Published Project Report
PPR490

Creating the future of transport

The acoustic durability of timber noise barriers on England's strategic road network

P A Morgan

Transport Research Laboratory

PUBLISHED PROJECT REPORT PPR490

The acoustic durability of timber noise barriers on England's strategic road network

by P A Morgan

Prepared for:	**Project Record:**	**387(387)HTRL**
		Acoustic durability of noise barriers over time
	Client:	**Highways Agency, Research and Development (Pam Lowery)**

This Published Report has been prepared for the Highways Agency. Published Project Reports are written primarily for the Client rather than for a general audience and are published with the Client's approval.

The views expressed are those of the author and not necessarily those of the Highways Agency.

	Name	Date Approved
Project Manager	P A Morgan	28/05/2010
Technical Referee	M J Ainge	27/05/2010

When purchased in hard copy, this publication is printed on paper that is FSC (Forest Stewardship Council) registered and TCF (Totally Chlorine Free) registered.

Contents

List of Figures

List of Tables

Executive summary

Presently, timber barriers are one of the most common mitigation measures against noise arising from traffic on England's Strategic Road Network (SRN). Barriers installed on the SRN must not only fulfil their acoustic function and structural design requirements in accordance with the Highways Agency's Specification for Highway Works (SHW) but also maintain their performance for a reasonably long life. The Agency's technical design guide, HA 66/95[1], stipulates that all types of noise barriers, including acoustic timber screens, remain serviceable for 40 years and should not require maintenance for 20 years.

Currently, the Highways Agency requires that the acoustic performance of barriers used on the SRN must have been tested, as appropriate, in accordance with Parts 1 and 2 of BS EN 1793[2,3], which assess sound absorption and sound insulation respectively under laboratory conditions.

However, the Agency specifications are only concerned with the performance of the barriers when they are new. The nature of the test methods in the standards means that they cannot be easily used to assess acoustic durability, which can be defined as a measure of the change in acoustic performance over the lifetime of the barrier. Furthermore, the test methods cannot be used for in situ assessment of performance.

Little is known about how the acoustic performance of timber noise barriers changes over the structural lifetime of the barrier and there are presently no specifications in place for acoustic durability. The Agency has therefore commissioned TRL to undertake a study of timber noise barriers on the SRN. This study is intended to provide indications on the long-term acoustic durability of a range of (generic) timber noise barrier types on the SRN. This information can then be used to inform industry and the Agency on how long-term acoustic durability might be specified in CE marking and Highways Agency specifications respectively.

The measurements have been performed, largely in situ, using a recently developed method for assessing airborne sound insulation performance. This was originally described in the European Standard BS CEN/TS 1793-5[4] (hereafter referred to in this report as 'Part 5') and, following separation of the standard into separate documents addressing airborne sound insulation and sound reflection, is now described in an updated form (including changes to the measurement positions) in the forthcoming European Standard prEN 1793-6[5] (hereafter referred to as 'Part 6').

The scope of the study has also been extended to investigate other factors relating to the assessment of sound insulation performance using the Part 6 method.

This report presents the findings from the complete study. The main conclusions are as follows:

Data availability and asset management

The selection procedure highlighted the lack of a comprehensive, centrally held database of noise barrier records within the Highways Agency. The existing Agency asset management record system EnvIS already provides the necessary mechanism for such a database. It is recommended that any future revision of EnvIS should, as a minimum, include the addition of suitable noise-barrier related fields covering all aspects of location, design and performance.

The acoustic durability of timber noise barriers

The final candidate barrier group to be assessed using the Part 6 method comprised 18 single-leaf reflective barriers (14 roadside and 4 test facility), 5 double-leaf reflective barriers (3 roadside and 2 test facility) and 8 single-leaf sound absorptive barriers (6 roadside barriers and 2 test facility barriers). Taking into account cancellations resulting from unsuitable weather conditions and the unavailability of road space, the following numbers of roadside barriers have been assessed: 11 single-leaf reflective, 4 sound absorptive barriers and 2 double-leaf reflective barriers.

In the absence of confirmed data for the majority of roadside barriers, assumptions have been made regarding the initial sound insulation performance based on discussions with industry experts. Where these barriers were site assembled constructions, the changes in acoustic performance over time suggest the possibility that the real initial performance is likely to have been less than observed in laboratory certified panels of the same design.

Overall, the results would suggest that for single-leaf reflective barriers, any degradation in acoustic performance occurs during the first 5 years after construction. Depending upon the initial performance, this decrease appears to be of the order of 4-7 dB. Performance would appear to remain relatively stable thereafter for at least the next 5 years, the limit of the current dataset. Similarly, the results for sound absorptive barriers suggest an average decrease in sound insulation performance of 7 dB after 5 years, although in this case the scatter of measurement results is significant. There is insufficient data to define more robust relationships for either type of barrier. There is insufficient data to draw conclusions in relation to double-leaf reflective barriers.

The effect of safety barriers on roadside prEn 1793-6 measurements

Based on the results of measurements taken on the TRL noise barrier test facility, it is concluded that the presence of a safety fence has no significant effect on the acoustic performance of a noise barrier when assessed in accordance with EN 1793-6.

As such, it is considered that the EN 1793-6 test method can be applied at the roadside without modification on barriers *with a minimum height of 3.0 m*, without the need to temporarily remove or modify any safety fence installed in close proximity to the barrier.

The effect of moisture content on early life sound insulation performance

Measurements show that the moisture content levels in pressure treated timber can decrease by as much as 25% as a result of drainage/evaporation of water in the preservative in the first 3-4 weeks after treatment. In that same time period, the airborne sound insulation performance, DL_{SI}, assessed in accordance with prEN 1793-6 reduces by approximately 8-10 dB as a result of this effect. Similar changes in performance are likely to be observed when testing in accordance with EN 1793-2. These changes could have a potentially significant effect on the performance rating of the barrier when described using the B and D classes in Part 2 and 6 respectively.

It is recommended that future certification of timber noise barrier products in accordance with either prEN 1793-6 or EN 1793-2 should not be taken until at least 4 weeks after the timber from which the barrier is manufactured has been treated with preservative.

The effect of variations in certification and in situ assessment geometry

The effects of using different loudspeaker and microphone heights for certification and in situ assessment appear to be negligible. However, this may not be the case for multi-element barriers where there are no seals used at the horizontal joint between panels. Care should therefore be exercised when selecting the measurement height for in situ assessment depending upon the design of the noise barrier.

Suitability of the method for use on England's strategic road network

It is considered that the test methodology defined in prEN 1793-6 is well-suited for in situ (roadside) application, and suitable for use under a wide variety of site conditions. Measurements are unaffected by varying levels of traffic and can be performed on barriers at least 3 m in height without the results being affected by the presence of the safety barrier. It is recommended that barriers lower than 3 m high should not be assessed unless there is no adjacent safety barrier.

It is considered that the method could provide an important asset management tool to the Agency, although for this to be the case, the provision of a centralised, high quality database for measurement data will also be required.

Significantly, the factors that most affect the potential use of the method as a routine assessment/asset management tool are unrelated to the method itself and are more practical/logistical issues relating to road space availability, traffic management, and levels of vegetation behind the barrier. These could have significant implications on the *scheduling* of assessments and the associated *direct/indirect costs of the measurements*.

The present study has been restricted to motorway locations with hard shoulder working. Further investigations are required to assess the feasibility of using the method for the assessment of barriers on non-motorway roads where hard shoulders are less common, any verge space between the running lanes and noise barriers is limited and the opportunities for daytime lanes closures are unlikely.

---

[1] Highways Agency, Scottish Executive Development Department, National Assembly For Wales and Department for Regional Development (2001). *Design Manual for Roads and Bridges. Volume 10 (Environmental Design and Management), Section 5 (Environmental Barriers) Part 2; Technical Requirements (HA 66/95)* [online]. [Accessed November 2008]. Available from World Wide Web: http://www.standardsforhighways.co.uk/dmrb/vol10/section5/ha6695.pdf

[2] BSI (1998). *BS 1793-1:1998. Road traffic noise reducing devices - Test method for determining the acoustic performance. Part 1: Intrinsic characteristics of sound absorption.* London, UK: British Standards Institution.

[3] BSI (1998). *BS 1793-2:1998. Road traffic noise reducing devices - Test method for determining the acoustic performance. Part 2: Intrinsic characteristics of airborne sound insulation.* London, UK: British Standards Institution.

[4] BSI (2003). *BS CEN/TS 1793-5:2003. Road traffic noise reducing devices - Test method for determining the acoustic performance. Part 5: Intrinsic characteristics of in situ values of sound reflection and airborne sound insulation.* London, UK: British Standards Institution.

[5] CEN (2010). *prEN 1793-6:2010. Road traffic noise reducing devices - Test method for determining the acoustic performance. Part 6: Intrinsic characteristics – In situ values of airborne sound insulation under direct field conditions [Working Draft].* Brussels, Belgium: European Committee for Standardisation.

Abstract

Timber noise barriers are one of the most common mitigation measures against traffic noise on England's Strategic Road Network. They are required not only to fulfil their acoustic function and structural design requirements in accordance with Highways Agency specifications, but also to retain their performance for a reasonably long life. The Agency's technical design guide, HA 66/95, stipulates that noise barriers should remain serviceable for 40 years and not require maintenance for 20 years.

Currently the Agency requires acoustic performance to have been assessed using recognised, standardised laboratory tests (EN 1793-1:1998 and EN 1793-2:1998) as appropriate to the barrier type. However, the Agency's specifications are only concerned with the performance of the barriers in new condition.

This report presents the results of a study commissioned by the Agency to investigate the acoustic durability of timber noise barriers on the network. This has been achieved through a programme of in situ measurements using recently developed test methods described in the forthcoming standard prEN 1793-6:2010 to determine airborne sound insulation characteristics.

The report also presents results from measurements to assess the impacts of moisture content on screening performance, the influence of panel design/geometry and factors affecting the practical roadside application of the prEN 1793-6 test method.

1 Introduction

Presently, timber barriers are one of the most common mitigation measures against noise arising from traffic on England's Strategic Road Network (SRN). A generally applicable acoustic requirement for a timber barrier is to limit the component of sound passing through it to a level 10 dB(A) less than the predicted noise level due to sound diffracted over the barrier.

Noise barriers installed on the SRN are required not only to fulfil their acoustic function and structural design requirements in accordance with the Specification for Highway Works (SHW) (Highways Agency, undated #2; Highways Agency, undated #3), but also to maintain their performance for a reasonably long life. The Highways Agency's technical design guide, HA 66/95 (Highways Agency *et al.*, 2001b), stipulates that all types of noise barriers, including acoustic timber screens, remain serviceable for 40 years and should not require maintenance for 20 years.

Currently, the Agency requires that barriers used on the SRN must have been tested in accordance with EN 1793-1:1998 and EN 1793-2:1998 (BSI, 1998a; BSI, 1998b; hereafter referred to in this report as 'Part 1' and 'Part 2' respectively), which assess the sound absorption and sound insulation characteristics (under laboratory conditions) depending upon the type of barrier (Part 1 will only be applied if the barrier is absorptive). However, these standards are only concerned with the performance of the barrier when new. They cannot be used to assess acoustic durability or be applied for in situ assessment.

Recently, alternative test methods have been developed for assessing the in-situ acoustic performance of noise barriers in terms of sound reflection and airborne sound insulation). These are prescribed in BS CEN/TS 1793-5:2003 (BSI, 2003a) (hereafter referred to in this report as 'Part 5'). A detailed description of the method for assessing the airborne sound insulation performance can be found in the report by Watts and Morgan (2005) which addresses validation of the method for timber noise barriers.

Following separation of Part 5 into separate documents addressing airborne sound insulation and sound reflection, the methodology for airborne sound insulation is now described in a revised form (including changes to the measurement positions for certain barrier geometries) in the forthcoming European Standard prEN 1793-6:2010 (CEN, 2010; hereafter referred to in this report as 'Part 6').

Little is known about how the acoustic performance of timber noise barriers changes over the structural lifetime of the barrier and there are presently no Agency specifications in place for acoustic durability. However, it is reasonable to assume that the installation quality, maintenance regime (if any) and materials used can have an effect not only on the initial acoustic performance, in terms of transmission loss, but also perhaps accelerate acoustic deterioration with time.

The recently introduced European standards relating to CE marking (BSI, 2005) and the assessment of long-term acoustic performance (BSI, 2007)[1], EN 14388:2005 and EN 14389-1:2007 respectively, cannot be successfully implemented by the Highways Agency if information on acoustic durability is unavailable. CE marking would provide the Agency with comprehensive information on both the acoustic and non-acoustic performance of noise barriers, which would then allow the most appropriate noise barrier product(s) to be chosen for a given situation.

1.1 Factors affecting acoustic durability

Factors that affect the acoustic performance and, as a result, the acoustic durability of barriers include the following:

- *Age of the barrier:* The structural characteristics of wood products will vary over time. Timber tends to warp/shrink leaving open cracks between joints and planks, which create gaps in the barrier allowing sound leakage through the timber panels.
- *Manufacturing and installation methods:* The quality of manufacture and installation can be pivotal to both the structural and acoustic durability of the noise barrier. For example, for the same design of noise barrier, prefabricated panels may provide different levels of sound insulation to those constructed on site.
- *Generic acoustic type:* Timber barriers can be generically classed as 'sound absorptive' or 'sound reflective'. Examples of the two types are shown in Figure 1.1 Sound absorptive barriers differ from their reflective counterparts by having

[1] A standard on the assessment of the long-term performance of non-acoustic characteristics has also been introduced (BSI, 2004)

an acoustically absorptive material mounted on the source side of the barrier, e.g. rock wool or similar. This material is protected from the weather by a water impervious membrane. However, over time the properties of the material may change or the material may sag, causing a deterioration of the acoustic performance. The performance of a reflective barrier should not alter greatly if well maintained.

- *Timber species used for manufacture:* A number of different species of wood have the potential for being used as a noise barrier. As the density of the timber increases, so the thickness required to achieve the same level of sound insulation decreases. The two most commonly used species in the UK are Spruce and Douglas Fir with densities of 390 kg/m^3 and 530 kg/m^3 respectively. Agency specifications include requirements relating to quality and preservation but stop short of specifying the type of timber.

(a) Sound reflective noise barrier (b) Sound absorptive noise barrier

Figure 1.1: Examples of different types of noise barriers

- *The quality of seals between panels and panels/posts:* The quality of these seals is particularly important where acoustic elements are either mounted in between steel I-section posts or where elements are arranged on top of one another to achieve the required barrier height. Where poor quality seals exist, then there will be the potential for sound leakage as well as the potential for movement of the barrier panels due to variations in climatic conditions.

1.2 Description of the primary measurement programme

The Highways Agency has commissioned TRL to undertake a study of the acoustic durability of timber noise barriers on the SRN using in situ testing in accordance with the airborne sound insulation method prescribed in Part 5/Part 6. This study is intended to provide the following:

- Indications of the long-term acoustic durability of a range of (generic) timber noise barrier types used on the SRN, which can be used to inform industry and the Agency on how long-term acoustic durability might be specified in the CE marking and Highways Agency specifications respectively. BS 14389-1 (BSI, 2007) specifically requires the expected durability (the change in sound absorption and airborne sound insulation performance) to be stated after 5, 10, 15 and 20 years. Ideally, the barriers assessed should cover this age range.

- A database of long term in situ sound insulation data from Part 5/Part 6 measurements which can be made readily available to the Agency and also to European partners on the CEN (European Standards) working group, TC 226 WG6, which is responsible for developing noise barrier standards

Undertaking this project has the additional benefit of demonstrating the practical suitability of the in situ testing method on the SRN.

This project is only concerned with the evaluation of the airborne sound insulation of timber barriers. Other aspects relating to the acoustic performance, e.g. sound reflection or sound diffraction are not considered.

1.3 Description of the supplementary measurement programme

In the course of selecting suitable barriers for testing, a number of separate issues were identified which were considered to have a possible impact on Part 5/Part 6 sound insulation measurements. These can be summarised as follows:

- *The potential impact of reflected sound from safety fences:* In many cases, the safety fence is positioned in close proximity to the noise barrier and sits in between the loudspeaker and noise barrier when conducting Part 5/Part 6 measurements
- *Changes to the measurement method in the transfer from Part 5 to Part 6:* Whilst the principles of the assessment method and the derivation of the results are largely unchanged, TG1 has proposed a modification to the sound insulation measurement method, which uses an array of free-field microphones instead of a single free-field microphone and path difference corrections. Such a change in approach offers potential improvement in accuracy and efficiency; the latter has indirect benefits on safety aspects when used at the roadside.
- *Variations between barrier dimensions used for certification and in situ testing:* For the certification of noise barrier products, Part 5/Part 6 require a barrier height of 4.0 m to be used in order to obtain sound insulation data over the widest possible frequency range. However, lower barriers, e.g. 3.0 m high, are commonly installed on the SRN. Single number ratings calculated for different barrier heights are not directly comparable because they are evaluated over different frequency ranges. Results must therefore be compared in terms of one-third octave bands.

TRL was requested to conduct additional measurements to investigate these issues and given approval to adapt its measurement system to allow the use of multiple microphones.

With regard to the acoustic performance of new timber barriers, Agency specifications for characterisation in accordance with Part 2 provide no guidelines on how soon after manufacture/treatment the noise barrier panels should be assessed. TRL was also requested to evaluate the effects on sound insulation performance caused by artificially high moisture content levels during the early lifetime of the barrier, resulting from the application of the timber preservative. These measurements were to be performed using the Part 5/Part 6 test methodology only. Although no precise correlation between the two methods can be derived from the results, it was expected that they would be able to provide an indication of the delay that should ideally occur between manufacture/treatment of the timber panels and their acoustic characterisation.

It is foreseen that one of the benefits of the Part 5/Part 6 method is its potential suitability for use at the roadside. However roadside measurements are subject to interruption/postponement due to inclement weather. Additional measurements have been undertaken within the test programme to examine the effect of rainfall on Part 5/Part 6 measurements, i.e. the effects of short-term changes in moisture content.

1.4 Structure of the report

The report is divided into 3 parts, structured as follows:

Part 1: Background information

- Chapter 2 provides some background to the development of Part 5 and Part 6 followed by a short overview of the measurement methodologies in each standard and the equations used to calculate the airborne sound insulation characteristics of the barrier. Any variations between the published methodologies and that used within the project are also outlined.
- Chapter 3 provides a short overview of current Highways Agency specifications for noise barriers on the Strategic Road Network.

Part 2: Acoustic durability of timber noise barriers

- Chapter 4 describes the processes involved with the selection of candidate noise barriers for inclusion in the main body of the study
- Chapter 5 addresses the investigations into the acoustic durability of timber noise barriers based upon an assessment of barriers both in situ and using purpose-built test facilities

Part 3: Factors affecting sound insulation performance and prEN 1793-6 measurements

- Chapter 6 addresses the effects of the presence of safety barriers on sound insulation performance
- Chapter 7 addresses the effects of moisture content on early-life sound insulation performance
- Chapter 8 address the effects of rainfall on Part 6 measurements of airborne sound insulation
- Chapter 9 addresses the effects of variations in Part 6 certification and roadside assessment measurements based on changes in panel geometry. The effects of using different dimension panels to construct a barrier of the same overall height are also investigated.
- Chapter 10 assesses the suitability of the prEN 1793-6 test method as an asset management tool for routine use in assessing the airborne sound insulation performance of noise barriers on the Highways Agency Strategic Road Network
- Chapter 11 presents a summary of the work and the final conclusions, together with recommendations for further work

Discussion on the purpose-built TRL noise barrier test facility, the effects of changing the number of free-field microphone measurements and small changes in loudspeaker and microphone position, illustrative cross-sections of the barrier designs and detailed one-third octave band sound insulation spectra for some of the measurements reported in the main chapters are presented in a separate document (Technical Annex – Morgan, 2010). These Annexes are referenced throughout this report.

PART 1: Background information

2 Assessment of airborne sound insulation: Overview of CEN/TS 1793-5 and prEN 1793-6

2.1 Background to the standards

CEN/TS 1793-5:2003 was published to provide alternative measurement procedures to those defined in EN 1793-1:1998 (sound reflection) and EN 1793-2:1998 (airborne sound insulation) that could be undertaken *in situ* rather than being restricted to laboratory conditions (i.e. a reverberation room).

A validation of the airborne sound insulation method for use with timber barriers of the type installed on England's strategic road network was undertaken for the Highways Agency in 2004/05 and reported by Watts and Morgan (2005).

It is noted that development and validation of the airborne sound insulation method has progressed at a faster rate than that of the sound reflection method and as such, a decision was taken by CEN TC226 WG6 TG1 (the European Standards Task Group responsible for the standards) to split Part 5 into two separate standards, with the airborne sound insulation method being defined as a new standard, prEN 1793-6:2010. Part 5 will retain only the sound reflection method but this requires further review and development before the standard is finalised.

prEN 1793-6 was submitted to CEN in March 2010 for review by CEN and individual national standards bodies. The test methodology has undergone minor changes from that first published in Part 5, and is discussed further in the following section. It is expected that it will become a full standard at some point during 2012. Parts 1 and 2 are also being amended accordingly to change their scope of application to products for use in reverberant conditions.

It is the proposal of TG1 that all noise barrier products for use at the roadside should be certified using Part 6 for airborne sound insulation once the standard is fully published and, in the longer term, Part 5 for sound reflection (certification using Part 1 will be retained in the short-medium term).

It is recommended that Highways Agency specifications and procurement procedures should be revised accordingly once these standards are introduced. However, it is considered by the authors to be beneficial to promote the Part 6 method to the UK noise barrier industry in the immediate future, so that they are familiar with the potential benefits and implications of changes to certification procedures.

Furthermore, the in situ test method in Part 6 offers the potential for conformity-of-production assessment, i.e. assessment of screening performance once barrier products have been installed at the roadside to determine conformity with contract specifications, as well as routine performance monitoring. Comment on these issues will be made throughout the remainder of the report based on practical experiences within the current study.

2.2 Overview of the test method

A detailed overview of the airborne sound insulation measurement method defined in Part 5 was presented by Watts and Morgan (2005). The principle differences between the Part 5 and Part 6 methods relate primarily to the measurement positions used for barriers where the post spacing is less than 4 m.

A simplified overview of the general measurement method is presented in the following paragraphs together with the equations for calculating the airborne sound insulation characteristics of a noise barrier.

Two sets of measurements are required to assess the performance, and are performed using a loudspeaker and microphone(s) as follows:

a) *The free-field measurement:* This is a measurement taken in the absence of the noise barrier, as shown in Figure 2.1.

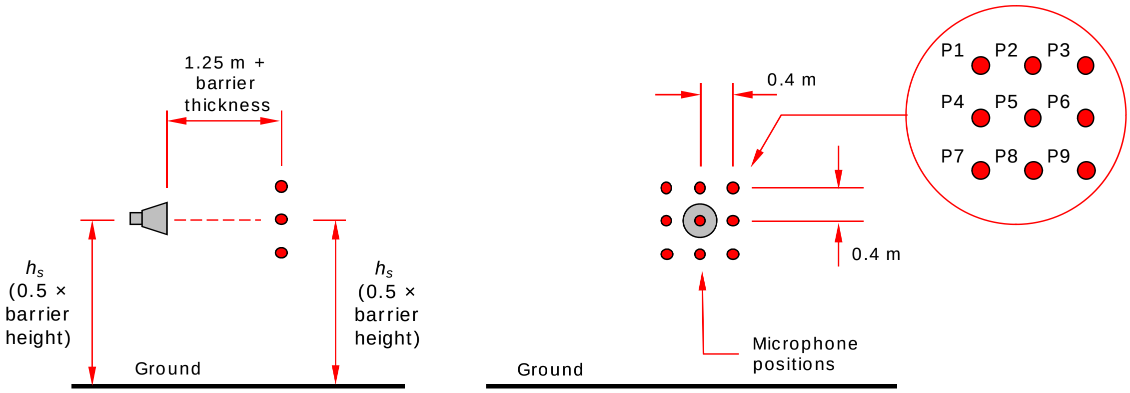


Figure 2.1: Free-field measurement set-up

b) *The transmitted measurement:* This is a measurement taken in the presence of the noise barrier, with the loudspeaker on one side and the microphone(s) on the other side, as shown in Figure 2.2.

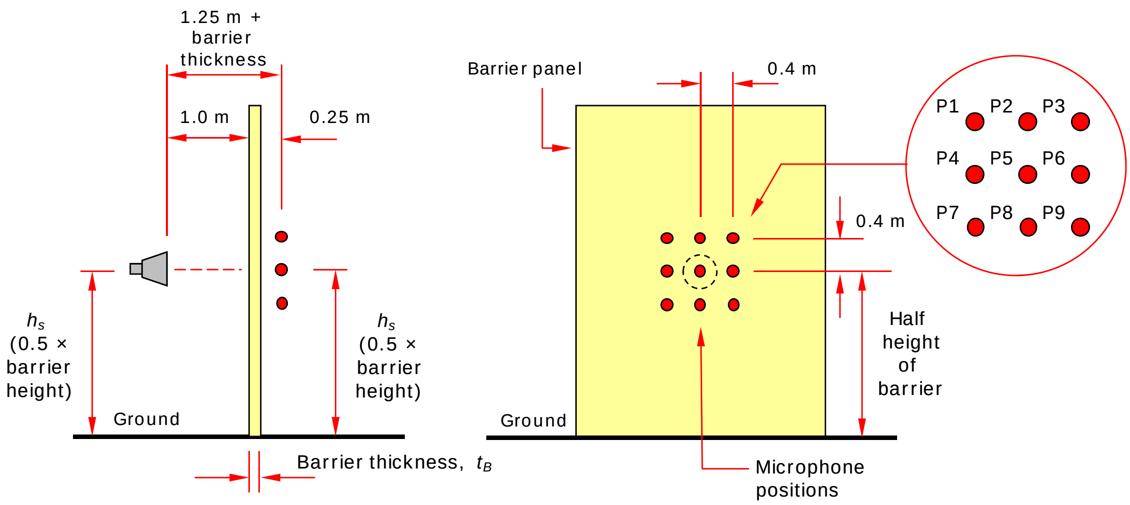


Figure 2.2: Transmitted measurement set-up

In both situations, measurements are taken at an array of 9 microphone positions as shown in the Figures. The heights above ground and the horizontal separation between the loudspeaker and the microphones are the same in both situations.

It is noted that in Part 5, the method uses only a *single-free-field measurement* at position 5, with the free-field levels at other positions being achieved through the application of path difference corrections; the use of free-field measurements at all nine microphone positions is one of the modifications to the method introduced in Part 6.

Figure 2.3 shows the loudspeaker and microphone array used in the measurements performed in this study (the microphone array is shown is fitted with 9 microphones).

Figure 2.3: Loudspeaker and microphone array used in the current study

The standard measurement positions based on the specifications in Part 5 are shown in Figure 2.4, where the X denotes the position of the axis between the loudspeaker and microphone P5, A with corresponding to the position for a panel measurement and B corresponding to the position for a post measurement.

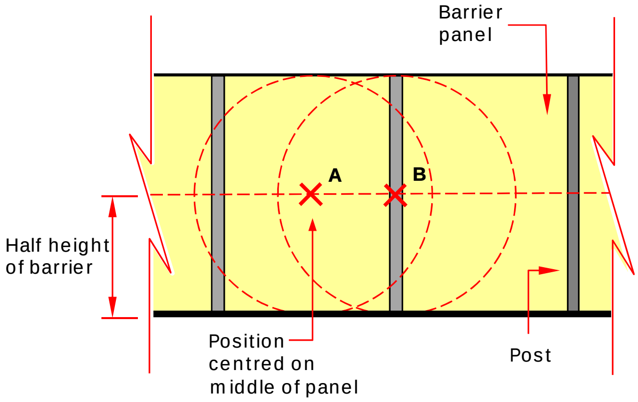


Figure 2.4: CEN/TS 1793-5 measurement positions for panels and posts
(A: Panel position; B: Post position; X denotes loudspeaker/microphone position 5 axis)

For Part 5 measurements, the thickness of the barrier, t_B, has been defined by the outer-most facing surfaces of the barrier within the area bounded by the dimensions of the microphone array. Figure 2.5 shows examples for timber barriers of measurements centred on posts and panels.

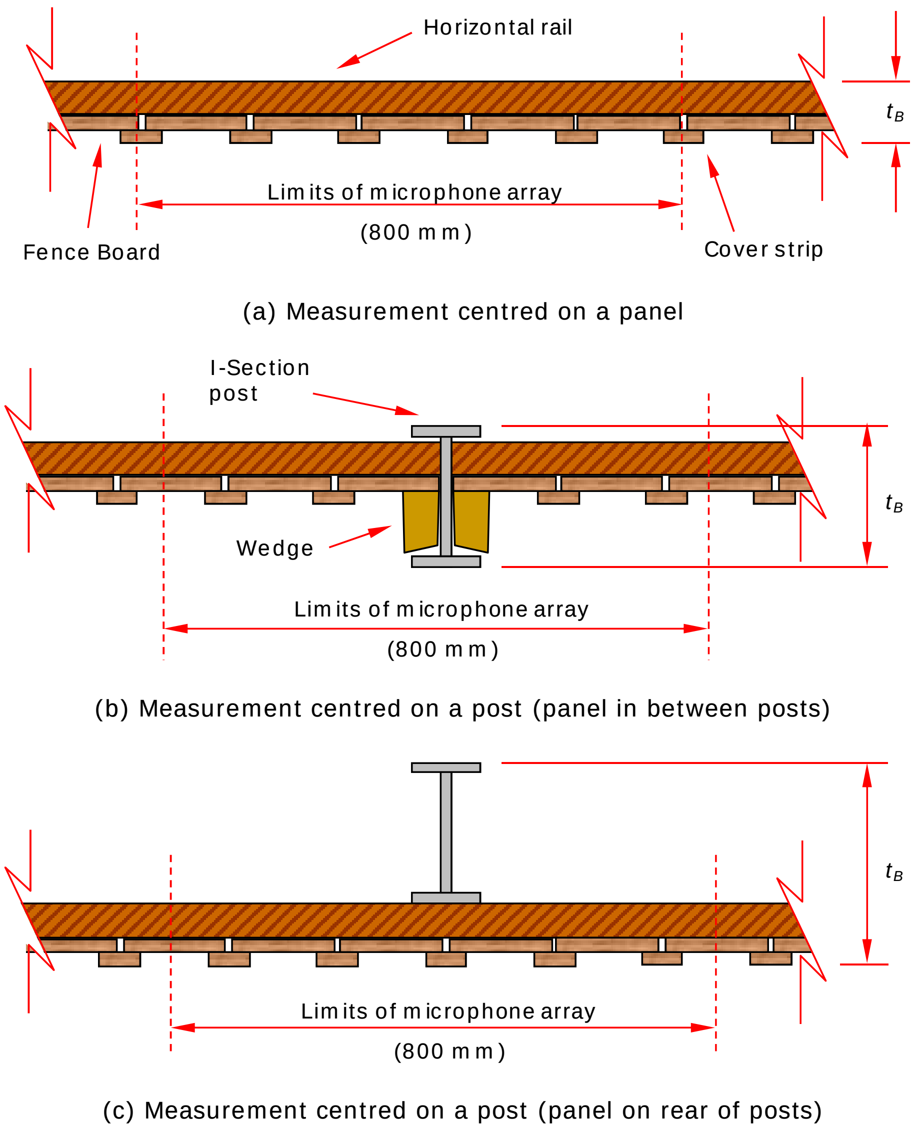
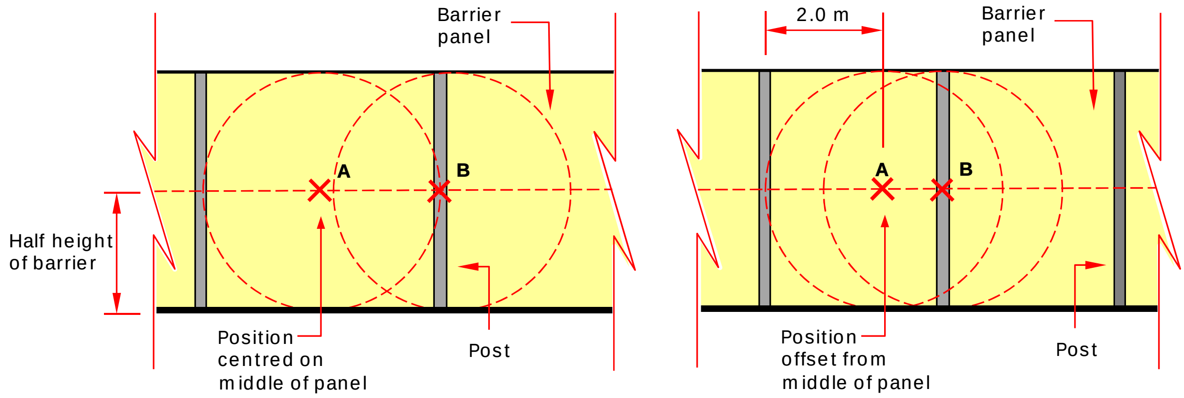


Figure 2.5: Defining barrier thickness, t_B, in CEN/TS 1793-5

Part 6 contains revised specifications for measurement positions, addressing two cases, i.e. post spacings greater than or equal to 4.0 m, and post spacings of less than 4.0 m, as shown in Figure 2.6.

Within Part 6, the effective thickness of the barrier has also been redefined to be defined by the most protruding parts of the device *within the tested area*, i.e. within the bounds of 4 m diameter circle shown in Figure 2.6. This has an impact on those measurements centred on the panel.

Figure 2.7 shows an example defining the effective thickness of a timber panel where the post spacing is less than 4 m. Further general examples are included in the text of the standard itself.



