noise barriers throughout their lifetime?
(Please tick all that apply)

- ☐ Monitoring of acoustic performance (Please specify type and frequency in the box below)
- ☐ Visual inspection (Please specify inspection criteria and frequency in the box below)
- ☐ No, but the installer is required to check performance (Please specify type of checks and frequency in the box below)
- ☐ No checks are undertaken by any party
- ☐ Other (please specify type of monitoring/inspection and frequency):

Please provide additional details here:

Lifetime durability

29) Do the acoustic elements of your noise barrier products deteriorate acoustically over their lifetime?

- ☐ Yes (Please specify in the box below which materials degrade and the mechanisms responsible for the degradation)
- ☐ No (Please specify in the box below why you consider the acoustic elements do not deteriorate acoustically)

Please provide further details:

30) Do you take measures to minimise the acoustic degradation of acoustic elements?

- ☐ No
- ☐ Yes (please specify):

Lifetime durability

31) Do you know the acoustic degradation curves (i.e. how acoustic performance degrades over time) for the acoustic elements or acoustic materials used in your noise barriers?

- ☐ No
- ☐ Yes (please specify in the box below or provide details by email to Dr Phil Morgan, in the Noise and Vibration team at TRL (Email: pmorgan@trl.co.uk)):

32) Do you take measures to ensure/extend the physical lifetime of acoustic elements?

- ☐ No
- ☐ Yes (please specify):

The future of noise barriers

33) How do you think the way in which noise barriers are procured, manufactured, installed and maintained will change in the future?
Consider, for example, changes in the types of materials used with regard to performance& sustainability, restrictions on the use of non-prefabricated products, etc.

Further comments

34) Please provide any further comments in the box below.

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Appendix C: QUESTIM noise barrier survey for noise barrier installers

Introduction

The QUESTIM project (QUietness and Economics STimulate Infrastructure Management) is funded by the National Road Administrations (NRAs) of Belgium/Flanders, Germany, Ireland, Norway, Sweden and the United Kingdom. The QUESTIM consortium comprises M+P Consulting Engineers, TRL (Transport Research Laboratory), Müller-BBM Schweiz AG and Aalto University, representing a cross-section of industry and academic expertise.

The objective of the project is to generate information on issues that inhibit the wider application of low-noise road surfaces and noise barriers across road networks in Europe, in order to allow NRAs the opportunity to better include these measures in the planning, construction, management and maintenance of their road networks.

You have been identified as a contact for a noise barrier installer.

We would like to invite you to complete this questionnaire about the noise barriers/screens you install on road networks to mitigate road traffic noise.

It includes questions on type of noise barrier installations undertaken, quality management systems, and installation and post-installation quality control.

We would be most grateful if you could assist us by completing the questionnaire. You may be directly contacted by the QUESTIM project team if further details or clarification are required.

We will not share your personal contact details with anyone else. We will also not name specific companies, individuals or products when reporting the survey outcomes. Your answers will be used to help develop common best practice guidance on noise

Your organisation

1) What is the name of your company? *

2) In what country is your company based? *

3) Please provide your contact details. Your information will be kept confidential and will only be used in case we need to contact you to clarify any of your responses. *

* Your name

* Your position/job title

* Email address

* Telephone number

Overview of operational activities

4) In what areas do you install noise barriers? (Please tick all that apply)

- ☐ Roads operated by National Road Authorities (NRAs)
- ☐ Roads operated by Local Road Authorities (LRAs)
- ☐ Railways
- ☐ For screening industrial/retail premises or equipment
- ☐ Other (please specify):

5) What types of noise barrier installation do you undertake? (Please tick all that apply)

- ☐ Installation of barriers including prefabricated (factory-built) acoustic elements
- ☐ Installation of barriers including prefabricated (site-built) acoustic elements
- ☐ In-situ construction of noise barriers or acoustic elements from individual component materials (e.g. erection of timber barriers between posts by fixing vertical planking to support members)

6) What types of materials are used to construct the noise barriers that you install? (Please tick all that apply)

- ☐ Timber
- ☐ Metal
- ☐ Concrete or cement bound
- ☐ Plastic (not recycled)
- ☐ Transparent materials (please specify in the box below, e.g. glass, acrylic)
- ☐ Other (please specify, e.g. recycled tyres):

Please specify which transparent materials are used:

Quality management requirements

7) Do you operate a standardised quality system(s), e.g. ISO 9001 type, in your company?