(a) Post spacings ≥ 4.0 m (b) Post spacings < 4.0 m

Figure 2.6: prEN 1793-6 measurement positions for panels and posts
(A: Panel position; B: Post position; X denotes loudspeaker/microphone position 5 axis)

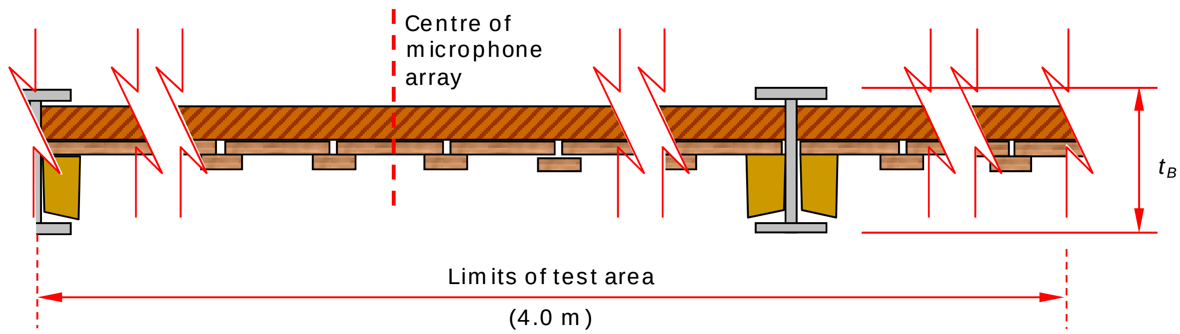


Figure 2.7: Defining barrier thickness, t_B, in prEN 1793-6.

2.3 Calculating airborne sound insulation performance

Results obtained using these measurement set-ups are converted to one-third octave band sound insulation levels, SI_j (where j denotes the relevant frequency band) using equation (7) in Part 5, given by

$$SI_j = -10 \times \log_{10} \left\{ \frac{\sum_{k=1}^{n} \int_{\Delta f_j} \left| F[h_{tk}(t) w_{tk}(t)] \right|^2 df \left(\frac{d_k}{d_i} \right)^2}{n \cdot \int_{\Delta f_j} \left| F[h_i(t) w_i(t)] \right|^2 df} \right\} \text{dB} \qquad (2.1)$$

where

$h_i(t)$ is the incident reference component of the free-field impulse response;

$h_{t,k}(t)$ is the transmitted component of the impulse response at the k^{th} scanning point;

$d_i(t)$ is the geometrical spreading correction factor for the reference free-field component;

$d_k(t)$ is the geometrical spreading correction factor for the transmitted component at the k^{th} scanning point;

$w_i(t)$ is the reference free-field component time window (using the Adrienne temporal window[2]);

$w_{tk}(t)$ is the time window (using the Adrienne window) for the transmitted component at the k^{th} scanning point;

F is the symbol of the Fourier transform;

j is the index of the j^{th} one-third octave frequency band (between 100 Hz and 5 kHz);

Δf_i is the width of the j^{th} one-third octave frequency band;

n = 9 is the number of scanning points.

The corresponding equation in Part 6, which eliminates the need for path difference corrections is equation (1)[3], given by

$$SI_j = -10 \times \log_{10} \left\{ \frac{\sum_{k=1}^{n} \int_{\Delta f_j} \left| F\left[h_{tk}(t) w_{tk}(t)\right]^2 \right| df}{\sum_{k=1}^{n} \int_{\Delta f_j} \left| F\left[h_{ik}(t) w_{ik}(t)\right]^2 \right| df} \right\} \text{dB} \qquad (2.2)$$

where

$h_{ik}(t)$ is the incident reference component of the free-field impulse response at the k^{th} scanning point;

$w_{ik}(t)$ is the reference free-field component time window (using the Adrienne window) at the k^{th} scanning point;

The single number rating of airborne sound insulation, DL_{SI}, is calculated using Equation (5) in Part 6 for panels (acoustic elements) and Equation (6) in Part 6 for posts. In general terms this is given by

$$DL_{SI} = -10 \times \log_{10} \left[\frac{\sum_{i=m}^{18} 10^{0.1 L_i} \times 10^{-0.1 SI_i}}{\sum_{i=m}^{18} 10^{0.1 L_i}} \right] \text{dB} \qquad (2.3)$$

where

SI_i is the sound insulation index measured in the i^{th} one-third octave band;

m = 4, which is the number of the 200 Hz one-third octave band (for certification purposes, DL_{SI} can only be calculated for the frequency range 200-5000 Hz (corresponding to a 4 m high noise barrier).

L_i is the relative A-weighted sound pressure level (dB) of the normalised traffic noise spectrum as defined in BS EN 1793-3 (BSI, 1998c) for the corresponding i^{th} one-third octave bands.

[2] See Section 4.4.5 of Part 5, Section 4.5.6 of Part 6 or Watts and Morgan (2005) for a definition and further explanation of the Adrienne temporal window which is used for windowing operations in the time domain.

[3] It should be noted that Equation (1) in the *Working Draft* of Part 6 is incorrect, because although the path difference correction has been removed, the denominator of the equation still assumes a single free-field transfer function rather than 1 for each microphone. The equation presented here is the corrected one.

Where both panel (acoustic elements) and post measurements have been taken, the *global* single number rating of sound insulation is calculated using Equation (7) in Part 6, given by

$$DL_{SI,G} = -10 \times \log_{10}\left[\frac{10^{-0.1DL_{SI,E}} + 10^{-0.1DL_{SI,P}}}{2}\right]\text{dB} \qquad (2.4)$$

where

$DL_{SI,E}$ is the single number rating of airborne sound insulation for panels (acoustic elements), in dB;

$DL_{SI,P}$ is the single number rating of airborne sound insulation for posts, in dB.

Figure 12 in the standard illustrates how the height of the noise barrier affects the low frequency limit of the sound insulation measurements. This in turn affects the calculation of DL_{SI}. By raising the lower frequency limit, e.g. from 200 Hz to 315 Hz, it is possible to artificially increase the value of DL_{SI}. The graph indicates that the evaluation of barriers with a height of 2.0 m or less is generally not recommended since the lowest valid one-third octave band is of the order of 630 Hz.

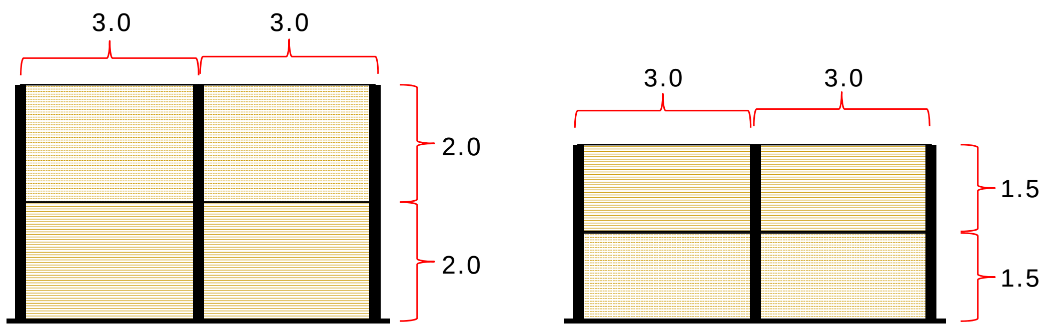
2.4 Use of the test method for product certification

In order to ensure consistency during certification and prevent invalid claims regarding sound insulation performance, the standard thereby states that for product certification, the test sample (comprised of acoustic elements and posts) shall have a *minimum height of 4.0 m* and a *minimum length of 6.0 m*. The test sample shall be mounted and assembled in the same manner as the manufactured device us used in practice with the same connections and seals. Accordingly, the single number rating, DL_{SI}, shall be calculated for a sample having these minimum dimensions (corresponding to the frequency range 200-5000 Hz (corresponding to a 4 m high noise barrier). *Values of DL_{SI} can only be reported for this frequency range.*

Where products would be installed in normal use with a height of less than 4 m, the products *must still be certified using a 4.0 m high test installation* and will have a DL_{SI} value as defined above. H*owever, any comparison between in situ performance and certification values will be restricted to third-octave band sound insulation indices only*, since the DL_{SI} value calculated say for a 3.0 m high barrier will be artificially high, as described in the previous section, and therefore not comparable with the certification DL_{SI}.

An example of how this might possibly be achieved for a 3.0 m high noise barrier of the type installed on the strategic road network is shown in Figure 2.8. Clearly, this is just one possible barrier design and the certification of other designs might require careful consideration depending on the manner of their roadside application.

A limited investigation on this issue is also reported in Chapter 9.



(a) Product as certified (b) Product as installed at the roadside

Figure 2.8: Example of a barrier installed at the roadside at a different height to that use for certification

2.5 Accuracy of the method

Repeatability and reproducibility of the method still require further investigation. Sound insulation measurements taken by different measurement teams on the same barriers as part of the European research project ADRIENNE suggested that the repeatability to be of the order of ±2 dB (Adrienne Research Team, 1998). Further 'Round Robin' tests are proposed as part of the current European 7th Framework project QUIESST (www.quiesst.eu).

A recent study on noise barriers installed along a high-speed rail line suggests that, when properly installed, a maximum difference between in situ measurements of sound insulation on similar samples of 1-2 dB in the value of the single number rating is achievable (Garai and Guidorzi, 2008), which is comparable to that for laboratory measurements. Larger differences are likely to be due to poor quality installation of the noise barrier products.

Measurement uncertainty has not been addressed in any depth at the current time; although an informative Annex on uncertainty is included in the forthcoming Part 6, there is presently insufficient data to derive robust uncertainty contributions.

Further work in this area is required and it is considered to early at this stage to specify uncertainties/accuracies/ tolerances in specifications, tender documents, etc.

2.6 Application of the test method within the current study

Free-field microphones: The current project commenced prior to the confirmation of measurement positions relating to post separations of less than 4.0 m by CEN TC226 WG6 TG1. Initial roadside measurements (three barriers as identified in Chapter 5), and the investigations into the effects of safety barriers and early-life moisture content (Chapters 6 and 7) were undertaken using the single free-field microphone and path difference correction approach as defined in Part 5. All remaining roadside measurements used 9 free-field microphone measurements as defined in Part 6. The effects of switching from one to 9 free-field microphones are discussed in Annex B (Morgan, 2010).

Measurement positions (lateral position along barrier): The project commenced before the latest proposals on defining barrier thickness in Part 6 were prepared by TG1. As such, all measurements have been taken using the positions defined in Part 5 and shown in Figure 2.4, i.e. with the panel measurements centred mid-panel (regardless of post separation) and the barrier thickness defined within the area bounded by the microphone array, unless stated otherwise in the text.

Measurement positions (barrier height): The current study has been restricted to the assessment of noise barriers with a height of 3.0 m or greater, with the exception of the panel geometry study on the noise barrier test facility (Chapter 9) which included a 2.0 m high barrier.

Where *roadside barriers* were greater than 3.0 m in height, practical limitations resulting from a combination of the test apparatus and local site conditions resulted in the measurements being performed as though the barriers were physically 3.0 m high, i.e. with the axis between the loudspeaker and microphone P5 at a height of 1.5 m relative to the *bottom* of the barrier. This restricts the lowest usable one-third octave band to 315 Hz. Since the results are not presented for the purposes of certification, then equation (2.3), i.e. the calculation of the single number rating, DL_{SI}, has been applied with a reduced frequency range of 315-5000 Hz, so that *all barriers* are consistently analysed as if 3.0 m high.

Where 4.0 m high *test facility installations* have been assessed using the full height of the barrier, this is stated in the text.

3 Current Highways Agency specifications for noise barriers

In relation to the procurement and application of noise barrier products on the SRN, the Agency's specifications currently state the following:

- *Initial acoustic performance - Testing:* In the Specification for Highway Works (SHW), Series 2500 (Highways Agency, undated #3), Clause 2504.16 requires that the acoustic performance of noise barriers "*shall have been tested… in accordance with BS EN 1793*".

- *Initial acoustic performance - Effectiveness:* In the Notes for Guidance on the Specification of Highway Works, Series NG 2500 (Highways Agency, undated #4), Clause 2504.14 states that "*the overall performance of a barrier should be at least 10 dB(A) higher than the calculated screening attenuation".* SHW Series 2500, Clause 2504.17 states that the sound insulation performance, expressed in terms of the single number rating DL_R (determined in accordance with BS EN 1793-2), shall meet that specified in Appendix 25/4 of the contract requirements.

  Where required, SHW Series 2500, Clause 2504.18 states that the sound absorption performance, expressed in terms of the single number rating DL_α (determined in accordance with BS EN 1793-1), shall meet that specified in Appendix 25/4 of the contract requirements.

- *Specification of materials for timber noise barriers:* SHW Series 300 (Highways Agency, undated #2), Clauses 304 and 311 set out the quality and preservation requirements for timber used in permanent works, including timber noise barriers. Clause 304.1 states that "*timber for use in permanent works shall be either of appropriate natural durability or be treated with wood preservatives in compliance with Clause 311".* Treatment requirements will vary depending on whether the timber is in or out of ground contact. There is also a requirement for structural timber used in noise barriers to be stress graded (Clause 304.4) and that these requirements are in accordance with those assumed in the structural design calculations (Clause NG 2504.10 (iii)). All timber used in both temporary and permanent works on the SRN, including noise barriers, is required to be purchased from legal and sustainable sources, as set out in Series 100, Clause 126 (Highways Agency, undated #1)

- *Serviceability and maintenance:* HA 66/95, Clause 7.1 states that "*a service life of 40 years is desirable, no major maintenance required for 20 years*" for all barrier materials. Clause 8.1 provides further details regarding maintenance considerations in this 20 year period, stating that barriers "*should be designed so that they require minimal maintenance other than cleaning or repair of damage*". Clause 8.7 lists normal maintenance activities as including "*tightening joints and fixings after initial construction*", "*painting and treating of metal or timber surfaces*" and "*periodic maintenance of planting*". Specifically in relation to timber barriers, Clause 7.2 states that "*it is a requirement of the specification that timber screens remain serviceable for 40 years and require no maintenance for 20 years*".

  It should be noted that HA 66/95 is an *advice note* and therefore has no mandatory function; the document serves only as recommendations for good practice.

- *Inspection of condition:* As part of standard HA procedures, Volume 2 of the Trunk Road Maintenance Manual (TRMM; Highways Agency, 1996) states that fences, walls, screens and environmental barriers should undergo detailed inspections of structural condition every 2 years. However, it is stated that detailed inspections in relation to integrity (general condition) every 6 months, noting that higher frequencies may be required in some locations, e.g. built-up areas where vandalism is known to be likely.
- *Addressing defects arising from condition surveys:* TRMM categorises defects arising from the inspections described above as either Category 1 (those requiring prompt attention because the represent and immediate or imminent hazard or because there is a risk of short term deterioration) or Category 2 (all other defects). Category 1 defects are required to be corrected or made safe at the time of inspection, with permanent repairs being undertaken within 28 days. Category 2 defects shall be repaired within planned programmes of works. These defects can be categorised in terms of priority which shall be considered, which together with access requirements, other works on the network, traffic levels and the need to minimise traffic management, in compiling programmes of work. Records of maintenance are required to be retained for at least 6 years.

PART 2: Acoustic durability of timber noise barriers

4 Selection of noise barriers for inclusion in the study

This chapter describes the criteria and processes used for selecting candidate noise barriers for inclusion in the study.

The performance of noise barriers is affected by a wide range of variables, as summarised in Section 1.1. However, in examining the performance of generic barrier types, additional variables may be introduced which may affect the final results. The objective was to eliminate as many of these variables as possible, during the selection process, to reduce uncertainty during the data analysis stage of this project.

Whilst the main selection process was undertaken at the beginning of the project, the candidate barrier set was supplemented over the duration of the project with additional barriers as and when suitable candidates were identified.

The *primary selection methodology* involved the interrogation of existing data sources to identify locations and ages, followed by visual inspections of possible candidate barriers to derive a barrier set for testing. In many instances, the age data was only determined after the barriers were included in the test programme.

The barrier set was supplemented over the duration of the project using a *secondary selection methodology* which involved the reverse procedure, i.e. the identification of suitable barriers via drive-by surveys/casual observation followed by an interrogation of third parties/data sources to determine the age data.

4.1 Primary selection: Identification of data sources

At the commencement of the project, TRL identified several sources of background data for use as part of the primary selection methodology. These were categorised into three broad groups: general databases, Highways Agency policy documents and detailed records. The following sections describe these data sources in more detail.

4.1.1 General databases and asset management records

- *EnvIS (Environmental Information System; Halcrow):* This database was developed for the Highways Agency and contains information on all the environmental aspects related to highways. This database has been populated using data from the Agency's maintenance systems.

- *Defra noise mapping database:* Fulfilling a requirement of the Environmental Noise Directive (European Commission, 2002), Defra developed a database, which amongst other information contains details of noise barriers throughout England and Wales. The database is in the format of a GIS map and contains basic information about barriers including the location, construction material and height. This information was collated from a variety of sources, namely Highways Agency records and drive-by surveys.

- *SMIS (Structures Management Information Systems; Highways Agency):* This contains information on all structures over 3 m high on the Strategic Road Network.

- *HAPMS (Highways Agency Pavement Management System):* This database contains information regarding the current condition of the SRN surfaces and pavements.

Further details on the individual Highways Agency databases/asset management records can be found in the Agency's Network Management Manual (NMM; Highways Agency, 2009).

4.1.2 Highways Agency policy documents

- *Hansard sites:* In 1999, the Agency developed criteria to identify locations on the SRN where there were serious and pressing noise problems, which did not have the early prospect of benefiting from the policy of using quieter surfacing on carriageways when maintenance was required. Locations across the network which were found to meet the published criteria were announced in Hansard on 11 November 1999 and are commonly referred to as 'Hansard sites'. These sites were then subject to individual studies to determine the most practical and cost-effective means of noise mitigation. Where the most effective means of mitigation was concluded to be the provision of noise barriers, their installation has been funded from an annual £5m ring-fenced budget. The programme of installation is currently ongoing (Highways Agency, 2003).

4.1.3 Detailed records

- *Barrier manufacturer records:* These were considered to be the primary data resource. TRL already has various contacts with certain barrier manufacturers from previous projects
- *Highways Agency Managing Agents (MAs):* In order to manage England's strategic network, the Agency has divided the country into fourteen areas and appointed MAs to oversee the day-to-day management. A letter detailing the project was sent out to relevant MAs accompanied by a brief questionnaire, asking for basic information of any acoustic barriers that may be located on the Strategic Road Network within the specific Agency Area

4.2 Primary selection: Preliminary survey of data sources

An initial review of the data sources described above identified that that no single source could provide the necessary information on barriers, and that the quality of data within many of these sources was highly variable and often poor. However, by combining information from the different sources, it was considered feasible to identify a provisional candidate list for further investigation.

4.2.1 General databases

The EnvIS database was currently being populated using data from the Highways Agency's maintenance systems, which did not originally include noise barriers. It was concluded that this data source did not contain the required information as only six timber noise barriers were identified within the database, three already in existence and three planned barriers.

The Defra noise mapping database, which includes the location of noise barriers throughout England & Wales, takes the form of a GIS map and contained basic information about individual barriers including the location, construction material and height (assumed from drive-by surveys), all of which aided the desktop identification of potential barriers. The database was manipulated to display all barriers which fitted the height and material criteria, allowing the database to be used as a cross-reference for other sources of information. The main limitation of the database was that it was compiled in 2005, so new barriers were not detailed.

The SMIS database contained a limited amount of information on noise barriers, as they are only recorded where the barrier is attached to or part of another structure as defined in DMRB Section 3.2.1 and is at least 3 m in height. This latter point would be highlighted as being particularly relevant during the Stage 2 (visual inspection) filtering.

The HAPMS database contains information regarding the current condition of the SRN road surfaces and pavements. While this gave location information for noise barriers, the associated date information in the database related to the date that the barrier information was entered into the database rather than the date that the noise barrier was constructed.

4.2.2 Highways Agency policy documents

The list of Hansard sites allowed candidate barriers where no age was provided to be cross-referenced. Installation of the first noise barriers as a direct result of the list began in 2001, therefore by comparing the locations of candidate barriers to the locations on the list, the barriers could not have been installed pre-2001.

4.2.3 Detailed records

Barrier manufacturer contract records were considered to be a crucial data resource. A detailed letter specifying the objectives of the project was sent to 15 barrier manufacturers including the three main fencing contractors responsible for barrier installations on the SRN. While many of the manufacturers provided feedback however, the quality of data varied immensely.

Based on discussions with barrier manufacturers and scheme designers, it appears that some contract specifications set out a “defects and maintenance” period of 20 years (based on the text of HA 66/95 which states that *“Environmental barriers should be designed so that they require minimal maintenance other than cleaning or repair of damage for at least 20 years”.* However, this is not standard practice encouraged by the Highways Agency and there is no formal guidance setting out such guarantee durations.

However, barrier manufacturers may only hold records of installations for 6-7 years in accordance with their QA policies, meaning that information on older barriers was frequently unavailable. That information provided by the manufacturers included relatively detailed ages and locations, however few barriers were identified that fitted the height criteria to be used within this project.

The procedures which had to be followed to gain information from the MAs responsible for the different Highways Agency areas were problematic since the request time for information was approximately 10 weeks. Completed questionnaires were received from 10 areas. The quality of the data received varied greatly, from maps which had to be cross referenced to gain location details to personally meeting staff at area offices. The information provided by the MAs was collated into a database for interrogation. Certain areas did not provide information due to their relatively rural nature. It is clear that no MA maintains a database for storing information on noise barriers. One area conducted their own site visits on our behalf to identify the location of barriers.

4.3 Primary selection: Filtering processes and selection criteria

Having collated all of the usable information from these data sources, the selection of barriers on the SRN for testing was based on a two-stage filtering process, as follows:

- *Stage 1 filtering:* Desktop review
- *Stage 2 filtering:* Visual inspection

The individual processes and the criteria used for filtering the candidate barrier list are described in the following sections.

4.3.1 Stage 1 filtering: Desktop review and preferred characteristics

It was expected that the individual data sources would identify a large number of barriers on the SRN, not all of which would be suitable for inclusion in the measurement programme. The desktop study was intended to eliminate all those barriers that were clearly unsuitable and which therefore did not require any further investigation or visual inspection. The following criteria were to be used in this filtering process:

Acoustic Property

As already noted, timber barriers are classed as either absorptive or reflective. It was already known that the majority of barriers on the SRN are reflective. The main focus of the study was therefore considered to be reflective barriers.

Barrier age

The age of the barrier affects the transmission loss due to the timber acoustic elements (panels) shrinking and warping, which create gaps in the barrier allowing sound leakage. Age is also a factor when discussing the decay of the wood and stability of the barrier. The age of the barrier can have an added effect if the barrier is absorptive as the absorbing material (usually fibre glass or similar) deteriorates significantly and can accumulate at the base of the barrier as a result of exposure to meteorological conditions. Figure 4.1 shows examples of absorptive barriers in good and poor condition.

Figure 4.1: Sound absorptive noise barriers in good and poor condition

Ideally barriers were to be selected to represent a variety of ages, ranging from newly installed to 20 years old (considered to be the maximum effective age of a barrier) with an equal or well balanced distribution across that range. Without an adequate range of ages, indicative indications of acoustic durability cannot be made.

Construction type and installation

Although previous studies (e.g. Watts and Morgan, 2005) have investigated the performance of both single and double-leaf timber barrier configurations, it was considered that this project should focus on the most common design type, namely single-leaf configurations. While single-leaf barriers are the most common form of barrier construction on the SRN, there are many variants in the arrangement of the timber components that make up the individual panels (examples are shown in Figure 4.2); this is discussed further in Section 4.5. Ideally, all the barriers selected for the testing programme would be of similar construction and timber arrangement, preferably originating from a single contractor. However, that level of information was not widely available.

Barrier height and width

As noted in Section 2.3, the lower frequency limit for Part 6 measurements is a function of the height of the noise barrier, such that as the height decreases, so the lower frequency limits increases. For example the third octave low frequency limit for a 3 m high barrier is 315 Hz whereas for a 2 m barrier the lower limit is increased to 630 Hz. Similarly, if the effects of any posts are to be discounted from the assessment of sound insulation, the width of the panel in between the posts has a similar effect as the height.

(a) Vertical elements, timber posts (b) Horizontal elements, steel posts

Figure 4.2: Different methods of construction for timber noise barriers

It was noted that for the purposes of qualification/certification (i.e. the calculation of the single number rating of sound insulation for CE marking), the minimum acceptable acoustic element dimensions for testing stated in Part 5, were 4.0 m x 4.0 m so as to characterise the performance over a wide frequency range. The width requirement has subsequently been revised in Part 6 to take account of acoustic elements with a width less than 4.0 m, however the height and the equivalent cross-sectional area of the full test sample remains the same.

For in situ assessment, such as in the current study, no such specifications are prescribed since the design of an individual barrier will be based on the requirements and local conditions where it is to be installed.

Barrier heights on the SRN generally range from 2.0 to 4.0 m, although the more common range is 2.0 to 3.0 m. The maximum panel width/post separation which has been observed on the SRN is 3 m. Wider post spacings would require much deeper foundations to withstand the increased wind loading, particularly on the higher barriers, and as such are rarely used.

It was therefore anticipated that all of the barriers selected for testing should be at least 3 m high ideally with a post spacing of 3 m to allow the sound insulation performance to be determined over an appropriate frequency range.

4.3.2 Stage 2 filtering: Visual inspection

Having reduced the initial list of barriers to those known to be potentially suitable for study, it was intended that a further reduction of the list, to identify the final candidate barriers for study, would be achieved by undertaking a visual inspection of the barriers. This would also serve to establish the accuracy of the information within the individual data sources. The following additional criteria were to be used in this filtering process:

Barrier Location

The location of the barrier, in terms of ease of access, was essential to the success of the project due to limitations in the portability of the test equipment (the TRL apparatus for performing Part 6 measurements uses a PC based system operated from a vehicle in close proximity to the barrier) or potential health and safety risks. Local limitations which prevented the inclusion of a barrier in the final measurement programme included the following:

- Where barriers are situated at the top of embankments and were either too far from the roadside or the angle/stability of the embankment was unsuitable for staff access. Sites where the gradient was not excessive have been included
- Where access to the rear of the noise barrier was not possible, either directly or due to a lack of access gates allowing access from the traffic side, or where the rear of the barrier was obscured by excessive vegetation and/or other objects
- Where there was no hard-shoulder available alongside the noise barrier or the hard-shoulder was not suitable for the level of traffic management required for the in situ measurements

Construction type and installation

The construction process used for the barriers varies. Barrier panels can be either assembled piece by piece in the field or prefabricated in a factory prior to mounting on or between the main posts. The quality of both the initial manufacture and the roadside installation can be pivotal to the structural and acoustic durability of the noise barrier. Only barriers that were structurally robust would be selected for acoustic testing, i.e. barriers that are clearly in very poor structural condition would be recorded but not included in the assessment. As far as is possible, only similar designs of barriers would be tested, i.e. if the construction of one reflective barrier differed considerably from the common design, it would not be included.

4.4 Primary selection: Conclusions from Stage 1 filtering

For both of the barrier types under consideration, the number of candidates identified for subsequent visual inspection was small, being approximately 30 in total. In some instances, no information was available as to whether the barrier was reflective or absorptive. Furthermore, it was not possible to determine when a large number of the barriers were constructed based on the information available during the review. Based on the limited sample size, it was concluded that this should not be allowed to restrict the measurement programme and that the age data could be collated at a later stage.

It is also noted that the desktop review was generally unable to identify the manufacturers of the barriers selected for visual inspection. Consequently, even if the age of the barrier could be identified, it was only possible to estimate the likely initial sound insulation performance, based on the single number categories of sound insulation described in Annex A of Part 2, performing a conversion to the Part 6 equivalent using, for example, the relationships developed by Watts and Morgan (2005).

The following sections provide further comment on the individual barrier types.

4.4.1 Single-leaf reflective barriers

Based on the information provided from the desktop review, the percentage of barriers on the SRN which are high enough for inclusion in the current study, i.e. 3 m or higher, was found to be comparatively small. It is noted that Clause 2.24 of HA 65/94 (Highways Agency, 2001a) states that generally heights have been *"restricted to 3m because it was judged that vertical faces taller than this would be visually intrusive"*. Following general discussions with barrier manufacturers, it was concluded that in a broad sense, many of those barriers coming towards the end of their structural lifetime were likely to be of the order of 2 m in height. Taller barriers, of the order of 3-4 m in height, have generally being installed within the last 7-8 years, the highest being very recent installations. Consequently, the proposed upper age range of the barriers to be tested may be significantly less than the 20 years specified in BS 14389-1.

4.4.2 Absorptive barriers

Based on the data available, discussions with manufacturers and the sample size identified as suitable for visual inspection, insufficient barriers were available to provide a suitably wide sample for assessing long-term durability. It was therefore concluded that measurements would be taken for absorptive barriers with the objective of providing a dataset which can be supplemented in future studies, but not for performing any in-depth analysis.

4.5 Primary selection: Conclusions from Stage 2 filtering

These visual inspections reduced the list of candidate barriers to the final test set by rejecting unsuitable barriers on the following grounds:

- The barrier type was different to that suggested by the desktop study and unsuitable for inclusion, e.g. the barrier was found to be an aluminium rather than timber construction

- The barrier height was insufficient for study (i.e. 2.5 m or less)
- Site conditions were unsuitable for performing measurements due to the presence of trees/bushes/dense undergrowth, either directly against the barrier or in sufficiently close proximity to prevent the positioning of the test apparatus. On at least two occasions, where access to the rear of the barrier was through access gates, the vegetation behind the barrier was sufficiently dense as to prevent the gate from being opened wide enough to permit access. In some cases, it was established that an environmental assessment was necessary in order to determine whether this vegetation could be cleared sufficiently to provide access to the measurement team.

  It has been observed that it is common practice to plant trees immediately behind newly installed barriers with the long-term aim of minimising visual intrusion to residents behind the barriers.
- Other more appropriate measurement positions were found on the same barrier in the near vicinity, i.e. generally at the next available access gate

Due to the limited number of barriers that were identified for inspection by the desktop review, it was not possible to achieve a candidate list that eliminated all of the factors identified previously that might affect the precision of the study. The following comments are noted:

- It was not possible to restrict candidate barriers to those constructed by a single manufacturer. As such, the physical design of the individual barriers varies. Considering the single-leaf reflective barriers alone, 3 basic designs were identified within the candidate group (based on the design of the main planking and cover strips but ignoring the number and positioning of horizontal rails). Illustrative cross-sections are shown in Annex D (Morgan, 2010).
- Within the candidate group, the method of construction can be broadly classified based on both the *longitudinal profile* and the *vertical profile* of the barrier. The following terminology will be adopted for this study:
  - *Modular barriers:* Longitudinal profile classification where the acoustic elements (generally prefabricated) are mounted in-between steel I-section posts
  - *Continuous barriers:* Longitudinal profile classification where the acoustic elements are constructed as a continuous length, generally assembled on site, and fixed to the front/rear of either steel I-section or timber posts
  - *'Single-element' barriers:* Vertical profile classification where the full height of the barrier is achieved using single acoustic elements. In the case of timber barriers, such barriers can be used with prefabricated acoustic elements when the height of the barrier is less than 2.5 m, and site-assembled acoustic elements for higher barriers
  - *'Multi-element' barriers:* Vertical profile classification where the full height of the barrier is achieved using multiple acoustic elements arranged on top of one another. In the case of timber barriers, these are generally constructed using pre-fabricated acoustic elements.

  Examples of these different constructions are shown in Figure 4.3

a) Continuous, single-element barrier (b) Modular, multi-element barrier

Figure 4.3: Example of different methods of barrier construction

- There was also inconsistency in the post spacings, with a range of 2.3 – 3.0 m. However the candidate group was not large enough to allow barriers with smaller post spacings to be eliminated. In some instances, therefore, the effective measurement area used to determine the sound insulation performance includes the presence of posts.
- Within the candidate group, the barrier height was variable. There were insufficient barriers of a single height to restrict the barrier set in such a manner

The above points must be taken into consideration during the analysis of measurement data within the test programme.

A total of 12 single-leaf reflective barriers and 4 absorptive barriers were identified as being suitable for full inclusion in the measurement programme, taking into account additional considerations highlighted below.

4.5.1 Additional considerations affecting roadside barrier selection

The visual inspections highlighted the wide range of site conditions at noise barrier locations, in terms of either the ground profile and/or the proximity of the safety barrier to the noise barrier. These factors required careful consideration to ensure that the barriers could still be assessed and as such, have affected the design and timetable of the measurement programme.

- At several of the test sites, there was a lack of flat level ground at the rear of the barrier (and in some cases also on the traffic side).
- At several of the test sites, the safety fence was positioned in between the loudspeaker and the noise barrier, which may potentially cause reflected sound to contaminate the measurement results. One possibility for overcoming this is to assume the top of the safety fence as being the datum ground level (as recommended by Watts and Morgan, 2005). However this reduces the effective height of the barrier being assessed and increases the lower frequency limit at which the sound insulation performance can be assessed. Chapter 9 reports on test facility measurements to investigate options for testing in such instances.

4.6 Secondary selection: Conclusions from drive-by surveys

As already noted, over the duration of the programme, the primary barrier set was supplemented using a secondary selection methodology which involved the identification of suitable barriers via focussed drive-by surveys or casual observation (the latter being where barriers were identified by chance) followed by subsequent interrogation of third parties/data sources to determine the age data. This process was only moderately successful, identifying an additional 4 barriers for inclusion, i.e. 2 single-leaf reflective and 2 absorptive barriers.

It was noted as a result of these surveys that there is an increasing use of double-leaf reflective barriers on new schemes. Two sites were identified where such barriers have been constructed within six months prior to the survey/observation. The decision was taken to include these barriers in the programme with the view to undertaking long-term monitoring. A further site with a considerably older double-leaf reflective barrier was also identified for inclusion.

4.7 Inclusion of roadside barriers from previous TRL studies

One of the most significant characteristics of the initial candidate group of roadside barriers was that none of the barriers were available for Part 6 testing immediately after installation. Although a number of schemes were identified where barrier installations were being carried out within the time frame of the current study, the logistics of these sites were such that there was insufficient space within the available traffic management to allow the project team to undertake Part 6 assessments in safety. As such, no initial Part 6 sound insulation performances could be measured.

One of the selected barrier installations on the M20 between Junction 10 and 11 had been previously tested using the Part 5 method within days of its installation in 2001 (Watts and Surgand, 2001). Although it was not possible to establish precisely which panels were tested, it was proposed to include the 2001 measurement results in the study as being representative of the overall barrier.

4.8 Selection of non-roadside barriers for inclusion in the study

Whilst there were no suitable test locations available during the current study where installation works were in progress (due to a lack of suitable working space within traffic management), it was still considered important to include measurements on new barriers since the equations for converting Part 2 DL_R values to their Part 6 equivalent DL_{SI} values have not been validated with a wider measurement programme. The availability of test facility measurement data was therefore reviewed.

Measurement data was available for the barriers tested in the original Part 5 evaluation study by Watts and Morgan (2005). These barriers included single-leaf reflective, double-leaf reflective and sound absorptive barriers. Furthermore, panels from these test configurations were still available for testing within the current study. However, it was noted that these were not the exact panels tested in 2005 since these were removed at the time and trimmed in size to perform Part 2 measurements in a reverberation chamber. It was noted that not all of the panels have been stored upright between posts in the intervening period.

The reflective barrier candidate group was also supplemented with measurement data from the new timber barriers being examined as part of the early-life moisture content and safety barrier investigations within the current project (Chapters 7 and 6 respectively).

Figure 4.4 shows examples of the barriers installed on the TRL noise barrier test facilities.

4.9 Outcome of the full selection process

The composition of the final candidate measurement group was as follows:

- 18 single-leaf reflective barriers (14 roadside barriers and 4 test facility barriers)
- 5 double-leaf reflective barriers (3 roadside barriers and 2 test facility barriers)
- 8 single-leaf absorptive barriers (6 roadside barriers and 2 test facility barriers)

(a) Barriers tested by Watts and Morgan (2005) (Crowthorne test facility)

(b) Barriers erected during current study (Bishops Castle Test Facility)

Figure 4.4: Timber noise barriers erected on the TRL noise barrier test facilities

It is noted that there are three locations M1 J8-9, M5 J11A-12 and M20 J9-10 where the candidate group includes barriers on both the northbound and southbound carriageway. In each case, the barriers on both sides of the carriageway are of identical design and constructed as part of the same scheme. This will help to provide a further indication of the consistency of build quality.

Table 4.1 – Table 4.3 provide summaries of the definitive test locations for single-leaf reflective, sound absorptive and double-leaf barriers respectively.

The estimated date of installation of each of the barriers is included in the Tables. Where possible, this has been determined from records held by the Highways Agency or HA Managing Agents either during the desktop survey or following subsequent investigations. Where such information could not be obtained, the values are estimated dates based on consultation with an industry expert who was able to give some indication of the year of installation, the month being assumed as July for simplicity.

It is assumed that all of the roadside barriers have been inspected and maintained in accordance with current Agency regulations (see Chapter 3).

Full details of the candidate barriers to be tested, including descriptions and site photographs are included in Annexes E-G (Morgan, 2010).

Table 4.1: Summary of candidate single-leaf reflective noise barrier locations
(Marker Post numbers correspond to the post nearest the measurement position)

Roadside barriers suitable for immediate assessment	M1, J27-28, N/B MP 216/4 (Nottingham) Installed: Oct 2003	M2, J2-3, E/B MP 48/2 (Rochester) Installed: Jul 2003 (estimate)	M5, J11A-12 N/B MP 89/9 (Gloucester) Installed: Jul 2002
	M5, J11A-12 S/B MP 89/5 (Gloucester) Installed: Jul 2002	M5 J18-19, S/ MP 144/1 (Bristol) Installed: Jul 1999 (estimate)	M40, J1A-2, E/B MP 34/9 (Beaconsfield) Installed: Jul 1999 (estimate)
	M40 J2-3, E/B MP 42/0 (Beaconsfield) Installed: Jul 1999 (estimate)	M6 J8-9, N/B MP 191/5 (Great Barr) Installed: Jul 2004 (estimate)	M3 J4a-5, W/B MP 60/4 (Fleet) Installed: Jul 2001 (estimate)
Roadside barriers with safety fences in close proximity	M4, J7-8/9, E/B MP 41/4 (Slough) Installed: Jul 2001 (estimate)	M6, J13-14, S/B MP 222/6 (Stafford) Installed: Jul 1989 (estimate)	M20, J10-11, E/B[1] MP 96/7 (Ashford) Installed: Oct 2001
	M20, J10-11, W/B MP 99/2 (Ashford) Installed: Oct 2001	M25, J6-7, C/W MP 45/3 (Redhill) Installed: Jul 2000 (estimate)	
Barriers tested on purpose-built test facilities	TRL Noise Barrier Test Facility, Crowthorne[2] Constructed: Apr 2004	TRL Noise Barrier Test Facility, Crowthorne[2] Constructed: Oct 2004	TRL Noise Barrier Test Facility, Bishops Castle Constructed: May 2008
	TRL Noise Barrier Test Facility, Bishops Castle Installed: May 2008		

[1] These barriers were also tested in 2001 when they were newly constructed. Note that the exact panels tested are not the same in both studies

[2] Measurement data from the current study will be supplemented with historical data from previous tests (Watts and Morgan, 2005). Note that the exact panels tested are not the same in both studies

Table 4.2: Summary of candidate absorptive noise barrier locations
(Marker Post numbers correspond to the post nearest the measurement position)

Roadside barriers suitable for immediate assessment	M1, J24a-25, S/B MP 191/5 (Nottingham) Installed: Sep 2004	M25, J12-13, C/W MP 86/3 (Staines) Installed: Jun 2003	
Roadside barriers with safety fences in close proximity	M1, J11-12, N/B MP 56/2 (Luton) Constructed: Jun 2004	M3, J4-4a, W/B MP 53/6 (Farnborough) Installed: Mar 2004	M3, J3-4, E/B MP 51/5 (Camberley) Installed: Jul 2003 (estimate)
	M25, J9-10 AC/W MP 67/0 (Leatherhead) Installed: Jul 2003 (estimate)		
Barriers tested on purpose-built test facilities	TRL Noise Barrier Test Facility, Crowthorne[1] Installed: Jun 2004	TRL Noise Barrier Test Facility, Crowthorne[1] Installed: Oct 2004	

[1] Measurement data from the current study will be supplemented with historical data from previous tests (Watts and Morgan, 2005). Note that the exact panels tested are not the same in both studies

Table 4.3: Summary of candidate double-leaf reflective noise barrier locations
(Marker Post numbers correspond to the post nearest the measurement position)

Roadside barriers suitable for immediate assessment	M1, J8-9, N/B MP 40/9 (Dunstable) Installed: Oct 2008	M1, J8-9, S/B MP 44/2 (Dunstable) Installed: Oct 2008	
Roadside barriers with safety fences in close proximity	M25, J8-9 C/W MP 53/8 (Leatherhead) Installed: Jul 2000 (estimate)		
Barriers tested on purpose-built test facilities	TRL Noise Barrier Test Facility, Crowthorne[1] Constructed: May 2004	TRL Noise Barrier Test Facility, Crowthorne[1] Constructed: Nov 2004	

[1] Measurement data from the current study will be supplemented with historical data from previous tests (Watts and Morgan, 2005). Note that the exact panels tested are not the same in both studies

4.10 Discussion: Data availability and asset management

The review of data sources to select candidate barriers for testing demonstrated that the level and quality of data held by any one source was highly variable and that there is little consistency between sources.

Furthermore, whilst generic barrier types are restricted to reflective and absorptive barriers, the visual surveys of the network highlighted the wide range of designs, heights, post spacings, construction materials and physical conditions that exist. The data sources reviewed generally failed to capture much of this information.

The lack of quality data was a significant hindrance in the development of a comprehensive test programme, and required significant effort on the part of the project team to overcome this obstacle.

The lack of comprehensive centrally held data on noise barriers within the Highways Agency means that MAs are responsible for collecting any data to inform their own processes. In several instances, MAs enquired whether any comprehensive information collated by the TRL project team's own investigations could be passed on in order to populate/improve their own noise barrier records. It is also considered a possibility that this issue means that information might not be passed on when there is a change in the appointed MA in any given area.

The mechanism for the provision of a comprehensive central database on noise barriers is already in existence within the HA, namely the EnvIS database referred to in Section 4.1.1. Clause 2.15.2 of the Agency's Network Management Manual (Highways Agency, 2009) and Interim Advice Note 84 Part 1 (Highways Agency, 2007) state that EnvIS is intended to include an environmental inventory of noise related environmental elements. IAN 84/1 defines an environmental element as being "*a man-made or natural asset,* *comprising the environment within and surrounding the trunk road network, for example… a noise barrier*".

Interrogation of the current EnvIS database as part of this research indentified relatively little noise barrier information.

With the inclusion of appropriate fields, the database could become an important, managed source of information. It is therefore recommended that any future revision of the database should, as a minimum, include the addition of the following noise-barrier related fields:

Barrier type and construction data

- Acoustic type (sound reflective or sound absorptive)
- Construction type: Single-leaf or double-leaf; modular or continuous (see Section 4.5); single element or multi-element (see Section 4.5)
- Primary construction materials (timber, metal, concrete or perspex); Secondary construction materials
- Height, length and post spacing (treating the barrier as a contiguous serious of fixed height sections)

Location data

- Road name, nearest junction numbers (where relevant) and approximate geographical location
- GPS coordinates by fixed height section
- Distance from edge of carriageway and, for barriers located on embankments, height above edge of carriageway
- A brief description of what the barrier is protecting
- Distance to the nearest residential property

Date of barrier installation, contract ID and details of installation scheme

Date of acoustic element manufacture

- This will only apply to prefabricated acoustic elements where the differs significantly different from date of installation

Name of manufacturer and/or installer

Initial acoustic performance characteristics

- Reported sound insulation category, B or D, corresponding single number rating of airborne sound insulation, DL_R or DL_{SI}, and one-third octave band sound insulation indices, R_i or SI_j determined in accordance with BS 1793-2 or prEN 1793-6 (depending on which is the Agency required test standard for characterisation at the time)

- Reported sound absorption category, A, corresponding single number rating of sound absorption, DL_{α}, and one-third octave band sound absorption coefficients, α_{Si} determined in accordance with BS 1793-1 (for sound absorptive barriers only)
- Long-term performance characteristics (as prescribed in BS 14389-1)

Monitored acoustic performance characteristics

- Sound insulation and, for sound absorptive barriers, sound absorption data as determined from routine monitoring. This data will be of the same type/format as the initial performance data).

Physical condition reports

- These should use the data from the regular condition inspections as required by TRMM (see Chapter 3).

Viewed from a general asset management perspective, the current lack of Agency knowledge of the locations, ages and conditions of installed barriers means that regular condition surveys, as required by TRMM (see Chapter 3), may either not be undertaken or may be deficient in addressing all noise barrier assets. As a result, area maintenance programmes may be failing to take necessary remedial actions to repair/replace damaged barriers, potentially resulting in reduced structural and/or acoustic durability.

However, it is acknowledged that noise barrier maintenance programmes are likely to only be carried out when other major works in the vicinity are scheduled (to minimise traffic disruption), so that the condition of the barriers might be less of a consideration unless there is a risk of seriously structural failure.

Viewed from the perspective of the EU Directive on the assessment and management of environmental noise, 2002/49/EC (European Commission, 2002), the lack of a robust, high quality network wide database, managed either by the Agency or by Defra, holding accurate and up-to-date noise barrier data is perceived as being likely to result in reduced accuracy noise maps. This could potentially result in either unnecessary or insufficient noise mitigation measures being specified within Action Plans to address noise from the Strategic Road Network.

Overall conclusions and recommendations

The selection process highlighted that the level of location and technical information held by any single source was highly variable and that there is little consistency between the data sources. This lack of data hindered the selection of candidate barriers for roadside testing and meant that it was not possible to identify all sites prior to the commencement of the measurement programme.

Overall conclusions and recommendations (continued...)

The composition of the final candidate measurement group was as follows:

- 18 single-leaf reflective barriers (14 roadside and 4 test facility)
- 5 double-leaf reflective barriers (3 roadside and 2 test facility)
- 8 single-leaf absorptive barriers (6 roadside and 2 test facility)

The lack of available technical data combined with the wide range of products in use has prohibited the investigation of a common, consistent design of noise barrier in this study.

The selection procedure highlighted the lack of a comprehensive, centrally held database of noise barrier records within the Highways Agency. The existing Agency asset management record system EnvIS already provides the necessary mechanism for such a database.

It is recommended that any future revision of EnvIS should, as a minimum, include the addition of noise-barrier related fields addressing barrier type and construction, location and information on what the barrier is protecting, the date of installation and details of the installation scheme, the date of the acoustic element manufacture (if significantly different from date of installation), details of the manufacturer and/or installer, initial acoustic performance characteristics, monitored acoustic performance characteristics, and physical condition reports.

The lack of quality information has the potential to affect Action Plans and result in reduced structural and/or acoustic durability of noise barrier assets on the network.

It is recommended that a comprehensive network survey of barriers installed on the SRN should be undertaken to identify and catalogue all of the necessary information.

5 The acoustic durability of timber barriers

This chapter addresses the main focus of the project, namely the investigation into acoustic durability in terms of the airborne sound insulation performance measured in accordance with Part 6. The study has been undertaken primarily on noise barriers installed alongside the Strategic Road Network (SRN).

5.1 Scheduling of the measurement programme

The measurement programme was based around two main time periods: summer/autumn 2008 (hereafter referred to as 'Phase 1') and summer/autumn 2009 (hereafter referred to as 'Phase 2'). A third period, spring 2010, was programmed for any barriers not assessed during the first two phases, although for reporting purposes any tests during this period will be listed under Phase 2.

The scheduling of the programme was primarily affected by two external factors over which the project team had no control, namely the availability of road space and/or traffic management, and unsuitable weather conditions. As a consequence, it was not possible to test the barriers in the same sequence or at the same point during each Phase, and the programme was subject to regular revision and amendment. In some instances, these circumstances were such as to prevent barriers being assessed at any time during the project.

In terms of road space, this could not be granted if the test site was within 5 km of other existing works/traffic management. Where the test sites were located directly within existing traffic management, it was not always possible to gain approval for the barrier assessments due to the impact on site access for other users.

Other reasons for non-assessment in individual phases included removal of the barrier as part of road-widening schemes, concerns related to safe site access and safe working conditions for the measurement team, the presence of excessively vegetation/undergrowth behind the barriers

The test facility measurements on barriers tested as part of the 2005 validation of BS CEN 1793-5 were only tested during Phase 2 due to time restrictions in Phase 1.

Table 5.1 - Table 5.3 summarise the final measurement timetables for single-leaf reflective, absorptive and double-leaf reflective barriers respectively and include the approximate ages (in months) when each barrier was tested relative to its estimated date of installation/manufacture. The month of construction has been assumed to correspond to an age of 0 months. The table also identifies whether each barrier was constructed using prefabricated acoustic elements (i.e. elements manufactured in a factory and then transported to site) or whether the acoustic elements were assembled on site (i.e. it is timber planking and rails are transported to the site in bulk rather than in panel form); this information is based on discussions with industry representatives.

Table 5.1: Summary of acoustic durability measurement programme for single-leaf sound reflective timber noise barriers

Barrier Location			Installation date* (Dates in brackets are estimates)	Build type (SA/P)**	Part 5/6 measurement programme			
					Phase 1	Barrier Age (Months)	Phase 2	Barrier Age (Months)
M1	J27-28	NB	Oct 2003	SA	Jul 2008	57	N/A	N/A
M2	J2-3	EB	(Jul 2003)	SA	Aug 2008	(61)	Jul 2009	(72)
M3	J4a-5	WB	(Jul 2001)	SA	*Untested*	---	*Untested*	---
M4	J7-8/9	EB	(Jul 2001)	SA	*Untested*	---	Mar 2010	(116)
M5	J11a-12	NB	Jul 2002	SA	Jul 2008	73	May 2009	82
M5	J11a-12	SB	Jul 2002	SA	Jul 2008	73	*Untested*	---
M5	J18-19	SB	(Jul 1999)	SA	Jul 2008	(108)	May 2009	(118)
M6	J8-9	NB	(Jul 2004)	SA	*Untested*	---	*Untested*	---
M6	J13-14	SB	(Jul 1989)	SA	*Untested*	---	*Untested*	---
M20	J10-11	EB	Oct 2001†	SA	Aug 2008	82	Jul 2009	91
M20	J10-11	WB	Oct 2001†	SA	Aug 2008	82	Jul 2009	91
M25	J6-7	CW	(Jul 2000)	SA	Sep 2008	(98)	Jun 2009	(107)
M40	J1a-2	EB	(Jul 1999)	SA	*Untested*	---	May 2009	(118)
M40	J2-3	EB	(Jul 1999)	SA	*Untested*	---	Jul 2009	(120)
NBTF Crowthorne 1			Apr 2004†	P	*Untested*	---	Aug 2009	64
NBTF Crowthorne 2			Oct 2004†	P	*Untested*	---	Aug 2009	58
NBTF Bishops Castle 1			May 2008	P	May 2008	0	Jul 2009	14
NBTF Bishops Castle 2			Jun 2008	P	Jun 2008	0	Jul 2009	13

* Estimated year of installation is based on information provided by an industry expert familiar with the installations. Month of construction selected for simplicity

** SA: Site-assembled acoustic elements; P: Prefabricated acoustic elements

† Historical Part 5 measurement data is available at installation for this barrier

Table 5.2: Summary of acoustic durability measurement programme for sound absorptive timber noise barriers

Barrier Location			Installation date* (Dates in brackets are estimates)	Build type (SA/P)**	Part 5 / 6 measurement programme			
					Phase 1	Barrier Age (Months)	Phase 2	Barrier Age (Months)
M1	J11-12	NB	(Jun) 2004	P	Sep 2008	51	Jun 2009	60
M1	J24a-25	SB	Sep 2004	P	Sep 2008	48	May 2009	56
M3	J3-4	EB	(Jul 2003)	SA	*Untested*	---	*Untested*	---
M3	J4-4a	WB	Mar 2004	SA	Jul 2008	52	Apr 2009	61
M25	J9-10	ACW	(Jul 2003)	SA	*Untested*	---	*Untested*	---
M25	J12-13	CW	(Jun) 2003	SA	Sep 2008	63	Jun 2009	72
NBTF Crowthorne 1			Jun 2004†	P	*Untested*	---	Aug 2009	62
NBTF Crowthorne 2			Oct 2004†	P	*Untested*	---	Aug 2009	58

* Estimated year of installation is based on information provided by an industry expert familiar with the installations. Month of construction selected for simplicity
** SA: Site-assembled acoustic elements; P: Prefabricated acoustic elements
† Historical Part 5 measurement data is available at installation for this barrier

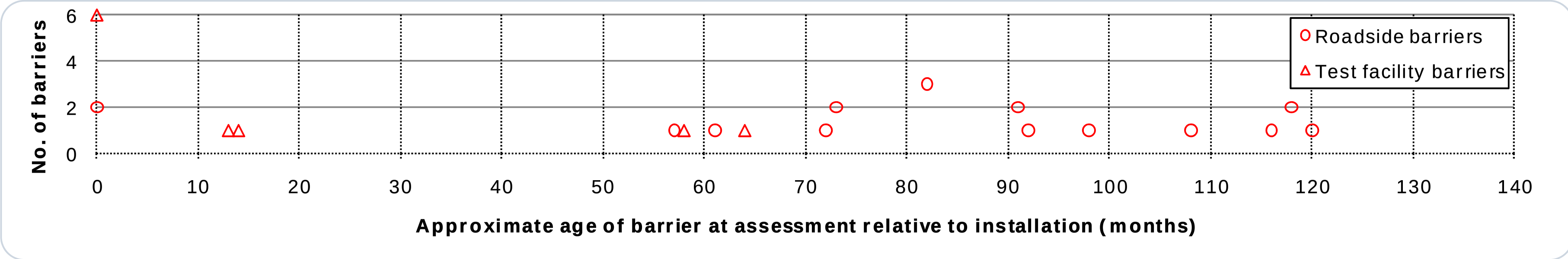
Table 5.3: Summary of acoustic durability measurement programme for double-leaf sound reflective timber noise barriers

Barrier Location			Installation date* (Dates in brackets are estimates)	Build type (SA/P)**	Part 6 measurement programme			
					Phase 1	Barrier Age (Months)	Phase 2	Barrier Age (Months)
M1	J8-9	NB	Oct 2008	SA	*Untested*	---	Sep 2009	11
M1	J8-9	SB	Oct 2008	SA	*Untested*	---	Sep 2009	11
M25	J8-9	CW	(Jul 2000)	SA	*Untested*	---	*Untested*	---
NBTF Crowthorne 1			May 2004†	P	May 2004	0	Aug 2009	63
NBTF Crowthorne 2			Nov 2004†	P	Nov 2004	0	Aug 2009	57

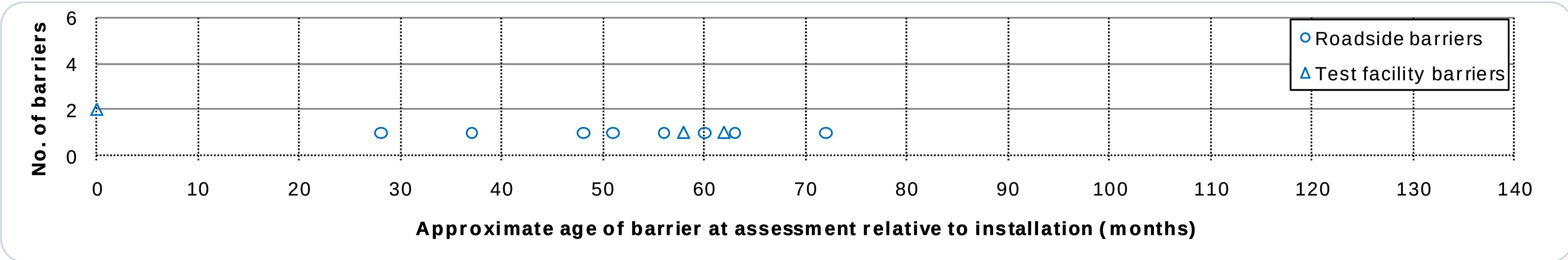
* Estimated year of installation is based on information provided by an industry expert familiar with the installations. Month of construction selected for simplicity
** SA: Site-assembled acoustic elements; P: Prefabricated acoustic elements
† Historical Part 5 measurement data is available at installation for this barrier

Figure 5.1 presents a graphical representation of the assessment age distribution for the three different barrier types where assessments have actually been performed, distinguishing in each case between the roadside assessments and those performed on the NBTF.

a) Single-leaf reflective barriers



b) Sound absorptive barriers



c) Double-leaf reflective barriers

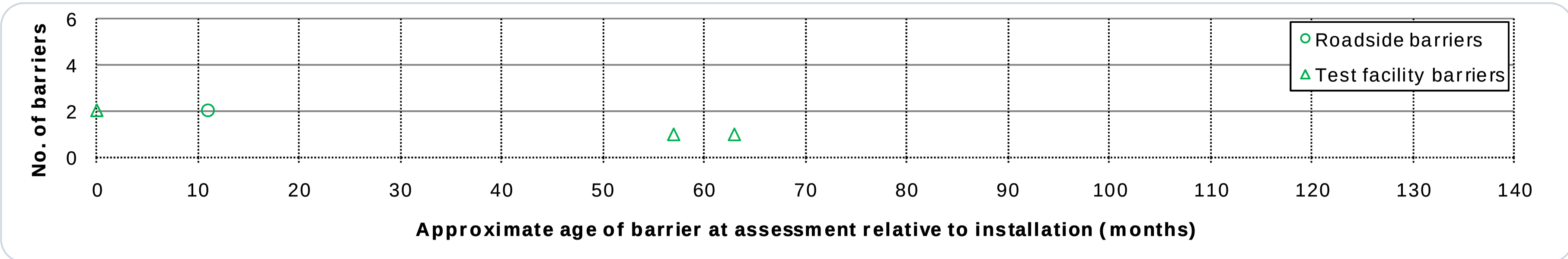


Figure 5.1: Age-related distribution of noise barrier assessments
(0 months: tested following installation)

Whilst, the selection of roadside barriers assessed in the test programme is only a limited sample of all of the barriers installed on the SRN, two observations appear evident:

- As already noted, barriers that are 3 m high appear to generally have only been installed within the last 10 years
- The age distribution of the barriers suggests that there has been a shift in the last 5-6 years in terms of the type of barrier being installed on the SRN. This shift suggests a decline in the installation of single-leaf reflective timber barriers with either double-leaf reflective of sound absorptive timber barriers becoming the preferred choice. This is also supported by the fact that all of the barriers tested when new have been installed on test facilities, as well as limited discussions with consultants responsible for the design of noise barrier schemes.

5.1.1 Factors affecting the measurement programme

The original proposals for the measurement programme were to undertake the following measurements:

- Measurements at multiple positions centred in between pairs of posts (hereafter referred to as 'panel measurements'), the objective being to determine the acoustic performance of the main panels of the noise barrier
- Measurements at two positions centred on individual posts (hereafter referred to as 'post measurements'), the objective being to determine the acoustic quality of the seals between the screening elements and the supporting posts

However as noted in Section 4.5, some of the barriers were constructed as continuous sections mounted onto either the front or rear face of the supporting posts as shown in Figure 5.2. In these cases, post measurements were not taken since it was considered that the presence of the post should not have any detrimental effect on the sound insulation performance due to there being no opportunity for sound leakage through the joint between the panel and post.

Figure 5.2: Noise barriers constructed as continuous sections with front or rear supporting posts

Weather conditions and issues relating to the provision of traffic management also prevented post measurements being taken at some sites.

The following points are also noted:

- It was not possible to restrict the assessment to barriers of a single design and construction. Panel widths/post separations were observed to vary from barrier to barrier, with a range of 2.4-3.0 m. Post thicknesses and constructions also varied significantly.
- Generally the thickness of the vertical timbers which comprised the main body of the noise barrier was 20-25 mm. Greater variation was observed in the size of the horizontal members used for providing structural rigidity. Depending on the design of the barrier, these may be positioned directly opposite three of the microphones in the measurement array.
- It was not possible to restrict the assessment to barriers of a single height. The minimum height used was 3 m, extending up to a maximum of 4.5 m. However, for practicality and safety reasons, all of the roadside measurements were conducted as though all of the barriers were 3 m high, regardless of their true height. This means that the loudspeaker and microphones 4-6 were positioned at approximately 1.5 m above ground in all situations.
- Part 6 states that the single number rating of sound insulation can only be calculated when it is determined for a 4 m high barrier. However, this is for certification purposes and therefore not relevant to the current study. The single number ratings presented in the following analysis here assume a barrier height of 3 m and are therefore determined using a reduced frequency range from 315 – 5000 Hz (in terms of the individual one-third octave bands).

5.2 Determination of initial sound insulation performance

For the majority of the roadside barriers included in the test programme, it has not been possible to determine either the manufacturer/installer or any detailed information relating to their initial sound insulation performance. The latter is of particular importance in the examination of acoustic durability. This section describes the resulting assumptions used within the study.

- *Type of timber:* In the absence of reliable data, it is assumed that all barriers are constructed from a common timber species, namely Douglas Fir which has a density of 530 kg/m^3.
- *Initial acoustic performance:* Unless evaluated as part of previous TRL studies, none of the roadside barriers will have been tested in accordance with Part 5 or Part 6. Assumptions regarding initial performance are therefore related to the Part 2 single number rating DL_R and the corresponding one-third octave band sound insulation indices, R_i.

Discussion with industry experts suggests that almost all of the roadside barriers in the study will have been classified under Part 2 as Class B3 products, meaning that the equivalent panels tested under laboratory conditions will have a DL_R value of greater than 24 dB.

However, as previously noted, barriers can be constructed using acoustic elements that are either assembled on site or pre-fabricated under factory conditions. On-site panel assembly potentially offers a lower degree of quality control over the installed product. Informal inspections of a roadside barrier outside of the current project have suggested that the sound insulation for in situ constructions may be as much as 10-12 dB lower than that for prefabricated barriers of identical design (Walters, 2010); however there is no data available to further validate this assessment. It is therefore considered unsuitable to automatically assume a reduced DL_R rating for site-assembled acoustic elements.

In terms of the roadside barriers in the current study, all of the single-leaf reflective barriers are formed from site-assembled elements, only two of the six absorptive barriers are formed from prefabricated elements, and all of the double-leaf reflective barriers are formed from site assembled elements.

All of the test facility installations, regardless of acoustic type, are formed from prefabricated elements.

The sound insulation performance of absorptive and double-leaf reflective barriers will be greater than that of the single-leaf reflective barriers based on the increased volume of material (timber and/or absorber) that incident sound will have to propagate through. Therefore, assuming an initial performance value of 24 dB for all of the barriers in the study is misleading. Further information is required to allow estimates of initial performance for these more effective barriers.

Through our discussions with industry contacts and a review of published literature, it has been possible to identify Part 2 DL_R ratings for barriers of the type installed on the SRN. The ratings, based on reported values from manufacturers accredited under NHSS Sector Scheme 2C (UKAS, 2005)[4] can be summarised as follows:

- *Single-leaf reflective barrier:* DL_R = 26 dB
- *Double-leaf reflective barrier:* DL_R = 32 dB
- *Sound absorptive barrier:* DL_R = 31 dB

All barriers correspond to Class B3 products. All Part 2 tests were performed using the panel arrangement shown in Figure 5.3a, i.e. tested as a ‘single element’ barrier in terms of the vertical profile.

In addition to the manufacturer data, the performance of different types of timber noise barrier (supplied by two different manufacturers) was assessed in accordance with Part 2 as part of the study by Watts and Morgan (2005) to validate the Part 5 method for timber barriers. To offer the best possible comparison between the datasets, the panels used for the provision of the manufacturer data above are of matching design. The measured ratings can be summarised as follows:

- *Single-leaf reflective panels:* DL_R = 17-18 dB
- *Double-leaf reflective panels:* DL_R = 23-26 dB
- *Sound absorptive panels:* DL_R = 23-26 dB

The single-leaf reflective panels correspond to Class B2 products, while the double-leaf reflective barriers and absorptive barriers correspond to Class B3 products. All of the tests were performed using the panel arrangement shown in Figure 5.3b, i.e. tested as a ‘multiple element’ barrier in terms of the vertical profile.

[4] All suppliers of noise barrier products for use on the Highways Agency’s strategic road network must be Sector Scheme 2C accredited. Sector Scheme 2C is a UKAS accredited scheme for quality management of noise barrier design, supply, installation and maintenance.

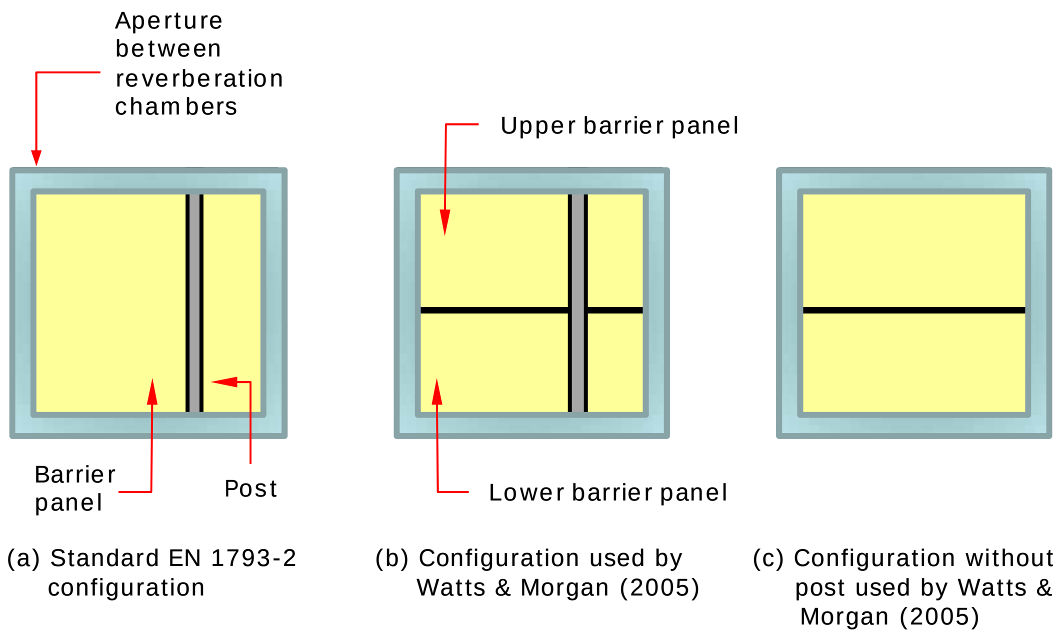


Figure 5.3: Panel arrangements for EN-1793-2 testing

It is observed that there is a significant difference between the manufacturer-reported Part 2 results and those determined by Morgan and Watts despite, in principle, the individual barrier panels being of identical design. Considering one of the single-leaf reflective barriers tested by Morgan and Watts, Figure 5.4 compares the measured one-third octave band sound reduction indices, R_i with those reported by the manufacturer of the panel. It is observed that there is a significant difference between the two curves. Similar differences are observed for the other types of barrier. The dip in performance observed at 2.5 kHz in the TRL results is discussed further in Section 7.3.2.