- ☐ Yes (Please specify in the box below)

☐ No (Please explain in the box below why you have no such systems in place)

Please provide details in the box below:

8) Are there additional requirements set out by the National Road Administrations that your company must comply with in order to install noise barriers on roads operated by those administrations?

☐ No

☐ Yes (please specify in the box below):

9) Are there additional requirements that your company must comply with in order to install noise barriers for *other customers*?

☐ No

☐ Yes (please specify in the box below):

Quality management requirements: subcontractors

10) Do you use subcontractors during the installation of noise barriers?

☐ No

☐ Yes – Whole subcontract (please specify in the box below)

☐ Yes – Elements, e.g. concrete, posts, etc. (please specify in the box below)

Please provide details in the box below:

11) If you do use subcontractors, are there special requirements that their company must comply with, e.g. ISO 9001 certification, etc., in order to undertake works for you?

☐ Yes (Please specify in the box below)

☐ No (Please explain in the box below why you have no such systems in place)

Please provide details in the box below:

Installation of noise barriers

12) If installing a prefabricated noise barrier/acoustic elements, are the components supplied with appropriate installation instructions, drawings or guidance (i.e. documentation, or supervision by a representative of the manufacturer)?

- ☐ Yes – A third-party representative is on site to supervise installation
- ☐ Yes – The components are accompanied by appropriate installation instructions
- ☐ No (Please describe the installation approach if no instructions or supervision are available)

13) If installing a barrier by constructing it from its component materials (e.g. the construction of timber panels), are the components supplied with appropriate installation instructions, drawings or guidance (i.e. documentation, or supervision by a representative of the manufacturer)?

- ☐ Yes – A third-party representative is on site to supervise installation
- ☐ Yes – The components are accompanied by appropriate installation instructions
- ☐ No (Please describe the installation approach if no instructions or supervision are available)

Quality control after installation

14) Once you have completed installation of a noise barrier, are any quality control checks undertaken?

- ☐ Yes – Quality control checks are undertaken, but by a customer representative
- ☐ Yes – Quality control checks are undertaken, but by the supplier of the prefabricated acoustic elements
- ☐ Yes –We undertake our own quality control checks
- ☐ No (Please describe why no quality control checks are undertaken)

15) If quality control checks are undertaken following installation, what types of checks are performed?
(Please tick all that apply)

- ☐ Measurements of acoustic performance (Please specify in the box below)
- ☐ Visual inspection (Please specify inspection criteria in the box below)
- ☐ Other (please specify types of check/procedures):

Please provide additional details here:

Monitoring noise barriers

16) Do you undertake any of the following quality control checks during the in-use lifetime of the noise barriers?
(Please tick all that apply)

- ☐ Measurements of acoustic performance (Please specify type and frequency in the box below)
- ☐ Visual inspection (Please specify inspection criteria and frequency in the box below)
- ☐ No, but checks are undertaken by other parties (Please specify type of checks and frequency in the box below, if known)
- ☐ No, and it is unknown whether any checks are undertaken by other parties
- ☐ No checks are undertaken by any party (Please describe why no quality control checks are undertaken in the box below)
- ☐ Other (please specify type of monitoring/inspection and frequency):

Please provide additional details here:

Maintaining noise barriers

17) Do you undertake any follow-on maintenance activities on noise barriers that you install?

- ☐ No
- ☐ Yes, directly (Please specify type of activity in the box below)
- ☐ Yes, but the work is subcontracted out to third parties (Please specify type of activity in the box below)

Please specify activities here:

The future of noise barriers

18) How do you think the way in which noise barriers are procured, manufactured, installed and maintained will change in the future?
Consider, for example, changes in the types of materials used with regard to performance and sustainability, restrictions on the use of non-prefabricated products, etc.

Further comments

19) Please provide any further comments in the box below.

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