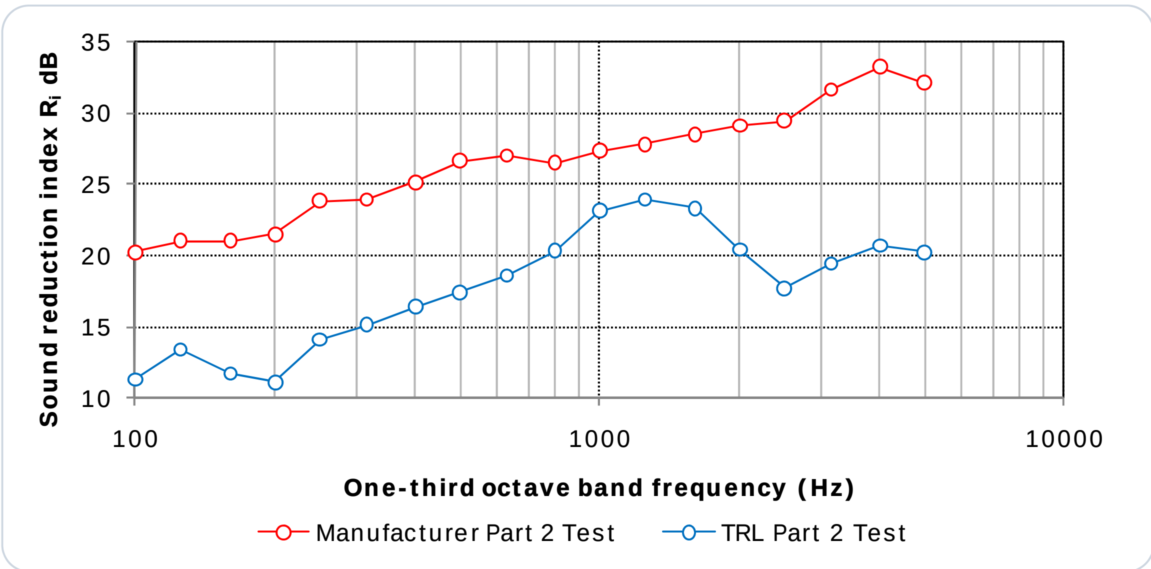


Figure 5.4: Comparison of manufacturer and TRL Part 2 sound reduction index spectra for a single-leaf reflective timber barrier

It is considered that one of the main reasons for this may have been that the latter tests were performed using the modified test arrangement shown in Figure 5.3b[5]. It is noted from both Figure 5.3b and Figure 5.3c that these arrangements differ from the normal Part 2 panel arrangement since they include *upper and lower* panel elements on either side of the post and therefore a horizontal joint is present approximately midway up the barrier. This approach was adopted so as to provide the best comparability with the barriers evaluated using Part 6, which used multiple 2 m high panels to achieve the overall 4 m height (i.e. a multi-element construction as defined in Section 4.5; see, for example, Figure 4.4b), with the loudspeaker/microphone axis opposite the joint between the two panels.

However there are a number of other factors that could also contribute to the difference between the results, which can be summarised as follows:

- The samples tested are of matching construction but not the exact same panels and were tested at different times in different laboratories. It is therefore possible that there was a difference in the moisture content and temperature of the panels.
- The quality of the seal between the posts and panels may differ between tests. Discussions with industry experts suggest that the difference between good and poor quality seals could affect the DL_R rating by as much as 5 dB (Walters, 2010). It is believed there was also a difference in the dimensions of the I-section posts used in the two tests.
- In the study by Watts and Morgan, the panels had been stored outdoors and exposed to local weather conditions for some time prior to the Part 2 tests as well as having already been erected and dismantled for the Part 6 tests. It is therefore conceivable that some distortion of the panels might have occurred as a result.

In relation to the reported and measured performance ratings, it was noted in Section 4.5 that the barriers to be tested in the current study can be broadly categorised in terms of their vertical profile as either 'single-element' or 'multi-element' constructions. As such, assumptions of initial sound insulation performance will take this into account.

It is was also stated in Section 5.1.1 that all of barriers would be treated as 3 m high in relation to the position of loudspeaker and microphones, regardless of their actual height. As such the DL_R ratings quoted on page 45 also require to be recalculated to account for the reduced frequency range corresponding to such a barrier height.

The following initial acoustic performances, based on Part 2 assessments, have therefore been assumed for all barriers where there are no available/reported values for the Part 6 single number rating DL_{SI}:

For 'single-element' barriers (based upon manufacturer-reported performance):

- *Single-leaf reflective barriers:* DL_R = 27.3 dB
- *Double-leaf reflective barriers:* DL_R = 35.0 dB
- *Sound absorptive barriers:* DL_R = 35.4 dB

[5] In addition, measurements were also taken without the presence of a post using the arrangement shown in Figure 5.3c. However, there was, in general, little difference between the single number ratings for each barrier using the two test arrangements.

For 'multi-element' barriers (based upon the logarithmic average of the results reported by Watts and Morgan):

- *Single-leaf reflective barriers:* DL_R = 19.2 dB
- *Double-leaf reflective barriers:* DL_R = 29.5 dB
- *Sound absorptive barriers:* DL_R = 30.8 dB

5.2.1 Conversion of sound insulation performance from Part 2 to Part 6

Previous work by Watts and Morgan (2005) derived equations for converting DL_R values from Part 2 tests to the equivalent Part 6 DL_{SI} values. These equations were derived by treating measurements for single-leaf reflective, double-leaf reflective and sound absorptive barriers as a single dataset.

A 4 m high barrier was used for the Part 6 measurements and the equations are derived using the average of the DL_R values corresponding to mid-panel and the best-performing post. The Part 2 measurements used the panel/post configuration shown in Figure 5.3a. Using the relevant frequency ranges in each standard (0.1-5 kHz in Part 2 and 0.2-5 kHz in Part 6), the relationship is given by the equation

$$DL_{SI} = 1.060 \times DL_R + 5.864\,\text{dB} \tag{5.1}$$

If the lowest usable frequency limit in the calculation of DL_R is matched to that for the calculation of DL_{SI}, then the relationship for 4 m high barriers is given by the equation

$$DL_{SI} = 0.893 \times DL_R + 8.306\,\text{dB} \tag{5.2}$$

The corresponding relationship for 3 m high barriers (using matching frequency ranges, 0.315-5 kHz) is given by

$$DL_{SI} = 0.856 \times DL_R + 8.787\,\text{dB} \tag{5.3}$$

In the current study, measurements have not always been taken across posts. As such a modified equation has been derived based on Part 6 measurements taken only mid-panel, but retaining the matching frequency ranges for 3 m high barriers. This relationship, shown in Figure 5.5 is given by

$$DL_{SI} = 0.962 \times DL_R + 6.263\,\text{dB} \tag{5.4}$$

Using this equation, where there are no available/reported values for the Part 6 single number rating DL_{SI}, the following values have been used as an estimate of the initial sound insulation performance (assuming a 3 m high barrier):

For 'single-element' barriers:

- *Single-leaf reflective barriers:* DL_R = 32.5 dB
- *Double-leaf reflective barriers:* DL_R = 39.9 dB
- *Sound absorptive barriers:* DL_R = 40.3 dB

For 'multi-element' barriers:

- *Single-leaf reflective barriers:* DL_R = 24.7 dB
- *Double-leaf reflective barriers:* DL_R = 34.6 dB
- *Sound absorptive barriers:* DL_R = 35.9 dB

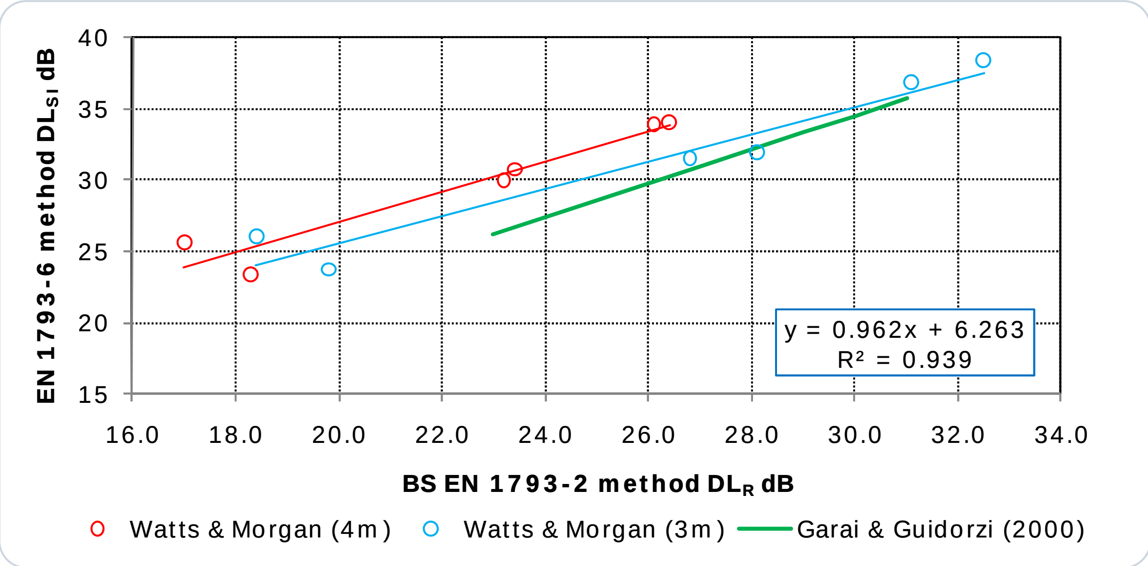


Figure 5.5: Relationships between single number ratings of sound insulation DL_R and DL_{SI} from Watts & Morgan (2005) and Garai & Guidorzi (2000)

Also shown in Figure 5.5 are is the relationship reported by the Department of Energetic, Nuclear and Environmental Control Engineering (DIENCA) in Italy from an assessment of mainly metal and concrete noise barriers (Garai and Guidorzi, 2000). The relationships are not directly comparable since the in situ results from the DIENCA measurements were based on the average of a panel and a single post measurement, and also derived using a different frequency range from the current study.

In the absence of more robust evidence, it is concluded that such an approach provides a reasonable estimate of the initial sound insulation, although not taking into account any loss of performance resulting from on-site assembly of acoustic elements.

5.3 Results: Single number ratings of airborne sound insulation

Table 5.4 - Table 5.6 summarise the results of the measurements on single-leaf reflective, sound absorptive and double-leaf reflective barriers respectively, in terms of the single number rating of airborne sound insulation, DL_{SI} (calculated for the reduced frequency range 315-5000 Hz). The tables also include the estimated initial performance values for those barriers not assessed using the Part 6 method when new, and measured Part 6 values in all other cases.

The results are also presented as a function of age in Figure 5.6 – Figure 5.8 for single-leaf reflective, sound absorptive and double-leaf reflective barriers respectively.

Table 5.4: Summary of airborne sound insulation results for single-leaf reflective timber barriers

Barrier Location			Build type (SA/P)†	New	2008 measurements					2009 measurements				
				DL_{SI}	Age (Months)	PA1 DL_{SI}	PA2 DL_{SI}	Average DL_{SI} dB	Δ DL_{SI} dB	Age (Months)	PA1 DL_{SI}	PA2 DL_{SI}	Average DL_{SI} dB	Δ DL_{SI} dB
M1	J27-28	NB	SA	32.5	57	18.8	18.6	18.7	13.8	*Untested*				
M2	J2-3	EB	SA	32.5	(61)	14.5	15.8	15.1	17.4	(72)	17.0	14.1	15.3	-0.2
M4	J7-8/9	EB	SA	32.5	*Untested*					(116)	18.6	17.8	18.2	
M5	J11a-12	NB	SA	32.5	73	20.1*	18.8*	19.4*	13.1	82	20.5	18.8	19.6	-0.2
M5	J11a-12	SB	SA	32.5	73	19.6*	19.1*	19.3*	13.2	*Untested*				
M5	J18-19	SB	SA	32.5	(108)	19.7	18.3	18.9	13.6	(118)	20	18.8	19.4	-0.4
M20	J10-11	EB	SA	24.4*	82	21.8	20.1	20.9	3.5	91	20.5	19.0	19.7	1.2
M20	J10-11	WB	SA	24.4*	82	20.1	20.9	20.5	3.9	91	19.9	20.5	20.2	0.3
M25	J6-7	CW	SA	32.5	(98)	19.7	19.5	19.6	12.9	(107)	17.2	17.6	17.4	2.2
M40	J1a-2	EB	SA	32.5	*Untested*					118	18.9	16.2	17.3	15.2
M40	J2-3	EB	SA	32.5	*Untested*					120	17.4	19.0	18.1	14.4
NBTF Crowthorne 1			P	25.9*	*Untested*					64	19.0	---	19.0	6.9
NBTF Crowthorne 2			P	22.7*	*Untested*					58	16.8	---	16.8	5.9
NBTF Bishops Castle 1			P	23.6	*Untested*					14	19.9	---	19.9	3.7
NBTF Bishops Castle 2			P	23.6	*Untested*					13	18.9	---	18.9	4.7

† SA: Site assembled; P: Prefabricated

* Performance determined using a single free-field measurement and path difference corrections, i.e. Part 5 methodology

Table 5.5: Summary of airborne sound insulation results for single-leaf sound-absorptive timber barriers

Barrier Location			Build type (SA/P)†	New	2008 measurements					2009 measurements				
				DL_{SI}	Age (Months)	PA1 DL_{SI}	PA2 DL_{SI}	Average DL_{SI} dB	Δ DL_{SI} dB	Age (Months)	PA1 DL_{SI}	PA2 DL_{SI}	Average DL_{SI} dB	Δ DL_{SI} dB
M1	J11-12	NB	P	40.3	51	28.0	28.9	28.4	11.9	60	27	26	26.5	2.0
M1	J24a-25	SB	P	40.3	48	33.3	31.2	32.1	8.2	56	31.2	30.2	32.0	1.2
M3	J4-4a	WB	SA	35.9	52	28.8*	30.8*	29.7*	6.2	61	29.5	31.4	30.3	-0.7
M25	J12-13	CW	SA	40.3	63	34.5	33.5	34.0	6.3	72	31.7	31.7	31.7	2.3
NBTF Crowthorne 1			P	32.1*	*Untested*					64	29.2	---	29.2	2.9
NBTF Crowthorne 2			P	40.4*	*Untested*					58	30.7	---	30.7	9.7

† SA: Site assembled; P: Prefabricated

* Performance determined using a single free-field measurement and path difference corrections, i.e. Part 5 methodology

Table 5.6: Summary of airborne sound insulation results for double-leaf reflective timber barriers

Barrier Location			Build type (SA/P)†	New	2008 measurements					2009 measurements				
				DL_{SI}	Age (Months)	PA1 DL_{SI}	PA2 DL_{SI}	Average DL_{SI} dB	Δ DL_{SI} dB	Age (Months)	PA1 DL_{SI}	PA2 DL_{SI}	Average DL_{SI} dB	Δ DL_{SI} dB
M1	J8-9	NB	SA	39.9	*Untested*					11	34.0	35.1	34.5	5.4
M1	J8-9	SB	SA	39.9	*Untested*					11	31.0	31.1	31.0	8.9
NBTF Crowthorne 1			P	31.3*	*Untested*					64	26.9	---	19.0	4.4
NBTF Crowthorne 2			P	40.5*	*Untested*					58	28.9	---	16.8	11.6

† SA: Site assembled; P: Prefabricated

* Performance determined using a single free-field measurement and path difference corrections, i.e. Part 5 methodology

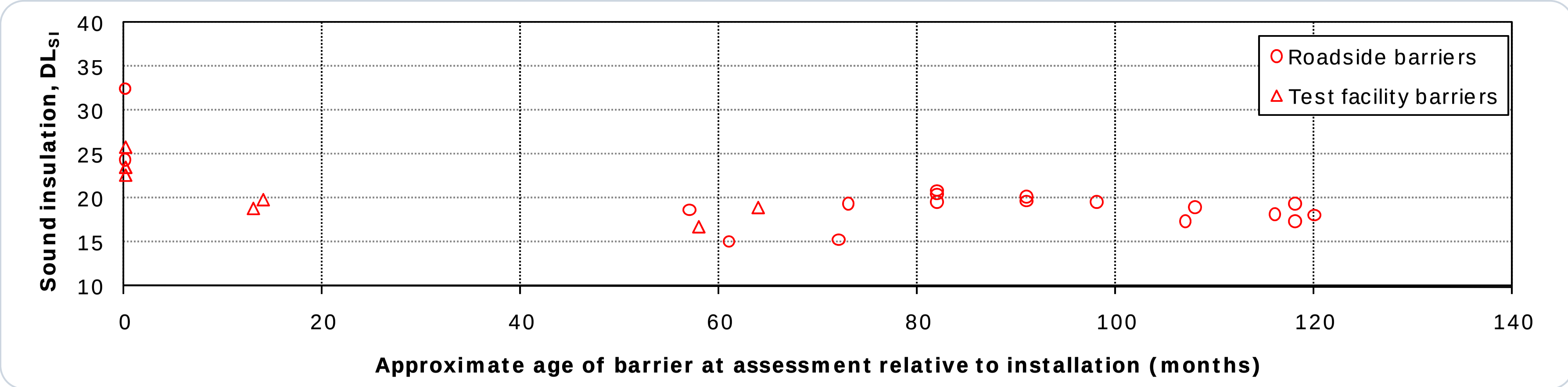


Figure 5.6: Airborne sound insulation performance of single-leaf reflective timber barriers as a function of age
(0 months: Point of installation)

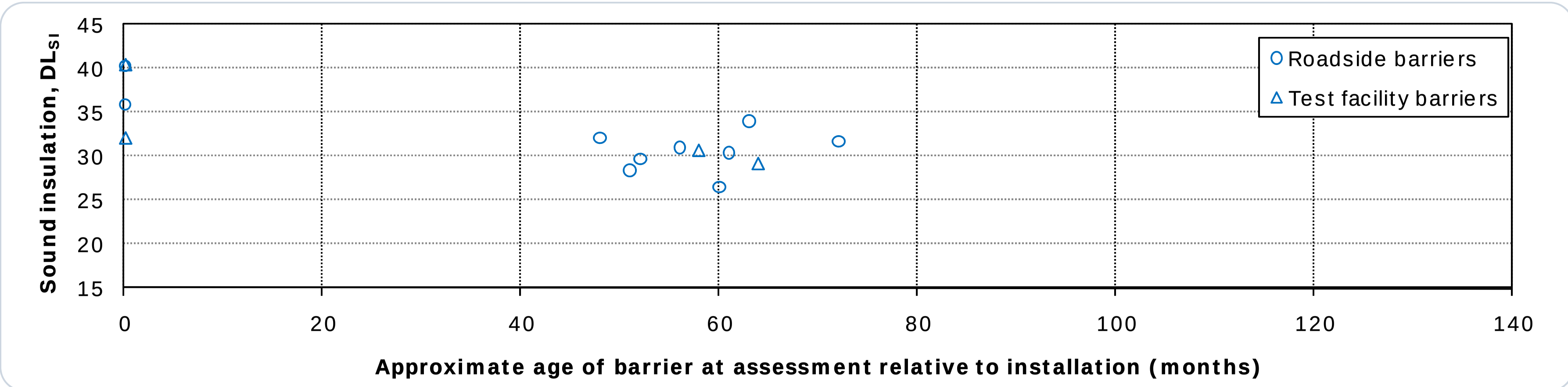


Figure 5.7: Airborne sound insulation performance of sound absorptive timber barriers as a function of age
(0 months: Point of installation)

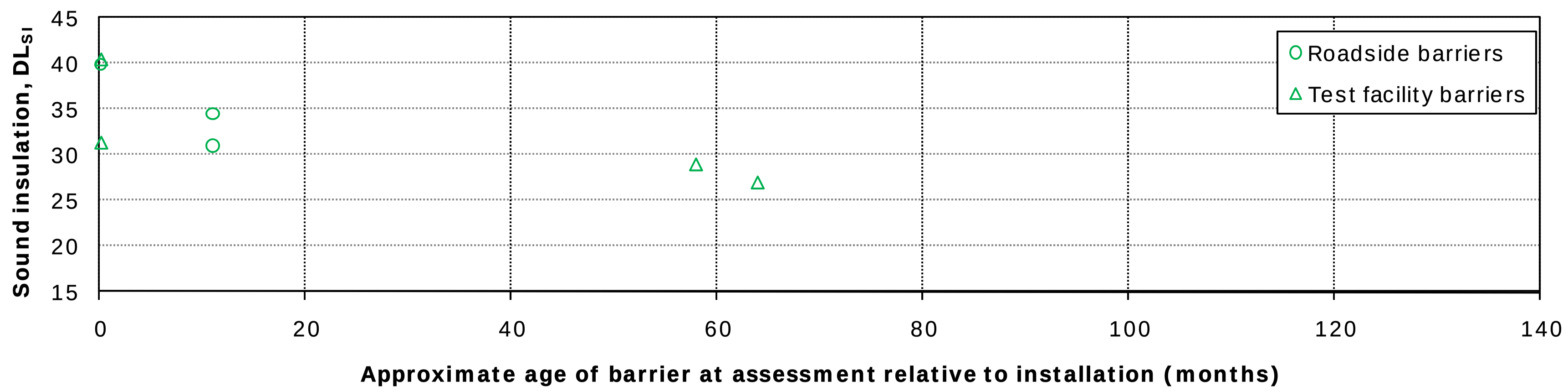


Figure 5.8: Airborne sound insulation performance of double-leaf reflective timber barriers as a function of age
(0 months: Point of installation)

5.3.1 Single-leaf reflective barriers

As is observed from Table 5.4, of the original 14 candidate roadside barriers identified for inclusion in the test programme, only 11 of these have actually been tested, as discussed in Section 5.1. Furthermore, only 6 of these have been tested during both measurement phases.

Figure 5.6 presents the results as a function of age at the time of testing for both roadside and test facility barriers; where multiple panels were tested on each barrier, the results have been averaged, so that there is a single DL_{SI} value for each barrier in any given year.

Initial sound insulation performance

The airborne sound insulation performance at 0 years of age (i.e. at or shortly after installation) in terms of DL_{SI} ranges from 22.7-32.5 dB. This is a significant range, especially considering that all of the barriers are expected to be Class B3 rating (when assessed using the Part 2 method).

Considering only those barriers where the Part 6 results have actually been measured, then the range narrows, being only 22.7-25.9 dB. This is still significantly less that then the 32.5 dB estimated value used for the other barriers. Considering a barrier which only just confirms to a Class B3 product (DL_R = 24 dB) would, from equation (5.4), have a DL_{SI} value of 29.4 dB, this is still significantly higher than the measured performances. It is noted that all of the measured barriers are “multi-element”, prefabricated constructions, whilst those where the performance is estimated are “single-element, site-assembled constrictions. Based on the results presented in Section 5.2, it is expected that there would be a deviation in performance between the two types of barrier.

It is also noted from Table 5.4 that all of the roadside barriers were site assembled at installation rather than constructed from factory prefabricated panels. Based on the measured levels and the comments in Section 5.2 on the potential differences in performance between in situ and prefabricated panels, it is possible that the initial performance of the roadside barriers may be overestimated.

Panel comparability

Considering the differences in the sound insulation performance between panels on the same barrier taken in a single year, comparable performance between the panels is observed for the 2008 measurements, with differences in DL_{SI} being no greater than 1.4 dB.

There is slightly more variation in the 2009 measurements, particularly in the case of the barrier installed on the M2, where the difference is approximately 3 dB. There were no visible defects in the condition of the two panels on that barrier that would immediately explain such variation, however it is noted that the change in sound insulation performance of the individual panels from 2008 to 2009 shows opposing trends, i.e. on one panel there is an increase in DL_{SI}, on the other a decrease.

Considering the two sites on the M5 J11a-12, where the barrier is of identical design and installed as part of the same scheme, the sound insulation performance of the panels is comparable, being within a 0.8 dB range. For the two sites on the M20 J10-11, the variation between the different barriers is also less than 1 dB.

Acoustic durability

For those roadside barriers where the initial performance is estimated, the sound insulation provided by the barrier after approximately 5 years is observed to have decreased from 32.5 dB to approximately 17 dB (based on the average results for the two barriers tested around that time period). This is a significant degradation in performance, especially considering that there were generally no major physical defects observed for any of the barriers. As already observed, all of these barriers are site assembled constructions rather than installations using prefabricated panels, with the panels mounted onto rather than in between posts. In view of comments in Section 5.2 on the potential differences in performance between in situ and prefabricated panels, it is considered that the large variation in performance is due to a significant overestimation in initial performance. If a 10 dB over-estimation in the DL_R value is assumed, equation (5.4) predicts an initial DL_{SI} value of 21 dB, giving a reduction in sound insulation of the order of 4 dB after 5 years.

Where barriers were assessed in both 2008 and 2009, changes in performance were generally less than 1 dB and therefore can be considered negligible.

For those roadside barriers where the initial performance was measured, namely the barriers installed on the M20 (Watts and Surgand, 2001), the average sound insulation performance is observed to have decreased by approximately 4 dB in just under 7 years. These panels are known to have been constructed in situ due to the novel design, although it is noted that the panels tested in 2001 are not the specific panels assessed in the current study.

For the test facility barriers, where the initial performance was also measured, then the performance of the oldest barriers was observed to decrease by 6-7 dB after a period of approximately 5 years. However, as with the barriers on the M20, it is noted that the panels tested in 2009 were not the exact panels tested in 2004, and that the panels had been removed from their original test location and reinstated on the new test facility. For the panels installed in 2008, a decrease of 4-5 dB is observed after only 1 year.

For the newer panels, such a significant decrease in performance was unexpected. However, it is noted that the initial performance of all of the test facility barriers was measured using a single free-field microphone and path difference corrections (the Part 5 methodology). Based on the results presented in Annex B (Morgan, 2010) for single-leaf reflective timber barriers, this may result in an overestimation of the sound insulation performance by as much as 1.5 dB. Furthermore, for the panels installed in 2008, there was a significant difference in the surface temperature of the panels during the measurement sessions, with the temperatures in 2008 being approximately 10°C higher than those in 2009; in both years the weather conditions prior to the tests had been considerably changeable. The results presented in Chapter 8 suggest that such an increase in surface temperature might also increase the sound insulation performance.

It is therefore concluded that the degradation in sound insulation observed for the test facility barriers, particularly those installed in 2008, is likely to be overestimated. All of the panels on the test facility barriers were prefabricated and installed in between steel I-section posts.

Considering the period from 5-10 years for all barriers, Figure 5.6 suggests that the screening performance of single-leaf reflective timber barriers remains relatively stable. The range of DL_{SI} values measured over this time period is approximately 14-20 dB with an average value of 18.4 dB.

Spectral performance

Considering the performance in terms of one-third octave band sound insulation values (see Annex E; Morgan, 2010), the majority of barriers tested demonstrated a decrease in performance around 2-3 kHz, similar to that observed in the TRL reverberation room tests and the Part 6 test facility evaluations reported in Chapters 6 and 7. This is discussed further in Section 7.3.2. In general, sound insulation performance was observed to peak around the 1 kHz one-third octave band with a loss of performance at high frequencies.

For the roadside barriers tested in both 2008 and 2009, the shape of the spectral curves was consistent.

Conclusions for single-leaf reflective timber barriers

Based on an assessment of 11 roadside barriers and 4 test facility installations, it is concluded that the initial sound insulation performance of site assembled barriers is likely to be less than measured during product certification. All of the roadside barriers in the present study are site assembled installations.

Where initial performance has been measured in accordance with Part 6, the results suggest that on average, sound insulation performance will have decreased by between 4-7 dB after 5 years. Although the results suggest higher degradations for barriers where the initial performance is estimated, if the latter is overestimated, then the degradations are closer to the 4-7 dB prediction.

The results suggest that following this initial degradation in performance, the sound insulation performance remains relatively stable for at least the next 5 years.

Comparisons between different panels on the same barrier showed similar levels of sound insulation performance.

A lack of data for the first 5 years of life means that robust conclusions cannot be drawn on the speed of the initial degradation and no accurate relationships for the acoustic durability of such barriers can be derived.

5.3.2 Sound absorptive barriers

As is observed from Table 5.5, of the original 6 candidate roadside barriers identified for inclusion in the test programme, only 4 of these have actually been tested, as discussed in Section 5.1.

Figure 5.7 presents the results as a function of age at the time of testing for both roadside and test facility barriers; where multiple panels were tested on each barrier, the results have been averaged, so that there is a single DL_{SI} value for each barrier in any given year.

Initial sound insulation performance

The airborne sound insulation performance at 0 years of age (i.e. at or shortly after installation) in terms of DL_{SI} ranges from 32.1-40.4 dB. This is the smallest range of the three types of barrier considered, but there is no change in the range when considering only those barriers where the Part 6 results have been measured.

The roadside barriers tested are a mix of prefabricated and site assembled constructions, as well as being a combination of single- and multi-element designs, whilst the test facility installations are prefabricated, multi-element constructions. It is therefore difficult to attribute the variation in performance to any specific characteristic; it is noted that are a wide range of different sound absorptive materials on the market.

It is also noted that the test facility barriers were originally tested using the Part 5 method with a single free-field microphone at position P5 and path difference corrections for all of the other free-field positions. The results presented in Annex B (Morgan, 2010) suggest that this approach is likely to overestimate the performance by less than 1 dB.

Panel comparability

Considering the differences in the sound insulation performance between panels on the same barrier taken in a single year, comparable performance between the panels is observed for the 2008 measurements, with differences in DL_{SI} being no greater than 1.5 dB. Similar differences are observed for the 2009 measurements.

Acoustic durability

For the roadside barriers, where all of the initial performances were estimated, the degradation in sound insulation performance at the time of the first Part 6 measurement varies significantly, from 6.2 dB to 11.9 dB (after the same time period of approximately 4 years). The scatter of data from 4-7 years is significant, with a range of approximately 8 dB, and no defined trend. However, averaging the initial data and the results centred around 5 years of age, it would appear that the acoustic performance of sound absorptive timber barriers will have degraded by approximately 7 dB after 5 years. It is considered unlikely that the availability of real initial performance values would improve this prediction.

Where barriers were assessed in both 2008 and 2009, the sound insulation is observed, in the majority of cases, to have decreased by approximately 2 dB in the following 8-9 months. However, it is noted that there was a significant change in the overall weather conditions between the 2 years, with 2009 being considerably wetter than 2008.

Considering the results from the single-leaf reflective barriers (Table 5.4), the use and durability of the materials used to provide the absorptive elements of the barriers, e.g. rockwool, and the associated protective membranes will play the most significant role in terms of the acoustic durability of sound absorptive barriers, since these materials protect the face of the timber oriented towards the traffic.

It is noted that the local conditions to which these barriers are exposed may accelerate degradation. For example, it is noted from specific visual inspections of some of the candidate barriers as well as general observations when driving on the network that sound absorptive timber barriers appear to be more prone to vandalism than their reflective counter parts. Numerous sections of barrier have been observed where the protective membrane appears to have been deliberately removed (i.e. the damage is extensive with large sections of the membrane missing, and much greater than might be expected from degradation due to exposure to sunlight, splash/spray, flying debris, etc.)

(a) M25 J12-13 (b) M25 J9-10

Figure 5.9: Examples of damaged and degraded protective membranes on sound absorptive timber noise barriers

Figure 5.9a shows one such example on the M25 between Junctions 12 and 13; the barrier was estimated to be only 5 years old when the photograph was taken. In contrast, the barrier installed between Junctions 9 and 10 on the clockwise M25 (Figure 5.9b) shows signs of membrane damage due to both vandalism and other mechanisms, the latter most likely being UV degradation. Such damage is easily identified through visual inspections.

Spectral performance

The spectral performance of the assessed barriers (see Annex F; Morgan, 2010) generally shows none of the degradation in performance at high frequencies observed for the single-leaf barriers, even for the oldest absorptive barriers. The presence of the absorptive material eliminates the dip in acoustic performance observed in the frequency bands around 2.5 kHz for single-leaf reflective barriers.

When comparing results from different years, there are no significant changes in the shape of the spectral profile observed for any of the barriers.

Conclusions for sound absorptive timber barriers

Based on an assessment of 4 roadside barriers and 2 test facility installations, it is concluded that the spread of sound insulation performance values is such as to prevent the derivation of an accurate relationship for the acoustic durability of this type of barrier. However, averaging the results suggests that the acoustic performance of such barriers will have degraded by approximately 7 dB after 5 years.

5.3.3 Double-leaf reflective barriers

As is observed from Table 5.6, all of the roadside barriers have only been tested on a single occasion. Figure 5.8 presents the results as a function of age at the time of testing for both roadside and test facility barriers; where multiple panels were tested on each barrier, the results have been averaged, so that there is a single DL_{SI} value for each barrier in any given year.

Initial sound insulation performance

The airborne sound insulation performance at 0 years of age (i.e. at or shortly after installation) in terms of DL_{SI} ranges from 31.3 to 40.5 dB. This is a significant range, although all of the barriers are of Class B3 rating (when assessed using the Part 2 method). It is noted that this is based on only 3 designs of barrier (the 2 sites on the M1 are of identical design and installed as part of the same scheme). The two test facility barriers are multi-element, prefabricated designs, whilst the roadside barriers are constructed from single element, site assembled panels, although it is these barriers that have the poorest and best performance. Based on the results presented in Section 5.2, it is expected that there would be a deviation in performance between the two types of barrier, although this does not explain the high performance for the second test facility barrier.

It is also noted that the test facility barriers were originally tested using the Part 5 method with a single free-field microphone at position P5 and path difference corrections for all of the other free-field positions.

It is noted that the measured performance of the roadside barriers differs by 3 dB, even though they are effectively an identical barrier.

Panel comparability

Considering the differences in the sound insulation performance between panels on the same barrier, comparable performance between the panels are observed for both of the M1 roadside barriers, with differences in DL_{SI} being no greater than approximately 1 dB. Considering those barriers are of identical design and constructed as part of the same scheme, an average of 3.5 dB is observed between the two. However, as noted above, the barriers are site assembled, so the level of build quality achievable will be less than for factory assembled panels.

Acoustic durability

For the roadside barriers, where the initial performance was estimated, the measurements were taken only a few months after the barriers were installed. After such a short period of time, the sound insulation has decreased by 5.4-8.9 dB. This is a significant decrease in performance. There were no significant faults visible on either barrier. The spectral performance curves presented in Annex G (Morgan, 2010) indicate a significant loss in acoustic performance in the one-third octave frequency bands 2 kHz and above. Whilst a similar dip in performance at these frequencies was observed for many of the single-leaf barriers (see also Chapter 6 and 7), it is noted that these panels were fitted in between steel I-section posts and as such, poor quality seals between the panels and posts may also contribute to the reduced performance.

For the test facility panels, the sound insulation performance is observed to have decreased by 4.4-11.6 dB after approximately 5 years. This range may be in part due to the manner in which some of the panels were stored in the period between tests (one set was stored upright between posts, the other was stacked horizontally). Since there are no intermediate measurements, it is not possible to determine how this level of deterioration was arrived at. Comparison of the spectral performance curves presented in Annex G (Morgan, 2010) shows significant changes in performance from 2004 to 2009, although it is noted that the test facility barriers were originally tested using the Part 5 method with a single free-field microphone at position P5 and path difference corrections for all of the other free-field positions. Although both barriers appear to still be in good condition some deterioration has evidently occurred. In the case of the first test facility barrier, the significant degradation in performance around the 2.5 kHz one-third octave band may be due to a change in the quality of the seal at the horizontal joint between the two panels.

Conclusions for double-leaf reflective timber barriers

Based on an assessment of 2 roadside barriers and 2 test facility installations, it is concluded that there is insufficient data to draw any conclusions on the speed of the initial acoustic degradation or derive an accurate relationship for the acoustic durability of this type of barrier.

5.4 Discussion

It is noted that for single-leaf reflective barriers the results suggest that any significant degradation in acoustic performance occurs within the first 5 years after installation. This corresponds to the period for which there is no acoustic performance data available. Although detailed age information is unavailable, the lack of recently installed single-leaf reflective barriers greater or equal to 3 m in height is contrasted by the wider presence of new/recent absorptive and double-leaf reflective barriers.

This may be due to site characteristics, e.g. sound absorptive barriers may be the preferred option where barriers are installed on both sides of the road. However, if this is not the case, the reasons for the shift in usage is unclear; based on current HA procurement policies, which specify barrier performance on the basis of sound insulation classes, e.g. B classes from BS 1793-2, and available manufacturers data, the classes would not differentiate between the different insulation performance of the different barrier types.

It is therefore recommended to review current HA procurement procedures and liaise with barrier manufacturers to establish whether the implied shift from the use of single-leaf reflective to absorptive or double-leaf reflective barriers is real and commonplace and restricted to the highway part of the SRN or whether it is common across the whole of the SRN, i.e. motorways and trunk roads.

If this is the case, for the whole of the SRN, then the medium-term acoustic durability of single-leaf reflective barriers, i.e. the durability within the first 5 years after installation, does not require further investigation. If single-leaf reflective barriers are still commonly installed on parts of the SRN, it is considered that further investigations of such barriers using the Part 6 methodology would be worthwhile.

Noise barriers where the acoustic elements are assembled on site can have a poorer sound insulation performance than those constructed using factory pre-fabricated elements. Initial feedback from the Highways Agency on revising Agency specifications to restrict future installations to the use of prefabricated acoustic elements suggests that there may be potential issues in respect of Barriers to Trade

It is noted that in Ireland, the National Roads Authority (NRA) has endeavoured to rectify this problem by introducing legislation prohibiting the use of site assembled panels; Volume 1 of the NRA Manual of Contract Documents for Road Works (MCDRW; NRA, 2009) states that *"environmental noise barriers are to be manufactured in a factory, where the barrier was developed and the factory shall be accredited to ISO 9001 for the manufacture of the specific noise barrier panel or components. No on site assemblies of environmental noise barrier panels are permitted"*.

An investigation is recommended to determine whether Agency contract requirements or specification requirements can be introduced to encourage wider use of prefabricated noise barrier products in order to improve build quality and ensure value for money.

Overall conclusions and recommendations

Whilst, the selection of roadside barriers assessed in the test programme is only a limited sample of all of the barriers installed on the SRN, the ages of the barriers suggests that there has been a shift in the last 5-6 years in terms of the type of barrier being installed. This shift suggests a decline in the installation of single-leaf reflective barriers with either double-leaf reflective of sound absorptive barriers becoming the preferred choice.

It was not possible to restrict the assessment to barriers of a common, consistent design and construction. Panel widths/post separations were observed to vary from barrier to barrier, with a range of 2.4-3.0 m. Post thicknesses and panel constructions also varied significantly. All barriers have been assessed as if 3 m tall regardless of overall height.

Overall conclusions and recommendations (continued...)

In the absence of confirmed data for the roadside barriers, assumptions have been made regarding the initial sound insulation performance based on discussions with industry experts.

Overall, the results would suggest that for single-leaf reflective barriers, any degradation in acoustic performance occurs during the first 5 years after construction. Depending upon the initial performance, this decrease appears to be of the order of 4-7 dB. Performance would appear to remain relatively stable thereafter for at least the next 5 years, the limit of the current dataset. Similarly, the results for sound absorptive barriers suggest an average decrease in sound insulation performance of 5 dB after 5 years, although in this case the scatter of measurement results is significant.

The following recommendations are proposed for further investigation:

- Review current HA procurement procedures and liaise with barrier manufacturers to establish whether the implied shift from the use of single-leaf reflective to absorptive or double-leaf reflective barriers is real and commonplace and restricted to the highway part of the SRN or whether it is common across the whole of the SRN, i.e. motorways and trunk roads.
- Investigate whether contract requirements such as those used in Ireland can be introduced to eliminate the installation of non-prefabricated barrier products, in order to improve build quality and ensure value for money.

PART 3:
Factors affecting sound insulation performance and prEN 1793-6 measurements

6 Safety fences and prEN 1793-6 measurements

Section 6.9 of HA 66/95 (Highways Agency *et al.*, 2001a) states that *"an acoustic screen closer than 4.5 m from the carriageway should be protected from the impact of errant vehicles by a vehicle restraint system. Where the clearance is less than 1.5 m, the environmental barrier should be combined with a safety barrier."*

Figure 6.1: Examples of safety fences in close proximity to noise barriers

A preliminary guidance note drafted for the Agency (Watts and Morgan, 2005) as part of the validation of the Part 5 airborne sound insulation test method for timber noise barriers stated that *"the test method has yet to be validated in situations where a safety fence is installed directly in front of the noise barrier. If it is necessary to test under these conditions it is recommended that only 4.0 m high barriers are tested and the top of the safety fence be treated as if it were the ground. For example, if the safety fence is 0.7 m high then a 4.0 m barrier is treated as if it was a 3.3 m high barrier, and is therefore tested at 1.65 m above the safety fence (i.e. 2.35 m above the actual ground)".*

Based on observations recorded during the desktop review and initial visual inspections, the application of 4.0 m high noise barriers on the network is not widespread; indeed many of the barriers on the network are 2.0-3.0 m in height, particularly those which are acoustically reflective.

If the above guidance is followed for these lower barriers, this significantly reduces the effective height of the barrier. Since the effective height is directly related to the lowest usable frequency in the determination of the one-third octave band sound insulation indices (*SIj*) as described in Part 6 (see Figure 12 in the standard), the use of an artificial ground level potentially prohibits the in situ assessment of lower barriers using this method.

It was therefore proposed to investigate the effects (if any) of the safety fence on the measured sound insulation indices when using the true ground level. It was considered that such an investigation would provide greater confidence in both the accuracy of the in situ measurement results (see Chapter 5) and the overall robustness of the Part 6 test method for in situ application on the Strategic Road Network (SRN).

6.1 Description of the measurements

Measurements were conducted using a 3.0 m high single-leaf reflective timber barrier installed on the TRL Noise Barrier Test Facility (see Annex A; Morgan, 2010). This height was selected because it was the most common barrier height encountered within the main acoustic durability study (Chapter 5) that still allows an acceptable frequency range to be used in the determination of the airborne sound insulation performance using equation (2.2).

The barrier was constructed from individual panels, 1.5 m in height and 3.0 m in width, erected in between steel I-section posts, with a total length of 9.0 m. The horizontal joint between each pair of panels was fitted with a rubber seal in accordance with the manufacturers design specifications. It is noted that the design does not recess the rubber seal into the timber. No rubber seals were used between the panels, posts or wedges.

The safety fence was constructed in front of the noise barrier using untensioned steel beam, specifically an Open Box Beam (OBB) conforming to BS 6579-5:1986 (BSI, 1986). This safety fence is of the type used where the space for deflection is limited and is representative of that most commonly installed adjacent to noise barriers on the SRN. The test arrangement is shown in Figure 6.2.

(a) View from front of barrier (b) View from end of barrier

Figure 6.2: Noise barrier test facility with temporary open box beam safety fence installation (mounted on inner posts at 600 mm in front of the noise barrier)

Based on a review of appropriate standards and literature, and the roadside barrier inspections from the main acoustic durability study, it was concluded that two possible installation positions were acceptable:

- *Position 1:* 600 mm in front of the noise barrier. This corresponds to the design deflection for single-height open box beam safety fence specified in Table 1 of BS 6579-5:1986[6]

[6] This distance was previously specified as the minimum acceptable clearance in Table 1 of DMRB Vol.2 Section 2, TD 19/85, 'Safety fences and barriers' (Highways Agency, 1985). This document has been superseded by DMRB Vol.2, Section 2, Part 8 (Highways Agency, 2006) which states that the Working Width Class (where the Working Width is the distance between the side facing the traffic before the impact of the road restraint system and the maximum dynamic lateral position of any major part of the system) for any installation should be specified by the Design Organisation.

- *Position 2:* 1000 mm in front of the noise barrier[7]

It was considered that provided a barrier at the 600 mm position could be demonstrated to have no significant effect, then tests with the safety barrier at the outer position would be unnecessary.

6.2 Results and evaluation

Due to poor weather conditions during the test programme, measurements were restricted to those centred mid-panel, i.e. measurements centred on a post were not taken.

Three different test scenarios were investigated:

- *Reference condition:* Noise barrier with no safety fence installed
- *Safety fence option 1:* Noise barrier with unmodified OBB safety fence;
- *Safety fence option 2:* Noise barrier with OBB safety fence clad in sound absorptive rockwool (the same material as used to provide the sound absorptive treatment in sound absorptive noise barriers)

Figure 6.3 compares the one-third octave band airborne sound insulation spectra and the corresponding single number ratings of airborne sound insulation, DL_{SI}, for each of the three test conditions.

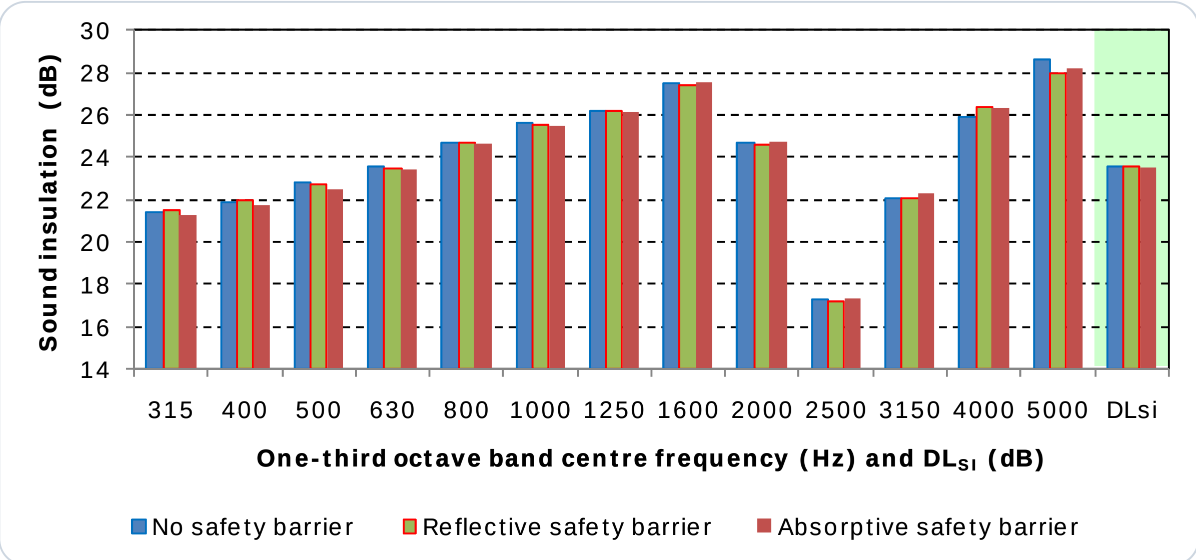


Figure 6.3: Comparison of the airborne sound insulation performance of a timber noise barrier with and without an open box beam safety fence installed at 600 mm in front of the noise barrier

In terms of the single number rating, the presence of the safety fence on the noise barrier is negligible, affecting screening performance by no more than 0.1 dB, well within the accuracy tolerances of the method. Furthermore, this difference would not be evident in reported DL_{SI} values since these are stated as integer values. In terms of the

[7] This distance was previously specified as the minimum desirable clearance in Table 1 of DMRB Vol.2 Section 2, TD 19/85, 'Safety fences and barriers' (Highways Agency, 1985)

one-third octave band sound insulation indices, the differences are similarly negligible, the presence of the safety barrier reducing the noise barrier performance by no more than 0.1 dB for the frequency bands 315-3150 Hz. Differences of up to 0.5 dB are observed at the highest frequencies, but these are similarly within the accuracy tolerances of the method.

It is observed that there is a significant decrease in the sound insulation performance in the one-third octave bands centred around 2.5 kHz. Similar reductions in performance were noted during both the roadside testing of reflective timber barriers and the moisture content effect investigations. This issue is discussed further in Section 7.3.2.

The one-third octave band sound insulation indices for the individual microphone positions are presented in Table 6.1 – Table 6.3. The differences with and without either of the safety barrier options for any microphone/frequency band are within ±2 dB.

Table 6.1: Sound insulation indices at individual microphone positions for the reference condition (no safety barrier)

1/3 octave band centre frequency	Sound insulation indices SI for microphone positions P1-P9 & the mean									
	SI_1	SI_2	SI_3	SI_4	SI_5	SI_6	SI_7	SI_8	SI_9	SI
315	22.8	21.9	20.0	22.3	24.5	21.6	19.1	22.0	21.0	21.4
400	23.4	22.2	20.1	23.0	25.8	22.0	19.4	22.4	21.4	21.9
500	27.5	22.6	21.5	24.3	24.2	24.7	19.6	22.7	22.2	22.8
630	29.1	24.1	22.7	24.0	22.6	25.4	20.5	23.9	24.3	23.6
800	29.1	27.1	24.5	23.3	21.8	25.7	22.2	26.0	29.6	24.7
1000	26.4	24.8	24.3	24.5	28.6	31.5	24.6	24.5	25.6	25.6
1250	24.5	25.8	24.2	33.0	31.5	29.7	25.9	25.0	24.7	26.2
1600	28.5	27.5	25.0	32.4	32.0	31.2	26.7	24.9	26.5	27.5
2000	25.2	26.9	23.5	26.7	25.7	25.8	22.8	22.3	26.3	24.7
2500	22.0	18.0	12.7	21.2	22.3	21.3	15.2	17.4	16.1	17.3
3150	23.3	27.1	16.1	29.3	32.7	27.9	23.5	23.3	19.5	22.1
4000	24.7	28.7	20.7	28.7	27.8	30.2	25.7	26.2	29.4	25.9
5000	25.1	25.5	27.0	36.6	34.6	34.2	32.6	28.6	28.3	28.6
DL_{SI} (0.3-5 kHz)	25.6	24.2	20.9	25.1	25.4	26.0	21.7	23.3	23.3	23.6

Table 6.2: Sound insulation indices at individual microphone positions for safety fence option 1 (noise barrier with unmodified OBB safety fence)

1/3 octave band centre frequency	Sound insulation indices SI for microphone positions P1-P9 & the mean								
	SI_1	SI_2	SI_3	SI_4	SI_5	SI_6	SI_7	SI_8	SI_9	SI
315	22.1	21.8	19.9	23.0	25.7	22.1	19.2	21.8	21.1	21.5
400	22.6	22.0	20.0	23.9	28.1	22.7	19.4	22.3	21.5	22.0
500	26.8	23.1	21.1	24.8	24.3	24.8	19.4	22.4	22.4	22.7
630	28.5	24.7	22.3	24.0	22.5	25.4	20.3	23.7	24.6	23.5
800	28.4	27.3	24.1	23.1	21.7	26.1	22.4	26.3	30.4	24.7
1000	26.0	25.0	23.9	24.6	28.1	31.1	24.7	24.3	26.3	25.5
1250	24.3	25.7	24.2	34.0	32.4	29.5	25.5	24.8	24.8	26.2
1600	28.6	26.8	24.9	32.1	33.7	31.5	26.6	24.8	26.1	27.4
2000	25.4	26.6	23.9	26.1	25.7	25.6	22.4	22.3	26.0	24.6
2500	21.9	18.2	12.5	21.2	21.9	21.2	15.2	18.0	16.2	17.2
3150	24.2	26.7	15.7	29.5	31.7	27.7	23.7	23.7	19.6	22.1
4000	25.4	28.1	20.9	28.7	29.2	30.6	27.9	26.5	30.2	26.4
5000	24.4	25.1	26.1	34.5	35.1	35.6	30.9	28.3	27.4	28.0
DL_{SI} (0.3-5 kHz)	25.3	24.3	20.7	25.2	25.5	26.2	21.6	23.4	23.5	23.6

Table 6.3: Sound insulation indices at individual microphone positions for safety fence option 2 (noise barrier with absorptive OBB safety fence)

1/3 octave band centre frequency	Sound insulation indices SI for microphone positions P1-P9 & the mean								
	SI_1	SI_2	SI_3	SI_4	SI_5	SI_6	SI_7	SI_8	SI_9	SI
315	21.8	21.7	20.2	21.7	24.7	21.4	19.3	21.5	21.2	21.3
400	22.4	22.0	20.3	22.1	26.3	21.9	19.5	22.2	21.6	21.7
500	26.5	23.0	21.3	24.1	24.0	24.9	18.9	22.4	22.1	22.5
630	28.1	24.6	22.4	23.7	22.4	25.5	20.0	23.8	24.2	23.4
800	28.3	27.2	24.1	22.9	21.5	25.8	22.6	26.3	30.8	24.6
1000	26.1	25.1	24.0	24.7	28.3	31.3	24.2	24.1	26.1	25.5
1250	24.2	25.6	24.0	33.8	32.1	29.4	25.4	24.8	25.0	26.1
1600	28.7	26.9	25.4	31.9	33.4	31.3	26.4	24.8	26.4	27.5
2000	25.2	26.8	23.8	26.1	25.8	25.6	22.5	22.5	26.3	24.7
2500	22.3	18.2	12.6	21.6	22.2	21.0	15.0	18.0	16.5	17.3
3150	24.1	26.7	16.1	29.6	32.1	27.6	23.7	23.7	19.9	22.3
4000	25.6	28.0	20.9	29.2	28.7	30.4	27.6	26.6	29.1	26.3
5000	24.6	25.5	26.0	35.2	34.6	35.7	30.9	28.2	28.1	28.2
DL_{SI} (0.3-5 kHz)	25.3	24.3	20.8	24.9	25.3	25.9	21.5	23.3	23.6	23.5

Conclusions and recommendations

On the basis of the results obtained from the test facility measurements, particularly the one-third octave band airborne sound insulation indices averaged over the 9 microphone positions, it is concluded that the presence of a safety fence has no significant effect on the acoustic performance of a noise barrier when assessed in accordance with Part 6.

As such, it is considered that the Part 6 test method can be applied at the roadside without modification on barriers with a minimum height of 3.0 m, without the need to temporarily remove or modify any safety fence installed in close proximity to the noise barrier.

7 Moisture content and early-life sound insulation

One of the factors likely to affect the behaviour of a timber noise barrier, in terms of its sound insulation performance, during the early stages of its lifetime is the considerable change in moisture content following treatment of the timber with preservative and the subsequent drainage/evaporation of the water within the preservative. An increase in the moisture content is known to increase the density of the timber, thereby improving the near-field acoustic efficiency.

All noise barriers approved for use on the Strategic Road Network are currently required to have undergone acoustic performance testing in accordance with BS EN 1793-1 (BSI, 1998a) and/or BS EN 1793-2 (BSI, 1998b) which assess sound absorption and sound insulation respectively when the barriers are new. Since barrier products are then procured based on the single number rating categories identified by these tests, A0-A4 and B0-B3 respectively, then a lack of information on the effect of moisture content may have the following impacts:

- The acoustic performance determined from the laboratory tests may be overestimated if the tests are performed using a barrier test sample that has very recently been treated with preservative
- Significant variations in moisture content may affect comparisons between measurements taken using the new Part 6 method for certification and those taken with the same method for conformity-of-production assessment, i.e. measurements taken shortly after installation, depending on when the barrier was initially treated with preservative

A programme of measurements was therefore proposed which focused primarily on examining the effects of the drainage/evaporation of the water within the preservative during the early lifetime of the barrier rather than the effects of changes in the prevailing weather conditions.

7.1 Description of the timber preservation method

The timber is pressure treated to BS EN 8417 Hazard Class 4 (BSI, 2003b; Class 4 requirements are where the timber is in contact with the ground or freshwater), as required by HA specifications (Highways Agency *et al.*, 2001b) using a preservative called Tanalith E 2494. This is a preservative which is diluted in water and is specifically intended for application in vacuum pressure plant. Once the timber has been treated, a period of at least 48 hours is recommended before the timber can be handled and the noise barrier panels manufactured using the treated timber.

It is understood that approximately 50% of the drainage/evaporation of the preservative occurs during the first week after its application. This is an artificial change in moisture content that is not representative of that which occurs under normal roadside conditions, e.g. changes due to weather conditions, splash/spray from passing traffic, etc. After that period it is estimated that it will typically take 4-6 weeks for the moisture content of the barrier to reach a typical average level of 15-20%, although this will be dependant upon the prevailing weather conditions over that period.

Most rain or spray does not penetrate the surface of the timber but is shed. Therefore, the moisture content of the total timber, i.e. excluding the surface, will not rise by more than 8% above the average level.

7.2 Description of the measurements

Measurements were conducted using a 4.0 m high single-leaf reflective timber barrier installed on the TRL Noise Barrier Test Facility (see Annex A; Morgan, 2010). The barrier was constructed from individual panels, 2.0 m in height and 3.0 m in width, erected in between steel I-section posts, with a total length of 12.0 m. The horizontal joint between each pair of panels is fitted with a rubber seal in accordance with the manufacturers design specifications. It is noted that the design does not recess the rubber seal into the timber. No rubber seals are used between the panels, posts or wedges. The panels forming the main focus of the measurements were those in between the 2nd and 3rd posts (from the left-hand end).

The measurement programme involved comprehensive measurements of both acoustic performance (sound insulation) and moisture content in the first week after the barrier was erected (it is noted that installation of the barrier took place 3-4 days after the initial treatment of the timber with preservative), followed by subsequent measurements at approximately fortnightly intervals for a period of approximately 3 months. The details of the programme are presented in Table 7.1.

Table 7.1: Summary of programme investigating the effect of moisture content on early-life sound insulation performance

Approximate age (days) of treated timber	Date	Description of work item
0 days	05-07-2008	Treatment of timber with preservative
2 days	07-07-2008	Manufacture of noise barrier panels from treated timber
3-4 days	07/08-07-2008	Erection of noise barrier at test facility
4 days	08-07-2008	1st acoustic assessment and core sample evaluation
6 days	10-07-2008	2nd acoustic assessment and core sample evaluation
8 days	12-07-2008	3rd acoustic assessment and core sample evaluation
23 days	22-07-2008	4th acoustic assessment and core sample evaluation
37 days	05-08-2008	5th acoustic assessment and core sample evaluation
51 days	19-08-2008	6th acoustic assessment and core sample evaluation
65 days	02-09-2008	7th acoustic assessment and core sample evaluation
79 days	16-09-2008	8th acoustic assessment and core sample evaluation
93 days	30-09-2008	9th acoustic assessment and core sample evaluation
107 days	14-10-2008	10th acoustic assessment and core sample evaluation

It is noted that the test facility is outdoors, meaning that the physical condition of the barrier over the duration of the study was subject to the prevailing weather conditions.

Delays during the installation of the panels, combined with variable weather conditions over the duration of the programme restricted the acoustic assessment to measurements taken mid-panel, i.e. no measurements were taken centred on a post.

It was established that the physical moisture content of the barrier panels could not be measured with a typical hand-held moisture probe due to the presence of copper within the timber preservative. It was recommended instead that the moisture content be measured in a manner based on the test procedure set out in BS 4072-2:1987 (BSI, 1987)[8], which involved extracting core samples from the barrier and determining the change in weight before and after drying the samples in an oven. However it was considered that the extraction of core samples would adversely affect the sound insulation performance of the test panel due to the leakage of sound through the holes left by the coring. The solution was to install an additional barrier panel from which to extract the cores. This was constructed from the same timber as the main test panels, manufactured/preserved at the same time and subject to the same weather conditions as the main barrier.

7.3 Results and evaluation

During the first week of measurements after construction, weather conditions were highly changeable with very heavy, prolonged periods of rain at times. Over the full period of the study, there were no extended wet or dry periods.

7.3.1 Moisture content analysis

All test cores were extracted from the vertical timbers forming the main part of the panel screen, using a holesaw with an external diameter of 40 mm. These timbers were 22 mm thick. In accordance with the method described in BS 4072-2:1987, it was intended that the dry weight of the core should be in excess of 8 grams. Figure 7.1 shows two such cores from the barrier. Two cores were extracted for each moisture content evaluation, the cores being taken from the same two timbers each time. Core samples were not extracted from the horizontal timbers of the barrier due to the thickness of these elements.

Figure 7.1: 40 mm diameter core samples extracted for moisture content determination

[8] It should be noted that a new edition of this standard was issued in 1999 (BSI, 1999) which replaced both the former BS 4072-1 and BS 4072-2. The description of the measurement method is no longer included in this latest version of the standard.

As already noted, the determination of the moisture content of the timber was based on the methodology described in BS 4072-2:1987. However, the relatively remote location of the test facility prevented the method being followed precisely. Samples removed from the oven were weighed directly without being cooled in a dessicator as required by the Standard. Furthermore, it was not possible to regularly check the weight of the samples at regular intervals. Samples were left in the oven overnight and the “dry” weight measurement taken after that period, in general after approximately 20 hours.

The moisture content is calculated as a percentage of the dry mass of the sample, using the equation

$$\text{Moisture content, } MC = \frac{100 \times (m_1 - m_2)}{m_1} \ \% \qquad (7.1)$$

where m_1 is the mass in grams of the sample when ‘wet’ and m_2 is the mass in grams of the sample after drying.

Table 7.2 summarises the results of the moisture content analysis for the two barrier timbers. Due to the nature of the timber, its placement in the bales following treatment (the initial evaporation of water in the preservative will occur more rapidly in those members on the outside of the timber bales) and handling during panel manufacture, the level of preservative present in the assessed timber samples may be different to that in the other timbers comprising the individual noise barrier panel. This is reflected in the different moisture content levels from the two cores samples extracted after the panel had been constructed.

Figure 7.2 presents the change in moisture content in the core samples as a function of time. With the timber being exposed to the elements, there may be subtle deviations in moisture content if measurements are taken after extended periods of rain or hot weather, e.g. the measurement after 37 days followed several days of prolonged heavy rain. The first measurements taken only 4 days after treatment gave an average moisture content of 39%, although the moisture content of the individual fence boards varied considerably (30% compared to 48%). This may be a result of the boards’ position within the timber bales when treated with preservative.

Over the next four days, the average moisture content in the timber reduced quite significantly from 39% to 25%), as a result of the evaporation of the preservative.

Approximately 3 weeks after treatment, the average moisture content in the studied timbers had reduced to approximately 14%. Fortnightly measurements over the next 12 weeks showed that the average moisture content was 15%, representative of the base level corresponding to the species of timber, varying within a range of ±1.5%.

In general, allowing for variations in the prevailing weather conditions, it appears reasonable to assume that the moisture content is sufficiently stable after one month for the sound insulation performance to be representative of its typical performance.

Table 7.2: "Wet" and "dry" core sample weights and moisture contents

Sample description	Age of sample after treatment	"Wet" weight (sample+bag; bag weight in brackets)		Time drying	"Dry" weight (sample only)		Moisture content, A (%)
		(g)	(oz)		(g)	(oz)	
Timber plank #1 (Right/wet)	4 days	14.458 (3.260)	0.510 (0.115)	20 hrs	8.647	0.305	29.5
	6 days	13.891 (3.260)	0.490 (0.115)	20 hrs	8.505	0.300	25.0
	8 days	13.891 (3.260)	0.490 (0.115)	23 hrs	8.647	0.305	22.9
	23 days	13.324 (3.260)	0.470 (0.115)	21 hrs	8.647	0.305	16.4
	37 days	14.742 (3.969)	0.520 (0.140)	20 hrs	9.355	0.330	15.2
	51 days	14.458 (3.402)	0.510 (0.120)	20 hrs	9.639	0.340	14.7
	65 days	13.608 (3.685)	0.480 (0.130)	20 hrs	8.647	0.305	14.8
	79 days	14.317 (3.827)	0.505 (0.135)	20 hrs	9.214	0.325	13.9
	93 days	13.750 (3.118)	0.485 (0.110)	20 hrs	9.355	0.330	13.7
	107 days	14.884 (3.260)	0.525 (0.115)	20 hrs	10.064	0.355	15.5
Timber plank #2 (Left/dry)	4 days	16.726 (3.260)	0.590 (0.115)	20 hrs	9.072	0.320	48.4
	6 days	14.033 (3.260)	0.495 (0.115)	20 hrs	8.647	0.305	24.6
	8 days	14.175 (3.260)	0.500 (0.115)	23 hrs	8.788	0.310	24.2
	23 days	13.324 (3.402)	0.470 (0.120)	21 hrs	9.072	0.320	10.9
	37 days	14.033 (3.969)	0.495 (0.140)	20 hrs	8.788	0.310	14.5
	51 days	12.332 (3.260)	0.435 (0.115)	20 hrs	7.796	0.275	16.4
	65 days	13.324 (3.969)	0.470 (0.140)	20 hrs	7.938	0.280	17.9
	79 days	13.041 (3.827)	0.460 (0.135)	20 hrs	7.938	0.280	16.1
	93 days	12.757 (3.260)	0.450 (0.115)	20 hrs	8.221	0.290	15.5
	107 days	13.466 (3.260)	0.475 (0.115)	20 hrs	8.647	0.305	18.0

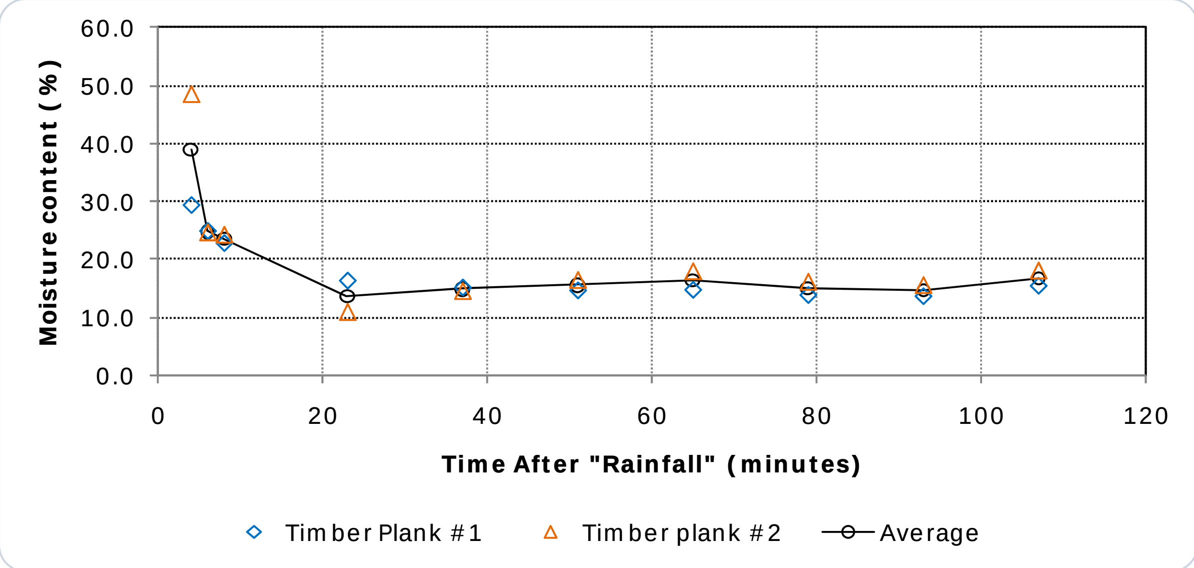


Figure 7.2: Variation in measured moisture content with respect to the 'age' of the treated timber ('age' defined as being the number of days following treatment)

7.3.2 Acoustic performance analysis

As already noted that although Part 5 recommends, albeit for certification purposes, that measurements be taken both in the middle of a panel (i.e. midway between the posts) and centred on a post between two panels, time restrictions immediately following the installation of the barrier and general weather conditions over the duration of the study prevented this approach being adopted on all occasions. All of the results presented in this section are therefore associated solely with those measurements taken mid-panel.

Figure 7.3 compares the single number rating of sound insulation DL_{SI} for the barrier derived assuming barrier heights of 4.0 m and 3.0 m (the results are derived from the same measurement data using Equation (2.3) but analysed over frequency ranges applicable to the corresponding barrier heights), with the maximum levels being 29.2 dB and 30.6 dB respectively, both measured the first time that the panel was assessed after being treated with preservative (4 days after treatment).

Considering the results for the 4 m high assessment, by the 8th day, the average sound insulation, DL_{SI}, had decreased from 29.2 dB to 27.1 dB. By the 23rd day after treatment, there was a further significant decrease in the sound insulation performance of approximately 4.6 dB. This deviation in performance corresponds with the significant change in moisture content over that period presented in Figure 7.2.

The results for the 3 m high assessment show similar trends, albeit with increased levels due to the reduced frequency range.

The fortnightly measurements over the next 12 weeks give an average sound insulation, DL_{SI}, of 22.1 dB with a lower limit of 21.2 dB and an upper limit of 22.5 dB.

While the single number rating of sound insulation measured in accordance with Part 6 is denoted DL_{SI}, the single number rating of sound insulation measured in accordance with BS EN 1793-2 (the current recognised test method) is denoted DL_R.

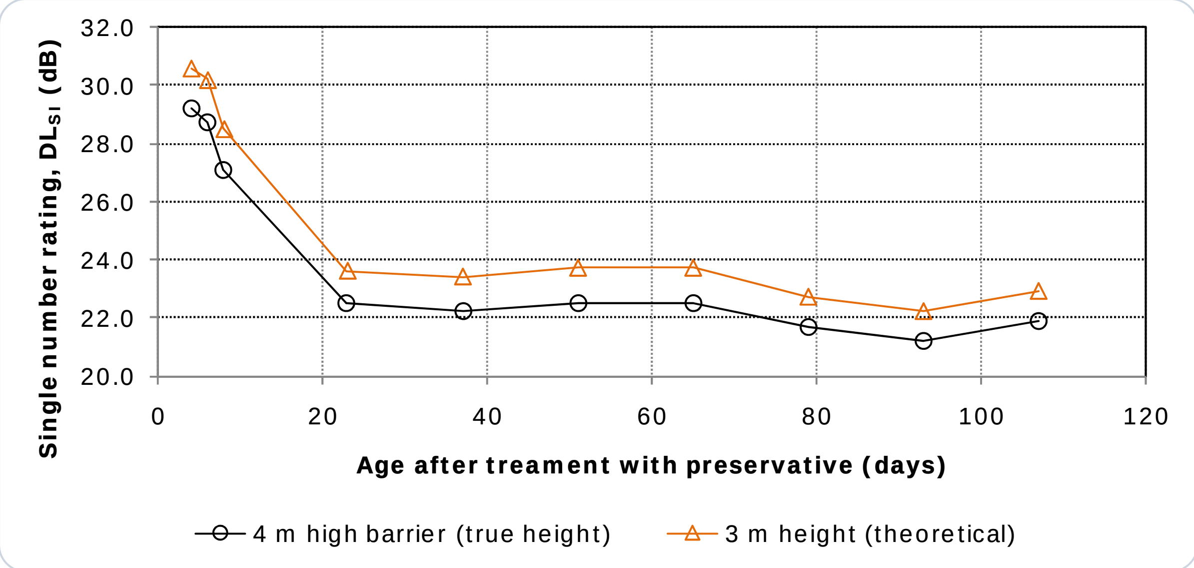


Figure 7.3: Variation in measured sound insulation performance with respect to the 'age' of the treated timber ('age' defined as being the number of days following treatment)

In a previous study validating the Part 5 test method for timber barriers, Watts and Morgan (2005) derived relationships between DL_{SI} and $\underline{DL_R}$ based on measurements of a small sample of timber noise barriers. Using only Part 5 panel measurements, the relationship derived for a 4 m barrier (using matched frequency ranges with a lowest usable frequency of 200 Hz) is presented in Figure 4.7 of that report, given by

$$DL_{SI} = 1.0239 \times DL_R + 5.477 \text{ dB} \tag{7.2}$$

and the relationship for a 3 m barrier (using matched frequency ranges with a lowest usable frequency of 315 Hz) is given by equation (5.4), such that

$$DL_{SI} = 0.962 \times DL_R + 6.263 \text{ dB} \tag{7.3}$$

It is noted that the equation derived for the 3.0 m high barrier was based on non-standard Part 2 measurements, in that the test arrangement in the reverberation chamber did not include a post.

It is also noted that the equations were derived using a sample group containing both reflective and absorptive barriers.

The published DL_R value for the panel types tested in this study is 26 dB (valid for a frequency range 100-5000 Hz). Recalculating to take account of the reduced frequency ranges for a 4 m high barrier tested to Part 5 (200-5000 Hz) give a DL_R value of 26.9 dB. Further reducing the frequency range to that for a 3 m high barrier tested to Part 5 (315-5000 Hz), gives a DL_R value of 27.3 dB.

Table 7.3 compares the measured Part 5 DL_{SI} values from the current study with the predicted results derived from the DL_R values using equations (7.2) and (7.3).

It is observed that for the 4 m high barrier, the measured result is approximately 4 dB less than the predicted result. For the 3 m high barrier, the measured result is approximately 2 dB lower than the predicted result.

Table 7.3: Comparison between measured and predicted values of DL_{SI}

Barrier scenario	Initial measured DL_{SI} (Day 4)	Predicted DL_{SI} Derived from DL_R using Equations (4.2) and (4.3) as appropriate
4 m high single-leaf reflective timber barrier	29.2 dB	33.0 dB
3 m high single-leaf reflective timber barrier	30.6 dB	32.5 dB

On initial consideration, there are a number of possible reasons which will contribute to the variation between the measured and predicted results:

- The two sets of barriers are not constructed from exactly the same timbers, even though the species of timber is the same, so there will be natural variations in the density of the timber.
- The (laboratory) test sample in the Part 2 test is not representative of that tested using the Part 5 in situ. The laboratory sample will have been installed and sealed to give optimum sound insulation, whilst the sample installed on the noise barrier test facility was installed to be representative of a typical roadside construction.
- Equations (4.2) and (4.3) are derived from a combination of single-leaf reflective, double-leaf reflective and single-leaf absorptive barriers and a small overall test sample. The relationships are likely to vary given a larger sample group and a restriction to reflective barriers only.

Figure 7.4 presents the one-third octave band sound insulation spectra assessed using a time window corresponding to the full 4 m height of the noise barrier; since the panels are only 3 m wide, this will include any effects at the posts.

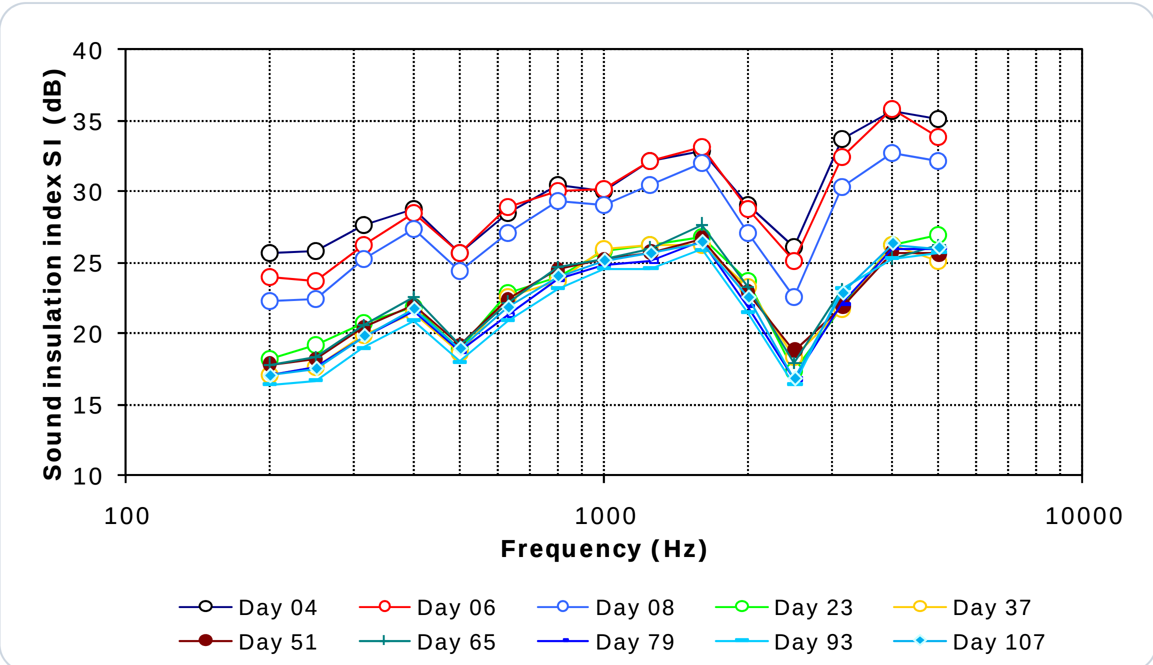


Figure 7.4: Sound insulation spectra assuming a 4 m high barrier

The degradation in performance as the moisture content in the timber reduces is clearly visible, as already observed for the single number ratings. It is observed that there are decreases in performance around the 500 and 2500 Hz third octave bands for all of the measurements, the latter being approximately 8 dB relative to the overall profile of the curve. The corresponding one-third octave band sound insulation indices at the individual microphone positions are tabulated in Annex H (Morgan, 2010).

Figure 7.5 presents the corresponding results based on an assessment of the barrier as if it were 3.0 m high; the lowest usable one third octave band increases from 200 Hz to 315 Hz as a result of the reduced length time window. The overall change in performance is not dissimilar to the 4.0 m high analysis, although the improvement in performance in the 500 Hz band suggests that this is likely to be a result of sound leakage at the interface between the panels and the posts (no form of seal is used in the design). However, the poor performance at 2500 Hz is still evident.

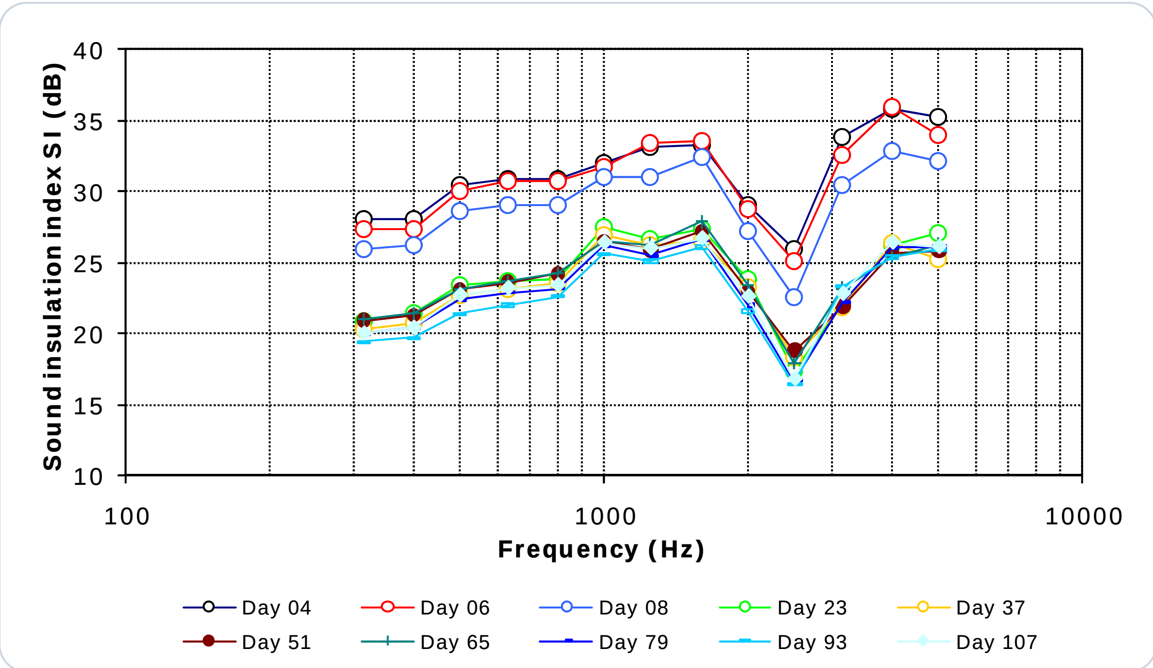


Figure 7.5: Sound insulation spectra assuming a 3 m high barrier

Considering the sound insulation spectrum obtained from Part 2 reverberation room tests for the same design panels (Figure 7.6), it is observed that no such dip in performance at high frequency is observed.

A visual inspection of the panels tested using the Part 6 methodology revealed no obvious construction defects; indeed, none were expected due to the panels being newly constructed under controlled, factory conditions.

It is noted that similar effects were also observed for the 3 m high noise barrier used in the safety fence effects assessment (see Chapter 5) as well as for single-leaf reflective barriers tested at the roadside (see spectra presented in Annex B; Morgan, 2010).

Previous work by Watts (1997) presented sound insulation assessments for a similar type of timber noise barrier determined using Part 2 testing and a sound-intensity based assessment approach; in both cases, similar dips in screening performance around 2.5-3.15 kHz were observed.

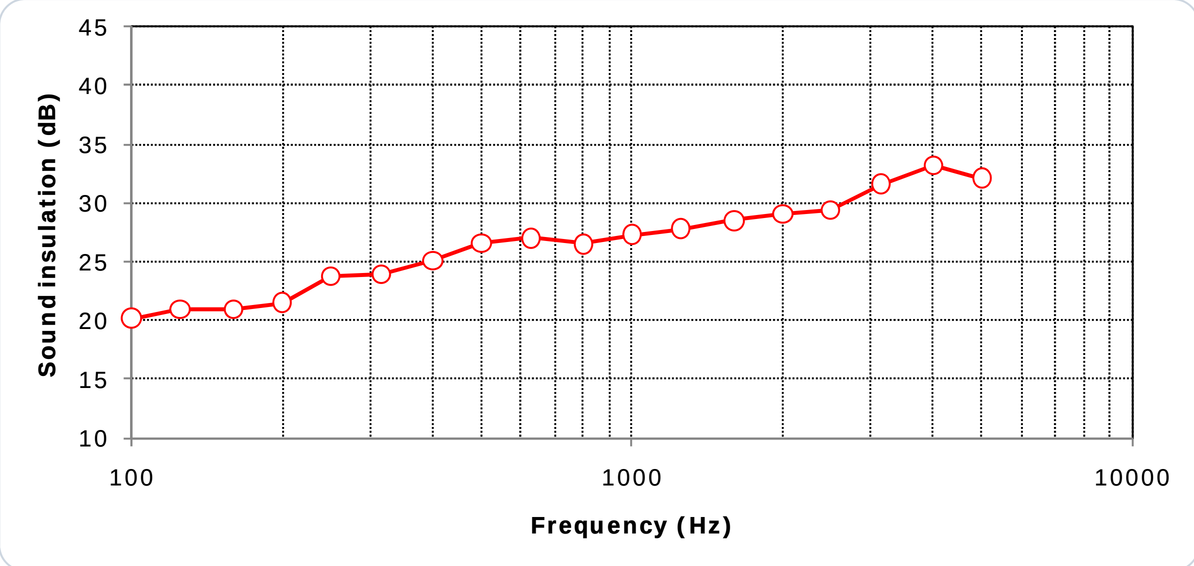


Figure 7.6: Sound insulation spectra determined using BS EN / TS 1793-5
(DL_R = 26.9 dB for the frequency range 200 – 5000 Hz)

It is therefore evident that the characteristic is a real effect, requiring investigation by other means. The sound insulation performance of noise barrier panels can also be predicted in terms of the Mass Law. This law describes the sound insulation (transmission loss) of a *limp, flexible* (non-rigid) panel in terms of the mass density and frequency[9], and is given by

$$R_i = 20 \times \log_{10}\left(\frac{\pi f \rho t}{\rho_0 c_0}\right) \text{dB} \qquad (7.4)$$

where ρt is the *surface density* or mass per unit area of the panel, and t is the thickness of the panel. It states that doubling the thickness or the mass of the panel increases the sound insulation by 6 dB. However, timber naturally possesses some stiffness or rigidity, so the mass law only provides an approximate guide to the amount of insulation that can be achieved.

The panels tested in the current study are calculated to have a surface density of 10.6 kg/m^2 (assuming a thickness of 20 mm (ignoring the presence of the cover strips) and the timber as being Douglas Fir, with a volume density of 530 km/m^3). The predicted sound insulation is shown in Figure 7.7, together with the Part 6 spectra.

[9] For each doubling of the weight or frequency of a screen/partition, the mass law predicts a 6 dB increase in the sound insulation.

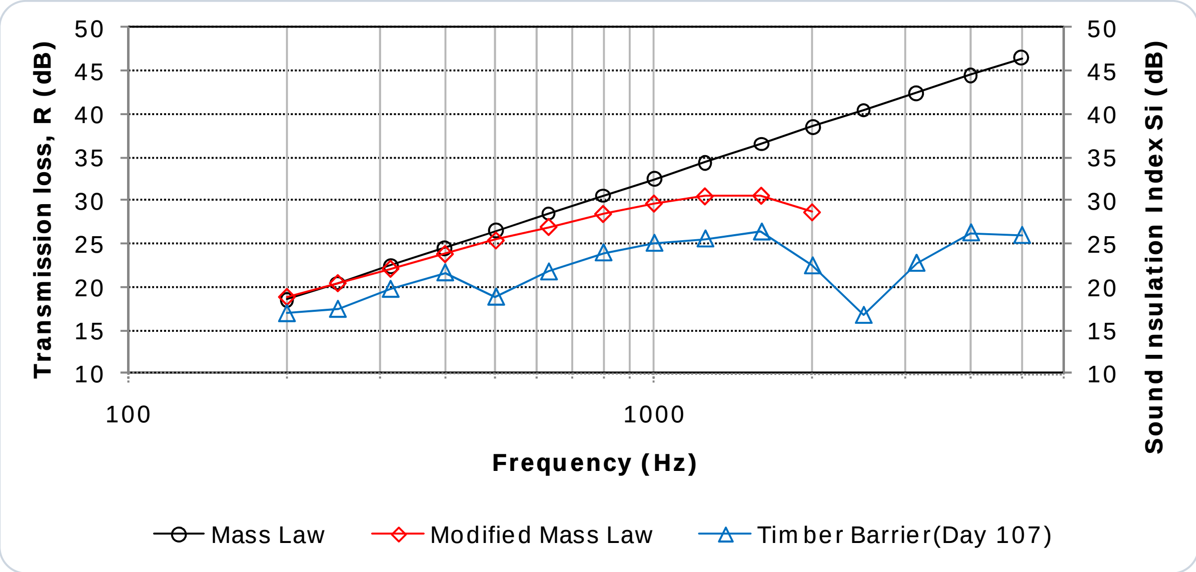


Figure 7.7: Predictions of sound insulation, *R*, based on surface density and measured values of sound insulation, S_i, using EN 1793-6

However this equation does not fully describe the sound insulation performance. When sound transmits through a panel or partition, a phenomenon known as the *coincidence effect* occurs. This is where the incident sound causes flexural vibrations to be generated in the panel by sound waves propagating *along* the face of the panel. When coincidence occurs, it results in a more efficient transfer of sound energy from one side of the panel to the other, causing a dip in the sound insulation performance. The lowest frequency at which wave coincidence occurs is referred to as the critical frequency, f_c. At that frequency, the wavelength of the bending waves in the panel match those of the incident sound. A modified mass law was derived by Sewell (1970), based on a theoretical treatment of the forced vibration component of transmission below the critical frequency, given by

$$R_i = -10 \times \log_{10} \left\{ \frac{\ln\left(k\sqrt{A}\right) + 0.16 - U(\Omega) + \dfrac{1}{4\pi k^2 A}}{\left(\dfrac{\pi f \rho t}{\rho_0 c_0}\left(1 - \dfrac{f^2}{f_c^2}\right)\right)^2} \right\} \text{dB} \tag{7.5}$$

where

k is the wavenumber ($=2\pi f/c$)

A is the cross-sectional area of the panel

$U(\Omega)$ is the shape factor correction (taken as 0 for square panels)

f_c is the critical frequency

For the panels tested in the current study, the critical frequency appears to be in the 2500 Hz third octave band and, in the absence of values for the Young's modulus (to calculate f_c precisely), the performance based on the modified mass law is based on this frequency and plotted in Figure 7.7. Excluding the effects of leakage at the posts in the

500 Hz octave band, the modified mass law curve gives a good estimation of the profile of the Part 6 curve, demonstrating that the reduction in performance is a real effect.

However, even allowing for the fact that the values are of R_i and S_i are not directly comparable (Part 6 measurements result in higher levels of sound insulation than Part 2 due to the differences in the incident sound field, Part 6 being normal incidence and Part 2 being random incidence), it is clear that the timber noise barrier panels provide lower levels of sound insulation than would be expected solely from a consideration of the surface density.

7.4 The relationship between early life acoustic performance and moisture content

Based on the measurement data reported in the previous sections, Figure 7.8 presents the relationship between the single number rating of sound insulation, DL_{SI}, and the percentage moisture content; the individual results are summarised in Table 7.4.

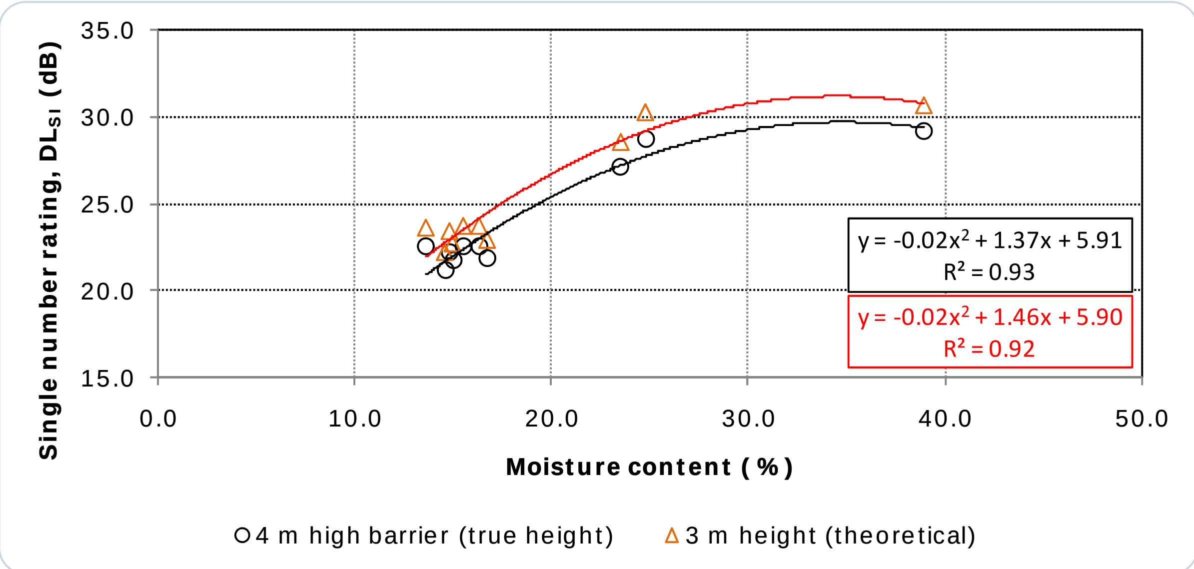


Figure 7.8: Relationship between moisture content and sound insulation performance

Table 7.4: Average moisture content and DL_{SI} for the 4 m high barrier

Day after treatment	4	6	8	23	37	51	65	79	93	107
Moisture content (%)	39.0	24.8	23.6	13.7	14.9	15.6	16.4	15.0	14.6	16.8
Single No. rating of sound insulation, DL_{SI} dB(A)	29.2	28.7	27.1	22.5	22.2	22.5	22.5	21.7	21.2	21.9

Performing a polynomial regression on the data, the relationship between the two parameters is shown to be

$$DL_{SI} = -0.02 \times \%MC^2 + 1.37 \times \%MC + 5.91 \text{ dB} \qquad (7.6)$$

for a 4 m high barrier (where %MC is the percentage moisture content), with an R^2 value of 0.93. While there is relatively little data for moisture contents above 25%, this would only be achieved by repeating the study and measuring every day for the first 10-12 days. It is not considered that this would change the conclusions of the study.

7.5 Discussion

It is considered that the changes in moisture content and associated sound insulation performance observed during this measurement programme could potentially result in the performance of a barrier being over-estimated if the product is tested too soon after the timber has been pressure treated.

Whilst the most significant impact will be if the performance of the barrier is considered in terms of the single number ratings, there could equally be an effect when rating a barrier in terms of the performance classes defined in either Annex A of Part 2 (classes B1-B3) or Annex A of Part 6 (classes D1-D4). A barrier that might for example perform as a class B2 under typical moisture content levels might be rated as a B3 if tested within the first few days after pressure treatment. This could potentially result in noise barriers being selected for installation that under normal conditions do not comply with current Highways Agency procurement conditions.

There are presently no guidelines on how soon after pressure treatment the airborne sound insulation performance of timber panels can be determined. Furthermore it is noted that the EN standards are product standards and, as such, do not include guidance relating to specific materials or products. Any such issues therefore need to be addressed either in national implementation documents or client specifications.

It is expected that the results from the current study will allow guidance to be drafted for inclusion in any revised Highways Agency specifications for noise barriers.

Conclusions and recommendations

Measurements show that the moisture content levels in pressure treated timber can decrease by as much as 25% as a result of drainage/evaporation of water in the preservative in the first 3-4 weeks after treatment. In that same time period, the airborne sound insulation performance, DL_{SI}, assessed in accordance with Part 6 reduces by approximately 8-10 dB as a result of this effect. Similar changes in performance are likely to be observed when testing in accordance with Part 2.

These changes can potentially affect the performance rating of the barrier when described using the B and D performance classes defined in Part 2 and 6 respectively, such that a barrier might achieve a higher performance rating if tested very soon after pressure treatment of the timber than if tested observed once ambient moisture levels are achieved. This could potentially result in inappropriate noise barriers being selected for installation under current Highways Agency procurement conditions.

Conclusions and recommendations (continued...)

On the basis of these results, the following recommendations are made in relation to the certification of airborne sound insulation performance in accordance with Part 6 (and Part 2):

- Certification measurements should not be taken until at least 4 weeks after the timber from which the barrier is manufactured has been treated with preservative
- Panels should be stored upright and outdoors for the period in between manufacture and assessment.

8 The effects of short-term moisture content changes

One of the advantages of the Part 6 method is its suitability for use at the roadside. However roadside measurements are subject to interruption/postponement due to inclement weather, an issue which makes the scheduling of routine assessments more complex. A study was proposed to investigate the effects of rainfall interruptions on Part 6 measurements by simulating a short rain shower (that would not immediately force an assessment team to vacate the test site on health and safety grounds) and comparing the sound insulation performance of the wet barrier as it dried out over a 3 hour period with the performance of the dry barrier prior to the shower.

8.1 Description of the measurements

Measurements were conducted using a 3.0 m high single-leaf reflective timber barrier installed on the TRL Noise Barrier Test Facility (see Annex A; Morgan, 2010) at two different times of year: during July 2009 (to be representative of summer conditions) and October 2009 (to be representative of spring/autumn conditions). The barrier was constructed from individual panels, 1.5 m in height and 3.0 m in width, erected in between steel I-section posts, with a total length of 9.0 m. The horizontal joint between each pair of panels is fitted with a rubber seal in accordance with the manufacturers design specifications. It is noted that the design does not recess the rubber seal into the timber. No rubber seals are used between the panels, posts or wedges. The panels forming the main focus of the investigation were those in the centre of the barrier.

Part 6 measurements were first taken with the barrier dry (there had been no rainfall prior to testing for several days). It is noted that due to the use of copper in the timber preservative, the only way to assess moisture content is to take core samples in the tests reported in Section 5.1. Since this destroys the acoustic integrity of the barrier, no test cores were taken during this investigation.

Then the barrier was sprayed with water in such a manner as to approximately simulate rainfall. In the July 2009 test, each side of the barrier were sprayed with water for 15 minutes. In the October 2009 test, only the traffic-facing side of the barrier was sprayed, again for 15 minutes. Part 6 measurements were then taken at 15-20 minute intervals for a duration of approximately 3 hours.

Figure 8.1: Wetting of noise barrier for simulated rainfall study

Figure 8.1 shows the wetting process and the view from the front of the barrier after wetting; the dry panels on either side of the panel being monitored can clearly be seen.

It is noted that the July 2009 measurements were taken mid-panel, whilst the October measurements were taken with the measurement position offset from the left-hand post by 2.0 m (representative of the revised Part 6 assessment of panels less than 4.0 m in width; see Section 2.2). No measurements were taken centred on a post.

8.2 Results and evaluation

Figure 8.2 presents the results of the July 2009 and October 2009 assessments, plotting sound insulation performance as a function of time, measurements being taken approximately ever 15-20 minutes. The Figure also plots air temperature and the surface temperature on the front face of the barrier at the same time intervals.

In both graphs, 0 minutes corresponds to the first measurement immediately after the cessation of the simulated rainfall. Negative minutes correspond to the time *prior to* the cessation of the simulated rainfall. For the July measurements the time between the dry barrier measurements and the first wet measurements was 30 minutes, whereas for the October measurements it was only 15 minutes. This was because both faces of the barrier were wetted in the former but only the front face was wetted during the latter.

It is observed, as would be expected, that higher air temperatures were recorded during the summer measurements, of the order of 15°C. It is also noted that the barrier is oriented approximately WNW-ESE and so the front face is exposed to direct sunlight for a large part of the day. There was considerably less cloud cover during the summer measurements, resulting in significantly higher surface temperatures.

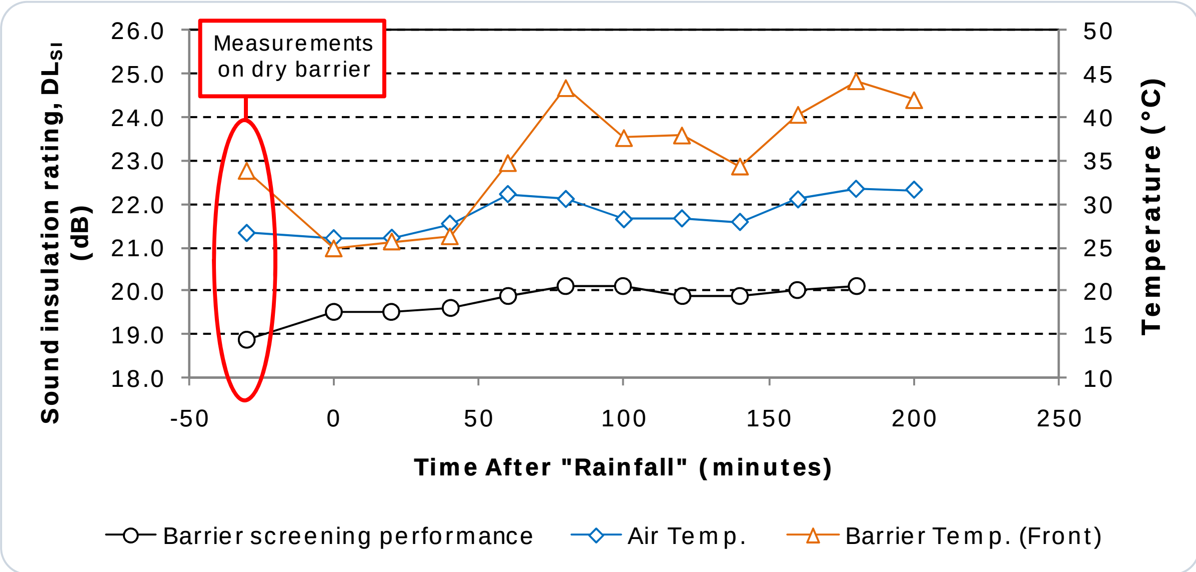
Figure 8.3 presents a photographic time history from the July 2009 measurements showing the front face of the barrier during the summer measurements. The evaporation of water/drying out of the barrier surface can be clearly seen, particularly over the first 60 minutes after the simulated rain shower.

In both the July and October measurements, despite the differences in the level of simulated rainfall, the sound insulation performance of the dry barrier expressed in terms of DL_{SI} is approximately 0.5 dB less than that of the barrier immediately after the rainfall[10].

The results show that when the surface temperature of the barrier remains approximately steady, then as the surface of the barrier begins to dry out, the sound insulation performance remains more or less constant. However, as shown in the July measurements (Figure 8.2a) when there is a significant increase in the surface temperature of the timber, in this case of the order of 20°C or greater (from 40-80 minutes), the sound insulation performance increases by approximately 0.5 dB. As the temperature decreases again so the sound insulation performance decreases slightly.

[10] It is noted that for reporting purposes in accordance with EN 1793-6, DL_{SI} is normally expressed in integer values only.

a) July 2009 assessment (summer conditions)



b) October 2009 assessment (autumn conditions)

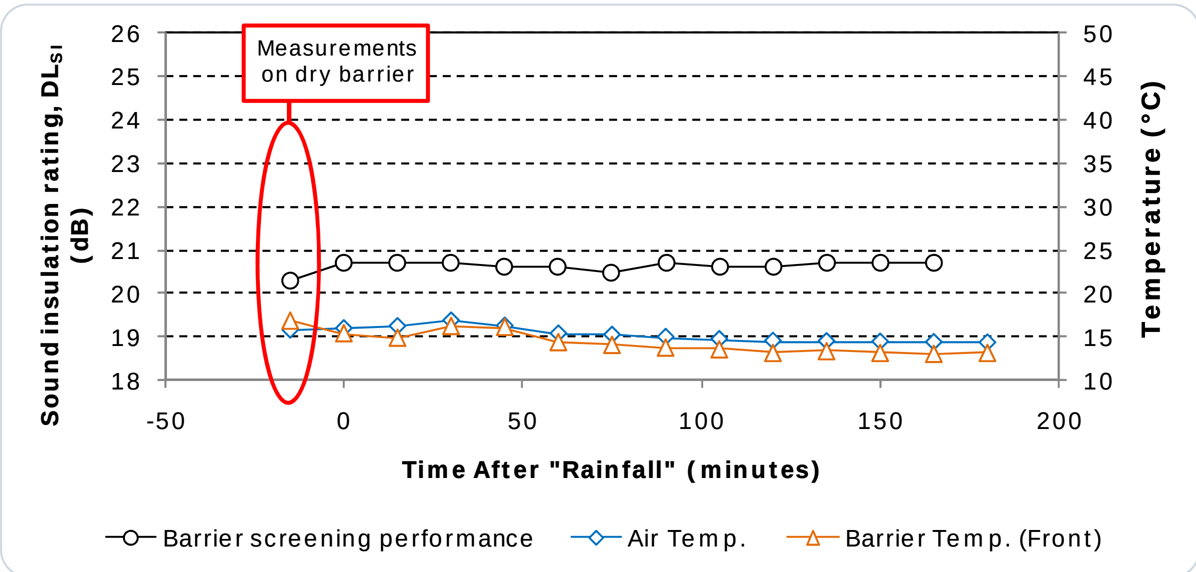
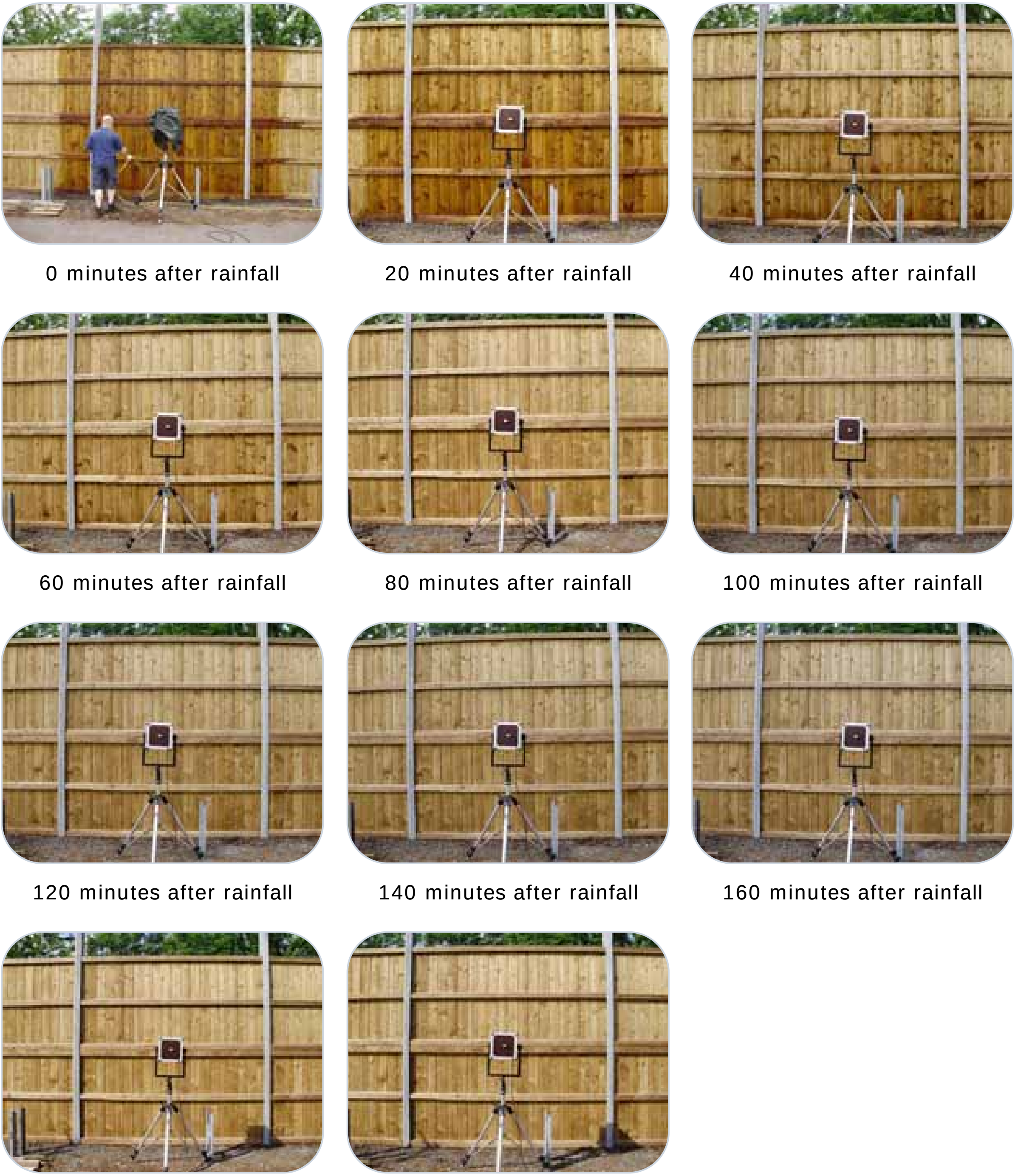


Figure 8.2: Variation in sound insulation performance with ‘drying time’ as measured during simulated rainfall study



0 minutes after rainfall | 20 minutes after rainfall | 40 minutes after rainfall

60 minutes after rainfall | 80 minutes after rainfall | 100 minutes after rainfall

120 minutes after rainfall | 140 minutes after rainfall | 160 minutes after rainfall

180 minutes after rainfall | 200 minutes after rainfall

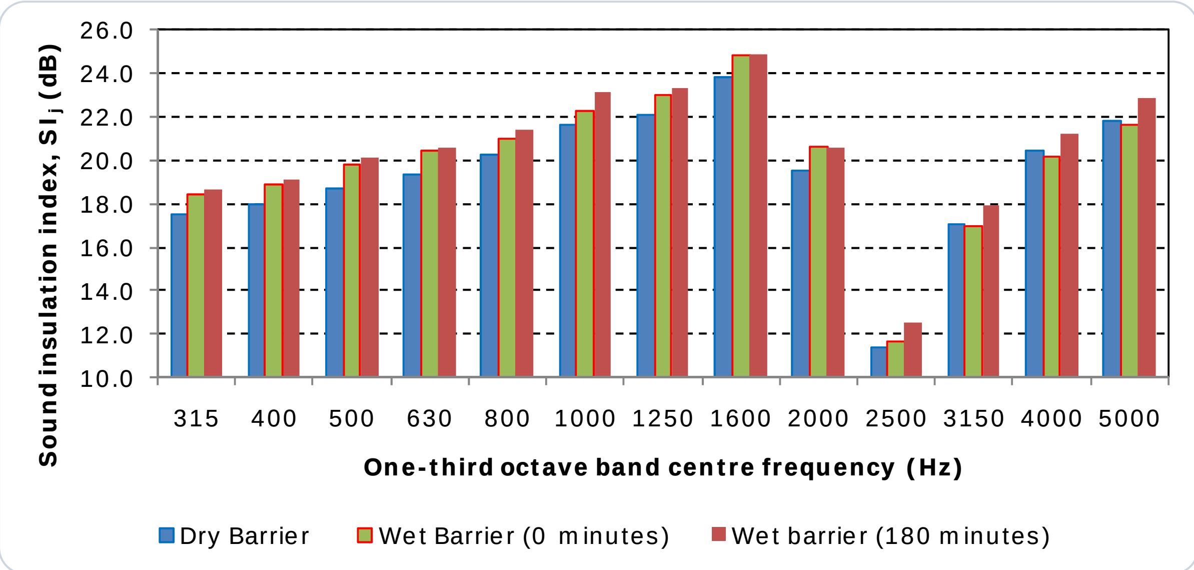
Figure 8.3: Photographic time history of water evaporation / drying out of barrier surface during July 2009 simulated rainfall study

This increase in performance is contrary to that reported by Watts (1997) for heated panels, who observed a 0.5-1 dB *decrease* in airborne sound insulation performance for a 20°C increase in temperature during tests on timber panels in a reverberation room. However, it is noted that the panels tested by Watts were dry prior to being warmed with a heater, whereas the panels in the current study were wetted and then heated only by exposure to direct sunlight.

However, these effects are small and, when considered in terms of integer values, the DL_{SI} increases by 1 dB when the barrier is subjected to rainfall and remains constant for at least 3 hours after the rainfall has stopped.

An examination of the corresponding one-third octave band sound insulation spectra (Figure 8.4) shows similar trends to the DL_{SI} values. The corresponding one-third octave band sound insulation indices at the individual microphone positions are tabulated in Annex I (Morgan, 2010).

a) July 2009 assessment (summer conditions)



b) October 2009 assessment (autumn conditions)

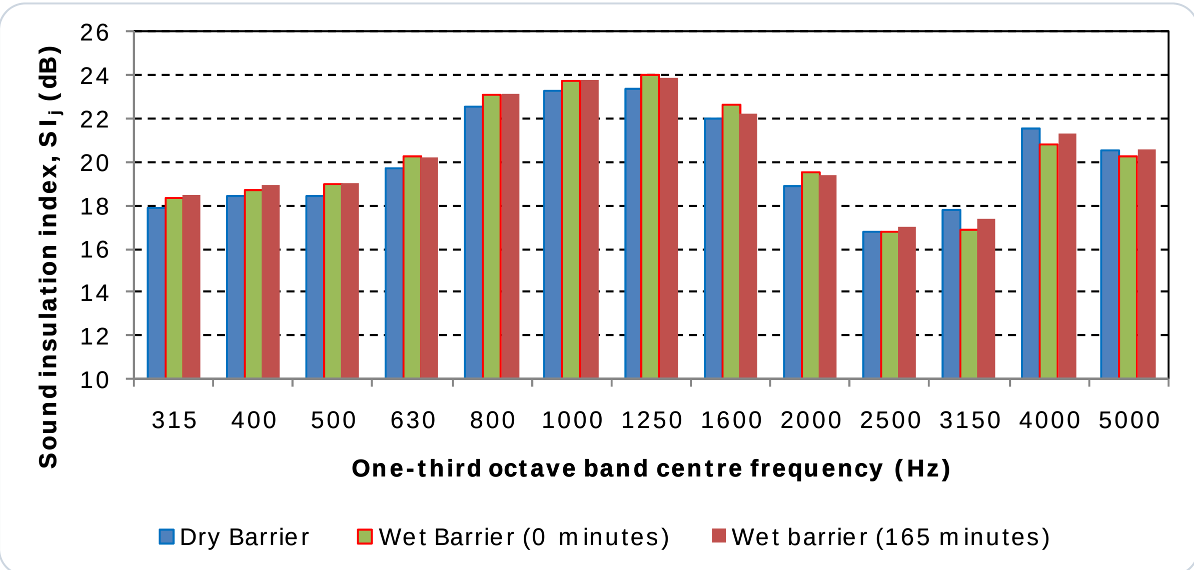


Figure 8.4: Variation in one-third octave band sound insulation performance with 'drying time' as measured during simulated rainfall study

In the context of how soon after rainfall to begin a new set of measurements, from the perspective of both certification and in situ testing at the roadside, Part 5 currently states that *"If the sample surface can be expected to have a significant void content, then measurements shall not be made until it has been verified that the pores are dry."* Such a broad statement is what would be expected within a product standard.

In the case of timber barriers, the presence of copper in the preservative means that the moisture content cannot be assessed using a hand-held moisture probe. As already noted, most rain or spray does not penetrate the surface of the timber but rather is shed from (run off) the face of the barrier. The measurements performed as part of this study only address light showers; however, the effects of prolonged, heavy rainfall are not expected to be significantly different. It is noted that roadside measurements are unlikely to be undertaken during wet weather due to the sensitivity of the measurement equipment and, of greater concern, health and safety risks to operatives taking the measurements.

Conclusions and recommendations

On the basis of simulated rainfall measurements undertaken in July and October 2009, it is concluded that the effects of rainfall on Part 6 measurements are small, being of the order of 1 dB increase in DL_{SI}. The performance of the barrier remains at this increased level for at least 3 hours after the rainfall has stopped.

The following recommendations are proposed:

Product certification assessments:

- Measurements should not be undertaken within 1-2 days of a barrier being exposed to rainfall, depending upon the duration and intensity of the rainfall

In situ (roadside) assessments

- Measurements should not be undertaken within 24 hours of a barrier being exposed to rainfall, depending upon the duration and intensity of the rainfall
- Where in situ (roadside) measurements are interrupted by rain, the primary consideration for continuing will be the health and safety of the assessment team.

  Providing that the duration and intensity of the rainfall is not sufficient to force an assessment team to vacate the roadside site, measurements can be resumed once the rain has stopped without any significant impact upon measured sound insulation performance. However, the measurement report must state that the measurements were rain affected.

9 Variation in EN 1793-6 certification and assessment

The design and geometry of noise barriers installed on the Strategic Road Network varies considerably, based on the level of acoustic screening required, the height of the barriers, the method of installation (prefabricated or site assembled acoustic elements), etc.

As noted in Section 2.3, Part 6 specifies minimum dimensions for product certification, namely a test sample (comprised of acoustic elements and posts) with a minimum height of 4.0 m and a minimum width of 6.0 m, so that the sound insulation performance is calculated over the frequency range 200-5000 Hz. The height above ground of the loudspeaker source and microphones P4, P5 and P6, $h_{s,}$ is 2.0 m (see Figure 2.2).

It is intended that the airborne sound insulation characteristics determined from this certification should apply to equivalent products installed at the roadside regardless of height. However, care must be taken when comparing in situ performance with certification values as follows: When the roadside barriers are the same height as the certified products, then a direct comparison of both DL_{SI} and the one-third octave band sound insulation indices, SI_i, is possible. However, when the height of the roadside barriers is less than the certification height, any performance comparison should be restricted to the one-third octave band sound insulation indices only (since the lower barrier height will artificially increase the DL_{SI} value due to the reduced frequency range used in its calculation).

In principle therefore, the certification sound insulation indices for a product should, providing the quality of manufacture and installation is comparable, be similar to those measured in situ for the same design of product when it is constructed with a lower height, e.g. comparing a 4.0 m high barrier constructed from two 2.0 m high panels with a 3.0 m high barrier constructed from two 1.5 m high panels.

A further consideration, as experienced during the roadside testing reported in Chapter 5, is that the combination of the design of test equipment and individual site layouts may prevent 4.0 m high barriers at the roadside being easily assessed using the certification geometry, so that h_s < 2.0 m (and therefore not equal to half the height of the barrier). For example, one site was encountered during the current project where the ground at the rear of the barrier was steeply sloping and at least 300 mm lower than the ground in front of the noise barrier.

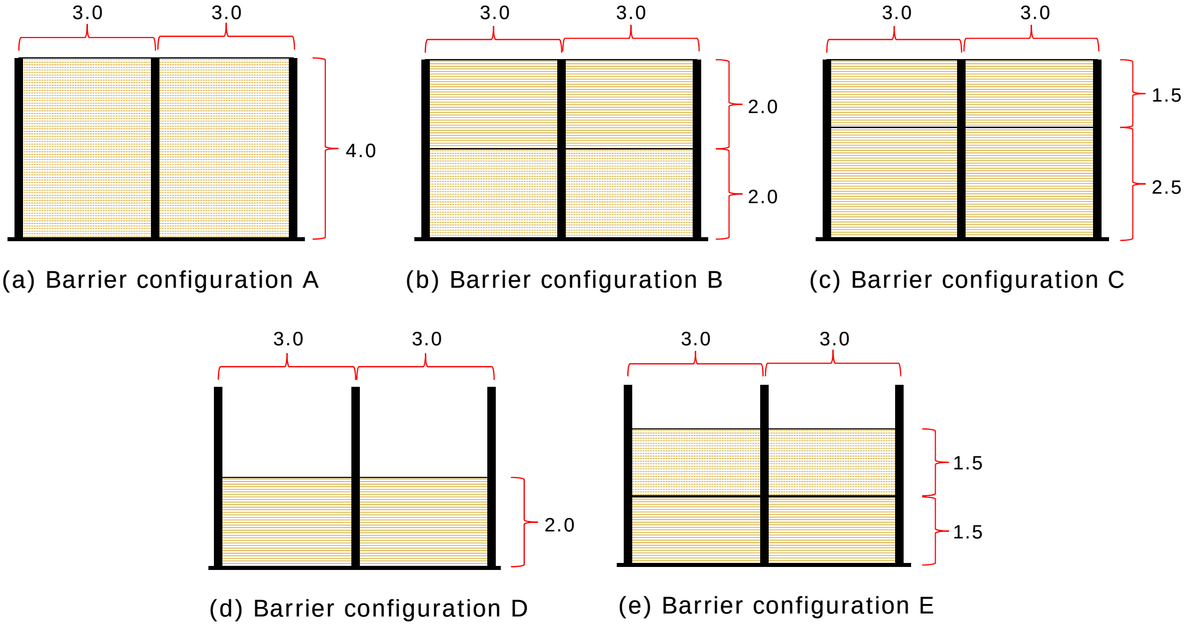
A series of measurements was therefore proposed to investigate the potential effects of these different approaches between certification and routine assessment measurements.

This assessment would be performed using a series of barrier heights and panel configurations representative of those encountered on the SRN during the roadside assessments reported in Chapter 5 and discussions with industry representatives.

In addition, a comparison of 4.0 m high barriers constructed from different size panels was also proposed to investigate if there are any acoustic benefits to be gained from using a particular panel geometry.

9.1 Description of the measurements

Measurements were conducted using single-leaf reflective timber barriers installed on the TRL Noise Barrier Test Facility (see Annex A; Morgan, 2010). The barriers were constructed from individual panels 3.0 m in width, erected in between steel I-section posts, with a total length of 6.0 m. The height of the barriers varied from 2.0-4.0 m, and the number of panels required to achieve the full height of any given barrier varied from one to two. It is noted that the post height was 4.0 m in for all panel configurations. The different panel configurations are presented in Figure 9.6 and summarised below.



(a) Barrier configuration A (b) Barrier configuration B (c) Barrier configuration C

(d) Barrier configuration D (e) Barrier configuration E

Figure 9.1: Barrier configurations for certification vs. in situ assessment

- *Barrier A:* Height = 4.0 m, comprising a single full-height panel. This barrier was defined as the reference case for single-element barriers.
- *Barrier B:* Height = 4.0 m, comprising two 2.0 m high panels. This barrier was defined as the reference case for multi-element barriers.
- *Barrier C:* Height = 4.0 m, comprising a lower 2.5 m high panel and an upper 1.5 m high panel.
- *Barrier D:* Height = 2.0 m, comprising a single 2.0 m high panel. Measurements were taken for h_s = 1.0 m. It is considered that Barrier A would be the equivalent design used for certification.
- *Barrier E:* Height = 3.0 m, comprising two 1.5 high panels. Measurements were taken for h_s = 1.5 m. It is considered that Barrier B would be the equivalent design used for certification.

For those multi-element barriers, the horizontal joint between each pair of panels was fitted with a rubber seal in accordance with the manufacturer's design specifications. It is noted that the design does not recess the rubber seal into the timber. No rubber seals were used between the panels, posts or wedges. The quality of the seal between panel and post is dependant upon the degree of fitness of the wedge.

All of the panels were prefabricated rather than site assembled. However, it is noted that Barrier A would never be used at roadside locations as a prefabricated panel because of the logistical difficulties of transporting panels of that size. In this study, transportation was not an issue since the TRL facility is located on the same site as the panel manufacturing plant.

This assessment was conducted towards the end of the study, by which time the measurement positions defined in Part 6 had been finalised (see Section 2.2). Since all future product certification will be based upon the Part 6 specifications, then in light of the width of the panels in the assessment (3.0 m), it was concluded that the offset measurement position (Figure 2.6) defined in Part 6 should be used rather than a position centred in between the posts as used in the other parts of this research project. As such, no comparison will be made with results outside of this assessment.

9.2 Results and evaluation: Certification vs. in situ assessment using comparable panel geometries

This phase of the measurements was to compare different height barriers constructed from the same panel configurations. In each case, the reference barrier is that which would be used for product certification, i.e. 4.0 m high, whilst the other barriers are of lower heights commonly used on the strategic road network, e.g. 2.0-3.0 m.

Based on the configurations presented in Figure 9.1, the comparisons are as follows:

- *Barrier A (certification; 4.0 m high) vs. Barrier D (in situ assessment; 2.0 m high):* This is effectively a comparison between different height single element barriers of the same design. It is noted that the number of 2.0 m high barriers currently being installed on the network is considerably fewer than those which are at least 3.0 m high or greater. Such low barriers, whilst historically common, are now more likely to be used in combination with earth bunds.
- *Barrier B (certification; 4.0 m high) vs. Barrier E (in situ assessment; 3.0 m high):* This is effectively a comparison between different height multi-element barriers of the same design.

Figure 9.2a) shows Barrier A, the configuration comprising a single 4.0 m high panel, viewed from the source side of the barrier. It is noted that the left-hand panel of this barrier included several splits and knots in the timbers closest to the measurement positions. As such, measurements have been carried out with the speaker orientated on both panels of the barrier.

Figure 9.2b) shows Barrier D, the configuration comprising a single 2.0 m high panel. The main difference with Barrier A for the purpose of these measurements is the position of the horizontal rails relative to the measurement height.

Figure 9.3 presents the comparison between the single number rating, DL_{SI}, and the corresponding one-third octave band sound insulation spectra, SI_j, for Barriers A (left and right panels) and D. It is noted that although the frequency ranges for the spectral data are different (due to the different heights of the barrier), for the purposes of accurate comparison the single number rating for both configurations has been calculated using the frequency range corresponding to the lower barrier, i.e. 0.8-5 kHz rather than the range for the 4.0 m high barrier that would be evaluated for product certification.

The most immediate observation is the significant difference in performance between the sound insulation performance of the left and right panels of Barrier A, with the left-hand panel providing lower sound insulation, between 1-4 dB, over almost all of the one-third octave bands considered. In terms of the single number rating, DL_{SI}, alone there is a 2 dB difference in sound insulation. The presence of the defects in the timber would therefore appear to contribute significantly to the performance of the barrier. If there is any variation in the quality of the seals at the post for each panel, this would also contribute.

(a) Barrier A (4.0 m high panels) (b) Barrier D (2.0 m high panel)

Figure 9.2: Single element barrier configurations on the noise barrier test facility

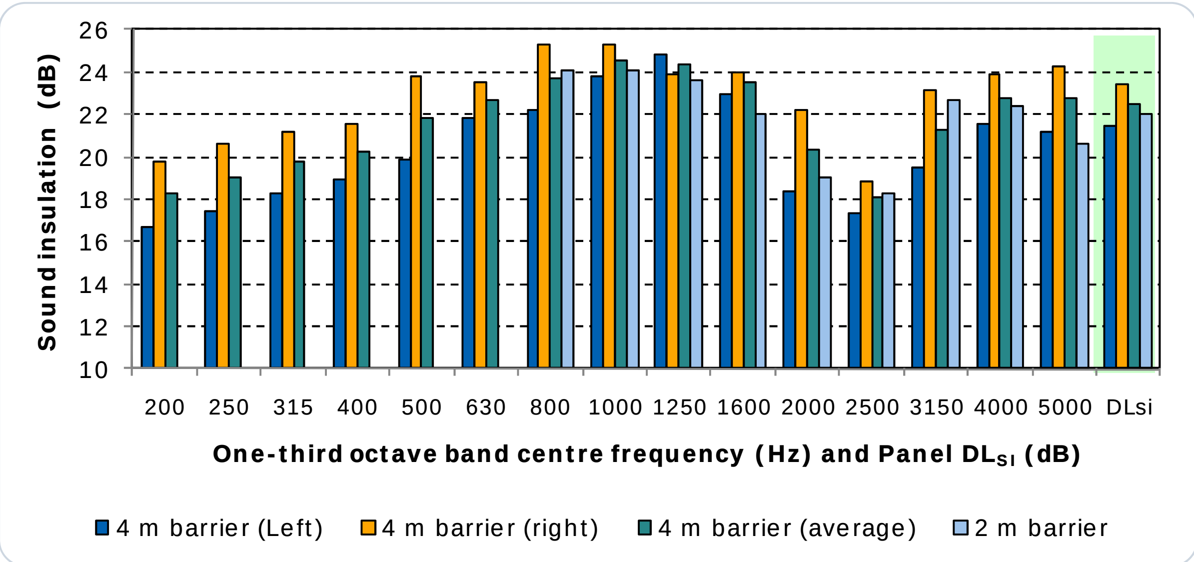


Figure 9.3: Comparison of airborne sound insulation performance for barrier configurations A and D (4 m and 2 m high respectively)

As such, the average sound insulation of the two panels is also shown in the Figure.

Comparing the best performing panel on Barrier A with Barrier D, then a difference of 1.5 dB is observed in the single number rating, with the 2.0 m high barrier providing the lowest sound insulation. In terms of the one-third octave band spectra, the 2.0 m high barrier gives up to 4 dB lower sound insulation.

Comparing the average results for Barrier A with those of Barrier D, then a difference of only 0.5 dB is observed in the single number rating. Differences in the one-third octave band sound insulation indices are generally less than ±1.5 dB.

Table 9.1 – Table 9.3 present the corresponding one-third octave band spectra and DL_{SI} values corresponding to the individual microphone positions, using only the reduced frequency range for both barriers, i.e. 0.8-5 kHz.

Table 9.1: Sound insulation indices at individual microphone positions for Barrier A (left panel, 0.8-5 kHz only)

1/37 octave band centre frequency	Sound insulation indices SI for microphone positions P1-P9 & the mean								
	SI_1	SI_2	SI_3	SI_4	SI_5	SI_6	SI_7	SI_8	SI_9	SI
800	25.2	27.1	21.9	20.3	23.9	19.8	23.4	22.2	22.9	22.2
1000	23.1	24.7	21.5	21.9	25.9	25.3	24.0	25.9	23.2	23.8
1250	22.7	22.3	22.0	28.6	26.9	32.0	26.9	24.3	23.7	24.8
1600	20.6	25.9	22.4	26.2	24.5	25.7	21.9	20.0	21.1	23.0
2000	16.3	22.3	16.7	20.9	21.5	19.7	20.5	16.2	14.6	18.4
2500	12.0	20.3	11.3	23.8	25.2	26.7	15.9	17.8	14.5	17.3
3150	18.1	18.4	22.7	25.1	25.4	31.1	13.3	16.8	15.9	19.5
4000	24.7	24.3	16.9	25.7	25.4	23.0	20.0	22.7	15.8	21.6
5000	22.2	21.8	17.3	24.2	25.3	25.6	18.6	20.2	13.8	21.2
DL_{SI} (0.8-5kHz)	19.3	23.2	18.7	22.9	24.6	23.4	20.7	20.5	18.8	21.5

Table 9.2: Sound insulation indices at individual microphone positions for Barrier A (right panel, 0.8-5 kHz)

1/3 octave band centre frequency	Sound insulation indices SI for microphone positions P1-P9 & the mean								
	SI_1	SI_2	SI_3	SI_4	SI_5	SI_6	SI_7	SI_8	SI_9	SI
800	23.5	25.2	23.8	26.3	26.2	27.7	27.2	25.8	22.8	25.3
1000	24.7	24.1	24.1	25.0	26.2	26.9	28.7	26.1	23.4	25.3
1250	21.9	21.8	23.7	22.9	26.9	27.2	25.0	24.1	23.0	23.9
1600	28.5	22.4	19.4	29.0	29.2	25.5	26.0	22.9	22.6	24.0
2000	18.6	20.7	22.2	22.4	27.4	28.8	19.7	21.5	21.0	22.2
2500	13.9	16.1	20.0	21.9	26.4	24.9	14.2	20.1	15.9	18.8
3150	27.8	25.7	17.3	28.7	32.2	24.4	18.9	23.5	17.7	23.1
4000	18.9	29.4	22.7	23.9	31.3	23.8	21.2	27.4	22.1	23.9
5000	21.3	28.9	23.3	23.8	29.6	24.3	19.1	25.2	21.2	24.3
DL_{SI} (0.8-5kHz)	21.0	22.0	21.9	24.4	27.1	26.5	21.9	23.7	21.3	**23.5**

Table 9.3: Sound insulation indices at individual microphone positions for Barrier D

1/3 octave band centre frequency	Sound insulation indices SI for microphone positions P1-P9 & the mean								
	SI_1	SI_2	SI_3	SI_4	SI_5	SI_6	SI_7	SI_8	SI_9	SI
800	23.9	26.9	27.6	24.2	23.8	20.2	24.0	29.5	24.2	24.1
1000	23.9	26.9	27.6	24.2	23.8	20.2	24.0	29.5	24.2	24.1
1250	24.5	21.0	28.7	25.2	20.4	25.7	29.0	22.8	25.9	23.6
1600	26.3	21.2	26.5	27.7	20.5	18.3	28.4	23.3	19.9	22.0
2000	27.0	22.2	22.7	20.3	18.4	13.9	28.1	24.8	16.5	19.0
2500	19.5	23.3	22.2	15.5	17.4	15.4	24.3	25.4	18.4	18.3
3150	20.0	27.1	30.2	18.7	21.9	23.3	22.6	31.5	27.2	22.7
4000	23.7	29.4	22.5	22.0	23.3	17.4	25.7	31.8	23.2	22.4
5000	27.9	28.5	22.0	21.1	19.5	15.1	24.3	31.2	18.9	20.6
DL_{SI} (0.8-5kHz)	23.7	23.5	25.8	22.0	20.9	18.4	25.4	25.7	21.3	22.0

In terms of the single number ratings, the sound insulation offered by the right-hand panel of Barrier A is greater at 8 of the 9 microphone positions than that for Barrier D, by approximately 1-3 dB.

Considering the average performance for Barrier A, there is considerable variation between the measured one-third octave band sound insulation indices and those of Barrier D, by as much as ±10 dB. In terms of the single number rating, DL_{SI}, the differences at the individual microphone positions vary between ±6 dB.

It must be noted that differences are to be expected since although the products are of equivalent design, there will be natural variations in the quality of the timber and no two panels will be exactly the same. Quantifying such effects for individual microphone positions is therefore difficult and the primary focus should be on the sound insulation spectra averaged over the nine microphone positions.

Figure 9.4a) shows Barrier B, the configuration comprising multiple 2 m high panels, viewed from the source side of the barrier. It is noted that the wedges used to hold the panels in between the posts on Barrier B were not sufficiently thick and so additional small wedges were added at several heights to try and improve the quality of the seal between the panels and posts. Figure 9.4b) shows Barrier E, the configuration comprising 1.5 m high panels. It is noted that there was a water container in close proximity to the barrier although it was not considered that this would interfere with the measurements.

On both barriers, there is a horizontal joint at the centre of the barrier, bounded by two 50 mm thick, 100 mm high rails on the source side of the barrier. On the receiver side of the barrier, the joint is covered by a 20 mm thick, 100 mm high cover strip.

Figure 9.5 presents the comparison between the single number rating, DL_{SI}, and the corresponding one-third octave band sound insulation spectra, SI_j, for Barriers B and E. Again the DL_{SI} values are calculated using the frequency range corresponding to the lower barrier height, i.e. 0.32-5 kHz.

(a) Barrier B (2 m + 2 m high panels) (b) Barrier E (1.5 m + 1.5 m high panels)

Figure 9.4: Multi-element barrier configurations on the noise barrier test facility

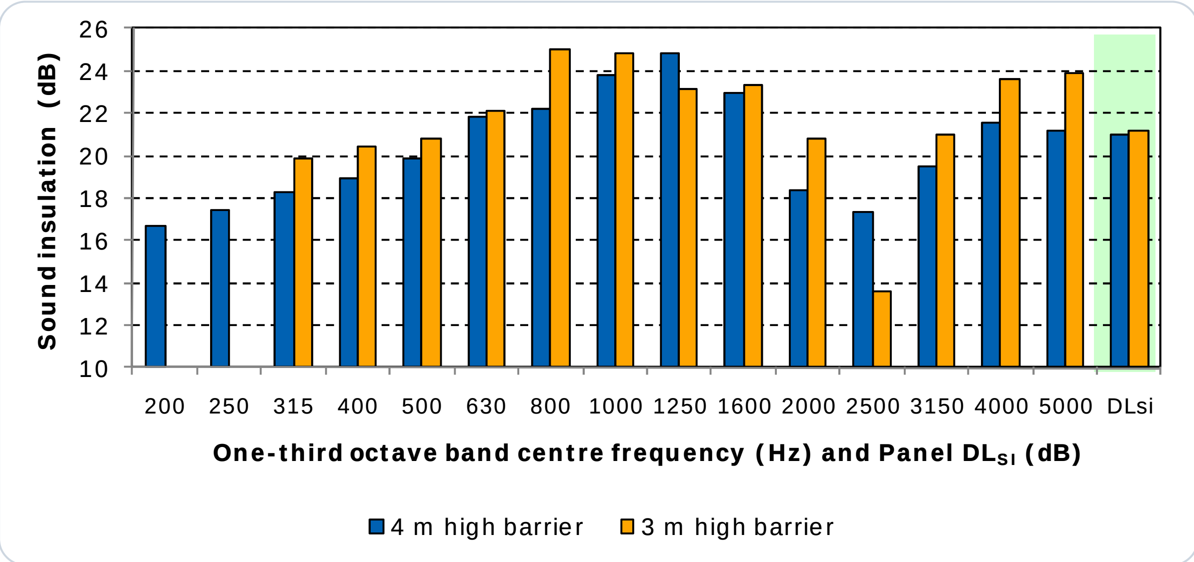


Figure 9.5: Comparison of airborne sound insulation performance for barrier configurations B and E (4.0 m and 3.0 m high respectively)

Whilst the difference in the single number rating, DL_{SI}, is negligible (only 0.2 dB) differences of up to 4 dB are observed at individual one-third octave bands. It is noted that the wedges used to hold the panels in between the posts on Barrier B were not sufficiently thick, so additional small wedges were inserted at several heights in order to try and improve the quality of the seal between panel and post. This may be a contributory factor in the 4 m high barrier performing more poorly at higher frequencies.

Table 9.4 – Table 9.5 present the one-third octave band spectra ands DL_{SI} values corresponding to the individual microphone positions using only the reduced frequency range for both barriers.

Table 9.4: Sound insulation indices at individual microphone positions for Barrier B

1/3 octave band centre frequency	Sound insulation indices SI for microphone positions P1-P9 & the mean									
	SI_1	SI_2	SI_3	SI_4	SI_5	SI_6	SI_7	SI_8	SI_9	SI
315	19.9	18.3	20.1	17.8	17.1	15.7	20.0	19.7	19.6	18.3
400	21.6	18.7	23.6	19.5	17.4	15.5	24.6	19.0	19.5	18.9
500	15.9	25.0	17.0	23.0	23.4	20.4	19.1	19.5	18.5	19.9
630	17.9	20.9	20.3	25.4	25.7	26.6	20.3	19.5	22.8	21.8
800	25.2	27.1	21.9	20.3	23.9	19.8	23.4	22.2	22.9	22.2
1000	23.1	24.7	21.5	21.9	25.9	25.3	24.0	25.9	23.2	23.8
1250	22.7	22.3	22.0	28.6	26.9	32.0	26.9	24.3	23.7	24.8
1600	20.6	25.9	22.4	26.2	24.5	25.7	21.9	20.0	21.1	23.0
2000	16.3	22.3	16.7	20.9	21.5	19.7	20.5	16.2	14.6	18.4
2500	12.0	20.3	11.3	23.8	25.2	26.7	15.9	17.8	14.5	17.3
3150	18.1	18.4	22.7	25.1	25.4	31.1	13.3	16.8	15.9	19.5
4000	24.7	24.3	16.9	25.7	25.4	23.0	20.0	22.7	15.8	21.6
5000	22.2	21.8	17.3	24.2	25.3	25.6	18.6	20.2	13.8	21.2
DL_{SI} (0.3-5 kHz)	18.9	22.4	18.9	22.4	23.1	21.6	20.6	20.2	19.1	21.0

Table 9.5: Sound insulation indices at individual microphone positions for Barrier E

1/3 octave band centre frequency	Sound insulation indices SI for microphone positions P1-P9 & the mean									
	SI_1	SI_2	SI_3	SI_4	SI_5	SI_6	SI_7	SI_8	SI_9	SI
315	26.3	20.4	19.7	22.6	18.8	18.2	25.7	17.6	19.7	19.9
400	32.3	20.8	20.4	24.4	19.0	18.6	30.6	17.6	20.3	20.4
500	19.5	22.4	19.4	21.8	23.3	22.4	18.5	19.8	20.2	20.8
630	21.0	24.2	21.0	23.4	24.6	22.7	19.6	22.1	20.6	22.1
800	30.9	27.3	27.0	29.3	24.8	22.2	24.5	27.8	21.5	25.0
1000	23.6	23.2	27.1	25.5	31.5	30.7	21.3	24.6	22.3	24.8
1250	24.2	23.6	22.4	27.1	28.1	26.6	19.4	22.8	19.0	23.1
1600	26.8	21.1	23.1	28.4	27.2	27.1	20.4	20.8	21.3	23.3
2000	27.5	21.9	18.6	28.0	27.1	20.8	16.8	22.0	16.1	20.8
2500	14.9	11.3	10.6	20.2	19.9	18.1	12.1	10.0	11.9	13.6
3150	20.3	20.0	20.6	26.5	33.8	27.5	15.3	17.5	16.5	21.0
4000	25.4	24.3	20.7	28.5	31.0	28.1	19.7	24.1	16.8	23.6
5000	21.6	26.1	17.4	29.6	35.2	27.0	19.3	23.5	19.3	23.9
DL_{SI} (0.3-5 kHz)	22.6	20.5	19.6	25.1	24.5	22.8	18.9	19.3	18.6	21.2

As was observed with the comparison of Barriers A and D, there is considerable variation in the sound insulation performance at individual microphone positions of approximately ±10 dB. In terms of the single number ratings at the individual microphone positions, the differences between the 2 barriers are generally within ±2 dB, except at microphones P1 and P4 where differences of approximately 3-4 dB are observed.

Conclusions

Based on the limited study reported here, comparison between sound insulation performance results for a certified product and a lower height product of the same design installed at the roadside is possible, based upon the one-third octave band sound insulation indices averaged over the 9 microphone positions.

Although prEN 1793-6 states that the single number rating, DL_{SI}, should only be calculated for the frequency range 0.2-5 kHz, adjusting the frequency range used in its calculation so that certification and in situ results can be directly compared also appears to be a suitable approach.

However, further consideration is required to define the permitted tolerances for the sound insulation indices against which installed products can be considered to meet the reported certification performance.

It is also noted from these measurements that the presence of defects in the timber, e.g. knots and splits, and the quality of the seals between posts and panels can have a measurable effect on the average sound insulation index. This must be taken into account in the development of the permitted tolerances.

9.3 Results and evaluation: Certification vs. in situ assessment using different loudspeaker microphone heights

This phase of the measurements focussed on barriers of identical height to that required for certification, but making the assumption that in situ assessment could only be carried out with the source and microphone height at a lower height, i.e. h_s < 2.0 m. As such, changes in performance should be primarily attributable to changes in either the position of any horizontal rails on the barrier or, in the case of multi-element barriers, the position of the horizontal joint between the panels relative to the loudspeaker and microphone positions (see for example Figure 9.6). Figure 2.2 shows the nomenclature used for the microphone positions.

The quality of the joints between the panels and posts is also of increased importance using the Part 6 measurement positions, since the centre of the measurement array is located closer to the posts.

The barrier configurations selected for evaluation were (from Figure 9.1) Barrier A, Barrier B and Barrier C. Assessments were carried out for h_s = 2.0 m (certification) and h_s = 1.5 m (in situ assessment). Therefore unlike the previous section, where the comparison was between physically different barriers, in this case there is no difference in the barrier itself, simply a change in the area of the barrier being assessed, in terms of both position and the size of the area.

In all cases, the single number ratings, DL_{SI}, have been calculated for the reduced frequency range 0.32-5 kHz (equivalent to assessing a 3 m high barrier), although it is acknowledged that this is only acceptable for research purposes and, according to the standard, it not permitted for general use.

In the case of Barrier A, the 4 m high single panel construction (see Figure 9.2a), the effect of reducing the height h_s from 2.0 m to 1.5 m to is to move the loudspeaker away from the horizontal joint at the centre of the barrier.

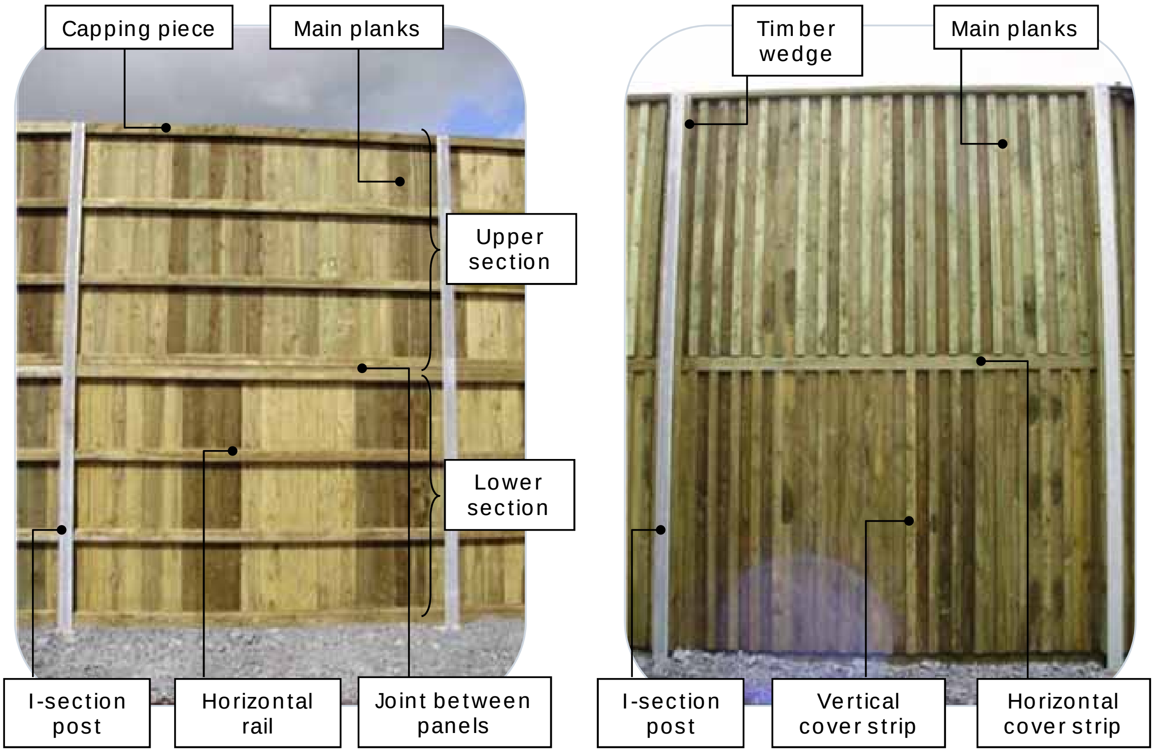


Figure 9.6: Example of multi-element single-leaf reflective timber noise barrier

The results for the assessment of Barrier A are presented in Figure 9.7. Using the lower assessment height was observed to result in an increased sound insulation performance, DL_{SI} increasing by approximately 0.5 dB. In terms of the one-third octave band sound insulation indices, in general the lower microphone height results in an increase in the sound insulation, by generally no more than ±1.5 dB. Most noticeably, the dip in performance in the frequency bands around 2.5 kHz becomes less pronounced; it is possible that this due to the microphone positions being closer to the rails, so that the panels are stiffer at that position.

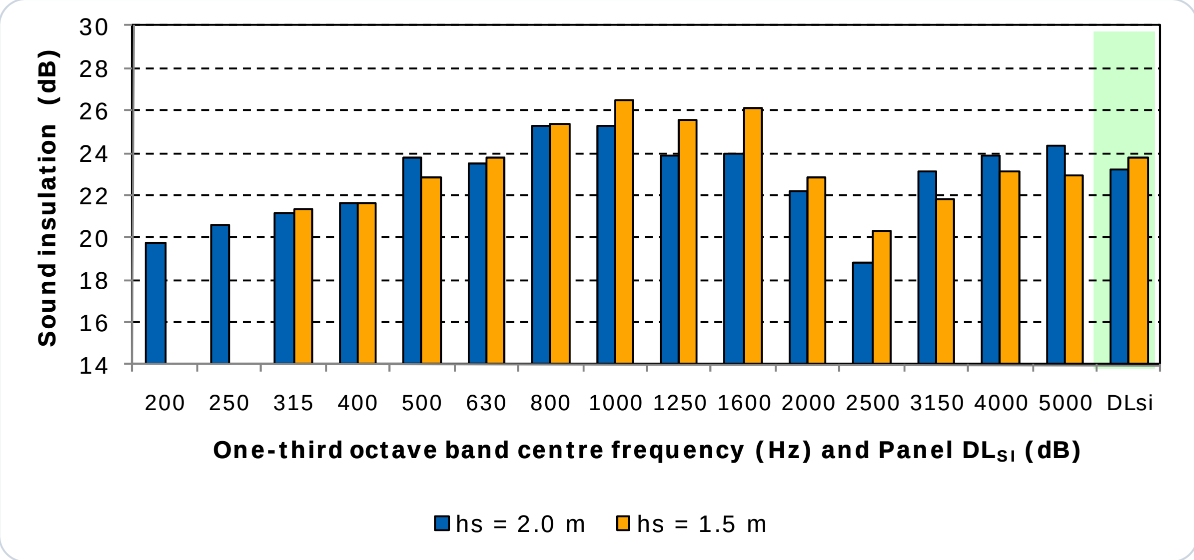


Figure 9.7: Barrier A sound insulation performance (h_s = 2.0 m vs. h_s = 1.5 m)

Table 9.6: Sound insulation indices at individual microphone positions for Barrier A, h_s = 2.0 m (right panel, 0.32-5 kHz only)

1/3 octave band centre frequency	Sound insulation indices SI for microphone positions P1-P9 & the mean								
	SI_1	SI_2	SI_3	SI_4	SI_5	SI_6	SI_7	SI_8	SI_9	SI
315	21.4	22.4	22.9	18.9	20.7	19.5	21.9	23.5	22.9	21.2
400	24.1	22.2	25.9	18.8	20.4	19.6	22.9	23.8	25.0	21.6
500	22.7	20.9	26.9	27.0	25.1	25.9	24.7	22.2	22.2	23.8
630	23.3	23.6	19.6	28.7	32.4	27.4	26.8	26.8	18.2	23.5
800	23.5	25.2	23.8	26.3	26.2	27.7	27.2	25.8	22.8	25.3
1000	24.7	24.1	24.1	25.0	26.2	26.9	28.7	26.1	23.4	25.3
1250	21.9	21.8	23.7	22.9	26.9	27.2	25.0	24.1	23.0	23.9
1600	28.5	22.4	19.4	29.0	29.2	25.5	26.0	22.9	22.6	24.0
2000	18.6	20.7	22.2	22.4	27.4	28.8	19.7	21.5	21.0	22.2
2500	13.9	16.1	20.0	21.9	26.4	24.9	14.2	20.1	15.9	18.8
3150	27.8	25.7	17.3	28.7	32.2	24.4	18.9	23.5	17.7	23.1
4000	18.9	29.4	22.7	23.9	31.3	23.8	21.2	27.4	22.1	23.9
5000	21.3	28.9	23.3	23.8	29.6	24.3	19.1	25.2	21.2	24.3
DL_{SI} (0.3-5 kHz)	21.4	22.1	22.0	23.8	25.9	25.1	22.3	23.8	21.2	23.2

Table 9.7: Sound insulation indices at individual microphone positions for Barrier A, h_s = 1.5 m (right panel)

1/3 octave band centre frequency	Sound insulation indices SI for microphone positions P1-P9 & the mean								
	SI_1	SI_2	SI_3	SI_4	SI_5	SI_6	SI_7	SI_8	SI_9	SI
315	23.1	21.9	24.4	21.1	21.4	23.1	20.3	18.8	20.1	21.3
400	24.2	22.3	25.4	21.6	21.6	23.8	20.8	18.8	20.4	21.6
500	26.0	25.4	19.8	26.7	26.1	19.1	24.8	24.2	22.4	22.8
630	25.9	26.1	20.0	28.1	27.7	20.4	26.4	26.4	23.6	23.8
800	25.8	26.1	21.8	27.7	27.5	24.5	27.0	25.5	25.1	25.4
1000	28.2	27.4	27.7	36.2	26.6	22.3	28.2	25.7	28.1	26.5
1250	25.1	25.8	25.0	33.7	26.8	23.3	25.4	25.1	24.5	25.6
1600	34.2	28.4	28.3	30.8	24.4	23.8	28.8	23.4	25.8	26.1
2000	19.0	23.6	21.1	23.8	21.8	22.1	23.7	26.5	29.0	22.8
2500	14.4	21.1	17.7	24.8	18.7	20.5	24.1	28.6	23.3	20.3
3150	17.7	23.5	17.3	24.9	27.7	17.4	29.2	27.3	22.8	21.8
4000	18.3	27.9	20.5	19.4	30.6	25.3	26.0	25.5	29.4	23.1
5000	20.1	24.3	22.5	19.9	24.2	24.8	26.5	28.2	23.5	22.9
DL_{SI} (0.3-5 kHz)	22.3	25	22.1	26	24.4	22	25.2	24.2	24.3	23.8

Considering the individual one-third octave band spectra at each microphone position, as presented in Table 9.6 and Table 9.7, whilst level differences of the order of ±10 dB are observed at all microphone positions, no individual group of microphones demonstrates any consistent change in the performance of the barrier. In this case, there is no difference in the barrier itself, simply a change in the area of the barrier being assessed, in terms of both position and the size of the area. In terms of the single number ratings at the individual microphone positions, these vary within the range ±3 dB.

Barrier B, is the configuration comprising multiple 2 m high panels (see Figure 9.4a). It is noted that the wedges used to hold the panels in between the posts were not sufficiently thick and so additional small wedges were added at several heights to try and improve the quality of the seal between the panels and posts. The effect of reducing the height h_s from 2.0 m to 1.5 m for this barrier is to move microphones P4-6 away from the joint whilst moving microphones P1-P3 closer to the joint. The results for the assessment of this barrier are presented in Figure 9.8.

Using the lower assessment height is observed to result in a reduced sound insulation performance, DL_{SI} decreasing by 0.7 dB. In terms of the one-third octave band sound insulation indices, the lower microphone height results in marginally lower sound insulation, less than ±1 dB except in the highest frequency bands.

The individual one-third octave band spectra at each microphone position, are presented in Table 9.8 and Table 9.9. Differences up to the order of ±10 dB are observed for individual frequencies/microphones. However, no specific microphone or specific frequency band is consistently the poorest. In terms of the single number ratings at the individual microphones, the differences are within the range ±3 dB.

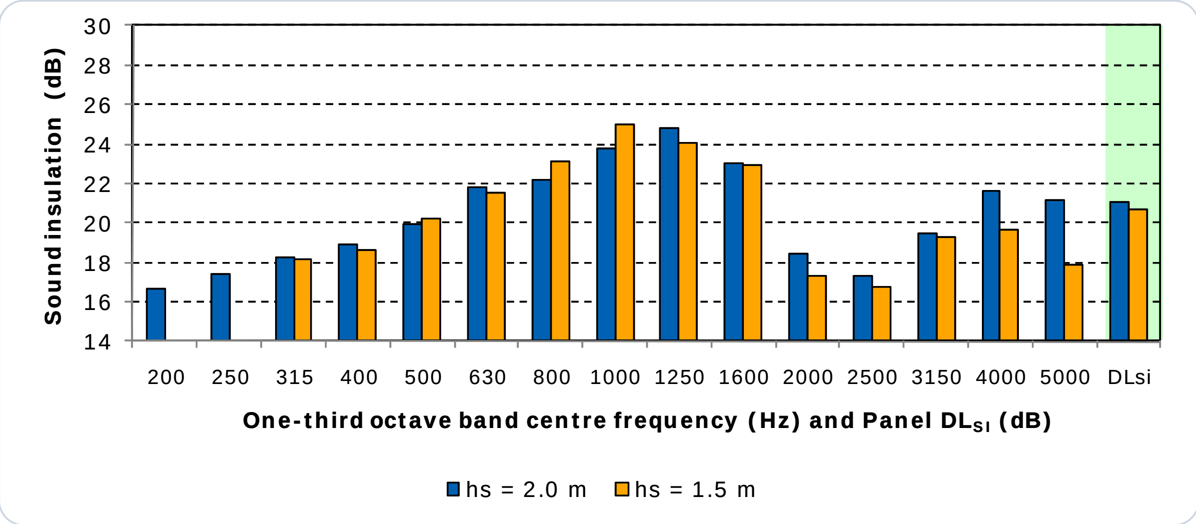


Figure 9.8: Barrier B sound insulation performance (h_s = 2.0 m vs. h_s = 1.5 m)

Table 9.8: Sound insulation indices at individual microphone positions for Barrier B, h_s = 2.0 m

1/3 octave band centre frequency	Sound insulation indices SI for microphone positions P1-P9 & the mean								
	SI_1	SI_2	SI_3	SI_4	SI_5	SI_6	SI_7	SI_8	SI_9	SI
315	19.9	18.3	20.1	17.8	17.1	15.7	20.0	19.7	19.6	18.3
400	21.6	18.7	23.6	19.5	17.4	15.5	24.6	19.0	19.5	18.9
500	15.9	25.0	17.0	23.0	23.4	20.4	19.1	19.5	18.5	19.9
630	17.9	20.9	20.3	25.4	25.7	26.6	20.3	19.5	22.8	21.8
800	25.2	27.1	21.9	20.3	23.9	19.8	23.4	22.2	22.9	22.2
1000	23.1	24.7	21.5	21.9	25.9	25.3	24.0	25.9	23.2	23.8
1250	22.7	22.3	22.0	28.6	26.9	32.0	26.9	24.3	23.7	24.8
1600	20.6	25.9	22.4	26.2	24.5	25.7	21.9	20.0	21.1	23.0
2000	16.3	22.3	16.7	20.9	21.5	19.7	20.5	16.2	14.6	18.4
2500	12.0	20.3	11.3	23.8	25.2	26.7	15.9	17.8	14.5	17.3
3150	18.1	18.4	22.7	25.1	25.4	31.1	13.3	16.8	15.9	19.5
4000	24.7	24.3	16.9	25.7	25.4	23.0	20.0	22.7	15.8	21.6
5000	22.2	21.8	17.3	24.2	25.3	25.6	18.6	20.2	13.8	21.2
DL_{SI} (0.3-5 kHz)	18.9	22.4	18.9	22.4	23.1	21.6	20.6	20.2	19.1	21.0

Table 9.9: Sound insulation indices at individual microphone positions for Barrier B, h_s = 1.5 m

1/3 octave band centre frequency	Sound insulation indices SI for microphone positions P1-P9 & the mean								
	SI_1	SI_2	SI_3	SI_4	SI_5	SI_6	SI_7	SI_8	SI_9	SI
315	23.1	18.7	19.9	20.1	17.4	18.1	19.6	16.6	15.6	18.2
400	25.4	18.9	20.3	21.1	17.5	18.4	20.9	16.8	15.9	18.6
500	19.5	20.2	19.9	20.0	21.2	20.7	19.6	23.5	18.1	20.2
630	19.8	20.3	21.2	20.7	23.8	21.3	20.6	26.0	20.9	21.5
800	21.8	20.7	24.7	22.7	26.2	21.8	22.9	23.9	27.5	23.1
1000	29.1	30.6	30.1	24.9	22.4	25.2	21.7	24.7	27.4	25.0
1250	28.6	23.4	23.1	25.7	21.8	26.5	25.6	22.4	27.2	24.1
1600	24.1	21.2	22.8	26.6	21.0	23.0	23.4	21.8	29.1	22.9
2000	19.7	19.3	13.8	18.2	15.2	14.8	23.4	23.1	20.8	17.3
2500	14.7	21.3	16.2	13.9	17.6	14.6	19.3	20.1	22.7	16.8
3150	12.4	17.7	21.1	15.8	21.6	24.7	20.3	25.7	31.7	19.3
4000	20.2	22.4	14.0	19.0	23.5	16.6	26.5	31.9	21.1	19.7
5000	17.9	18.7	14.0	18.2	18.5	13.9	28.7	24.9	19.6	17.9
DL_{SI} (0.3-5 kHz)	20.5	21.1	19.7	20.5	20.2	19.7	21.9	22.1	21.8	20.7

Figure 9.9 shows Barrier C, the configuration comprising one 2.5 m high panel and one 1.5 m high panel. This asymmetric panel arrangement is increasing in popularity with barrier manufacturers since it offers the greatest logistical benefits in terms of the number of panels that can be transported by a single flatbed articulated truck.

As with Barrier B, there is a horizontal joint present in this configuration, with similar rails and cover strips present.

There were also similar issues with the fitment of the wedges on this barrier, resolved again through the use of small packing wedges.

Figure 9.9: Barrier C (2.5m + 1.5m high panels)

The effect of reducing the height h_s from 2.0 m to 1.5 m is to move the loudspeaker and microphones further away from the horizontal joint.

The results of this assessment are presented in Figure 9.10. In terms of the average single number rating, DL_{SI}, the effect of the change in measurement height was observed to be negligible, being only 0.1 dB. However, in terms of the one-third octave band sound insulation indices, a far greater variation is observed between the two sets of measurements than was seen for the other barriers, for the most part in the range ±2 dB, with no one case resulting in consistently higher levels.

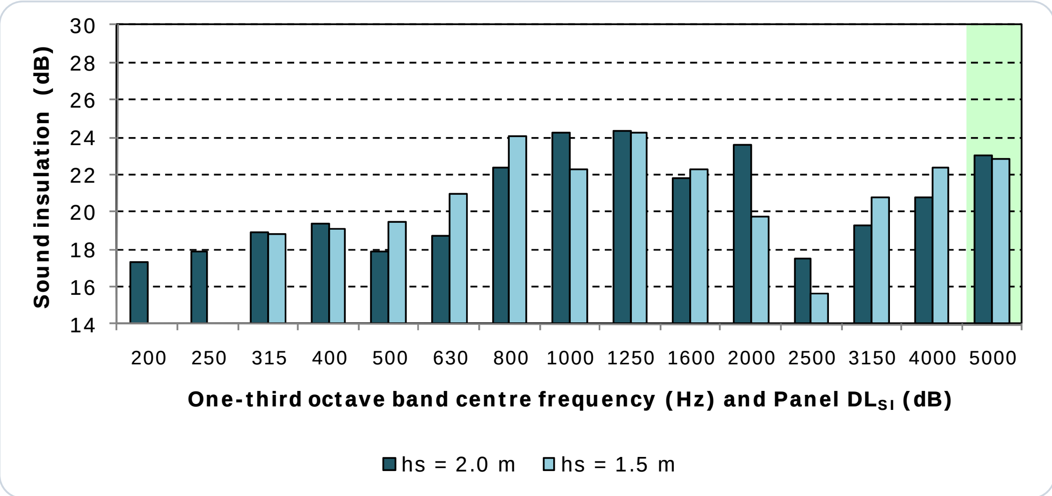


Figure 9.10: Barrier C sound insulation performance (h_s = 2.0 m vs. h_s = 1.5 m)

The individual one-third octave band spectra at each microphone position, are presented in Table 9.10 and Table 9.11. Differences up to the order of ±10 dB are again observed for individual frequencies/microphones. However, no specific microphone or specific frequency band is consistently the poorest. In terms of the single number ratings at the individual microphone positions, these vary within the approximate range ±2 dB.

Table 9.10: Sound insulation indices at individual microphone positions for Barrier B, h_s = 2.0 m

1/3 octave band centre frequency	Sound insulation indices SI for microphone positions P1-P9 & the mean									
	SI_1	SI_2	SI_3	SI_4	SI_5	SI_6	SI_7	SI_8	SI_9	SI
315	21.0	19.8	24.1	20.9	17.7	17.5	19.3	17.9	16.7	18.9
400	26.1	19.0	26.4	23.1	17.0	18.0	23.2	17.7	17.6	19.4
500	14.4	30.0	15.2	17.9	26.7	16.4	17.0	22.4	15.8	17.9
630	19.1	21.2	25.4	15.7	20.0	26.5	15.4	15.5	24.1	18.7
800	27.7	20.6	20.6	26.7	25.1	20.7	25.3	22.9	20.2	22.4
1000	28.1	24.1	24.8	27.7	24.6	23.8	23.3	21.8	23.5	24.2
1250	26.8	25.7	26.0	27.6	22.7	26.5	24.9	20.4	26.2	24.3
1600	19.3	24.9	25.4	20.2	23.0	27.9	17.0	20.3	25.4	21.8
2000	22.0	22.7	21.1	28.8	26.3	23.5	22.5	26.2	20.7	23.6
2500	14.5	23.9	13.9	16.8	20.4	16.3	15.2	23.1	17.4	17.5
3150	13.6	22.9	18.9	16.9	19.5	22.0	20.5	21.1	24.0	19.3
4000	19.3	22.3	19.3	19.0	23.0	18.8	23.8	23.1	22.7	20.8
5000	21.9	27.8	24.1	20.9	25.5	19.0	25.5	28.0	20.1	23.0
DL_{SI} (0.3-5 kHz)	19.9	22.7	20.7	20.9	22.1	21.0	19.7	20.4	20.6	21.0

Table 9.11: Sound insulation indices at individual microphone positions for Barrier B, h_s = 1.5 m

1/3 octave band centre frequency	Sound insulation indices SI for microphone positions P1-P9 & the mean								
	SI_1	SI_2	SI_3	SI_4	SI_5	SI_6	SI_7	SI_8	SI_9	SI
315	25.5	17.0	17.9	23.6	19.8	20.1	22.4	16.0	16.7	18.8
400	33.1	17.0	18.2	26.0	20.1	20.8	24.8	16.0	16.9	19.1
500	17.3	21.3	21.5	18.4	19.2	21.2	16.3	21.6	20.2	19.5
630	18.6	23.1	21.7	19.7	20.6	21.8	17.9	25.4	23.3	21.0
800	27.5	23.6	21.1	24.3	24.3	22.3	28.6	25.4	31.0	24.1
1000	28.3	24.5	24.1	19.7	22.0	21.8	21.1	21.9	25.0	22.3
1250	24.8	19.6	25.9	24.2	25.6	24.9	25.4	26.4	28.9	24.2
1600	18.9	19.1	25.5	23.9	20.4	29.2	21.1	27.1	27.5	22.3
2000	22.9	23.9	21.9	20.7	19.2	15.0	20.7	28.6	19.7	19.8
2500	16.7	22.0	16.5	13.7	17.4	11.6	15.6	25.0	16.2	15.6
3150	19.7	21.0	24.4	16.8	21.1	26.9	18.4	26.3	23.5	20.8
4000	29.0	24.0	25.4	23.3	23.2	17.9	22.1	27.8	21.2	22.4
5000	29.2	30.2	21.6	20.1	24.0	19.0	22.1	28.9	20.3	22.8
DL_{SI} (0.3-5 kHz)	21.7	21.1	21.6	20.3	21.1	19.4	20.5	22.6	21.7	20.9

Conclusions and Recommendations

For each of the barrier configurations assessed, whilst there is variation between the one-third octave band spectra for the different measurement heights, in each case the difference in the single number ratings (calculated using a reduced frequency range of 0.32-5.0 kHz) was observed to be less than 1 dB.

Based on these results, it is concluded that the effects of using a reduced height h_s for the loudspeaker and microphone array are negligible. However, this may not be the case for multi-element barriers where there are no seals used at the horizontal joint between panels. Care should therefore be exercised when selecting the measurement height for in situ assessment depending upon the design of the noise barrier.

9.4 Results and evaluation: The effects of varying panel size combinations for a fixed barrier height

The third phase of the measurements was based around a fixed barrier height of 4.0 m and was designed to compare the effects on sound insulation performance when using different sizes of panel in the construction in order to ascertain whether there might be benefits in using either single or multi-element barriers. Variations in the number and size of the panels used to achieve the full height of the barrier means that the presence and position of horizontal joints in the barrier differs with each design. The three barrier configurations tested, using h_s = 2.0 m, are those shown in Figure 9.1, which can be summarised as follows:

- *Barrier A:* Height = 4.0 m, comprising a single full-height panel.
- *Barrier B:* Height = 4.0 m, comprising two 2 m high panels.
- *Barrier C:* Height = 4.0 m, comprising a lower 2.5 m high panel and an upper 1.5 m high panel.

It is noted that the wedges used to hold the panels in between the posts on both Barriers B and C were not sufficiently thick, so additional small wedges were inserted at several heights in order to try and improve the quality of the seal between panel and post.

Based on the differences between the left and right panels of Barrier A observed in Section 9.2, the average results for Barrier A are used in this comparison, which is presented in Figure 9.11.

In terms of the single number rating, DL_{SI}, both the multi-element panels provide 0.7 dB less sound insulation than the average of the 4 m single panels. In terms of the one third octave band levels, the 4 m high barrier is the best performing barrier across almost all frequency range. However, as already noted such a barrier would not be used in practice as a prefabricated barrier.

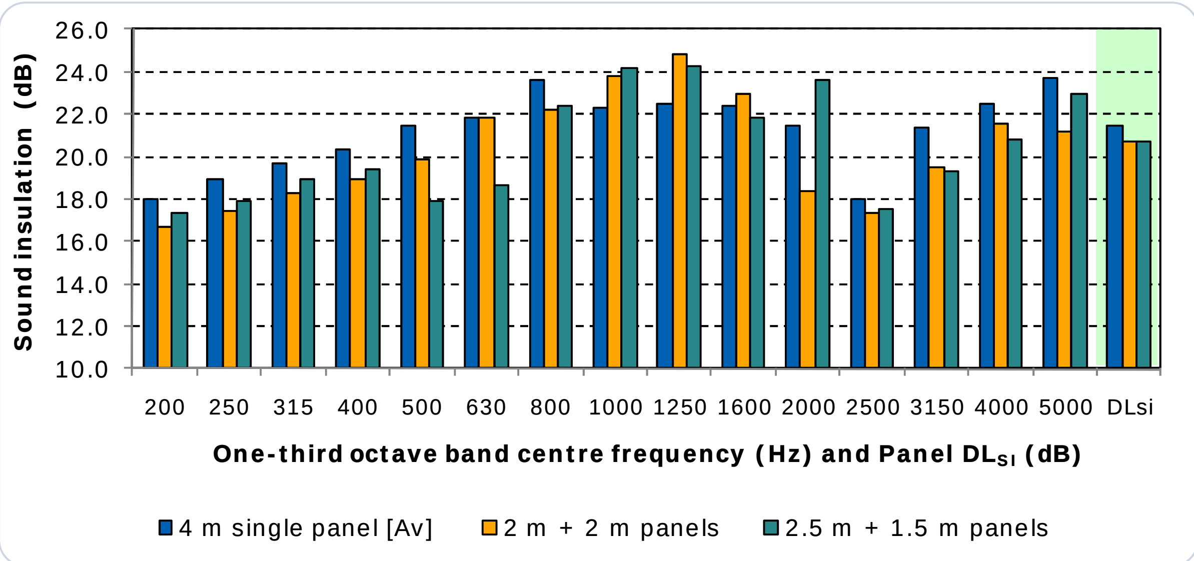


Figure 9.11: Sound insulation performance of 4 m high barriers constructed from different size panel arrangements (Barriers A, B and C)

The individual one-third octave band spectra at each microphone position, are presented in Table 9.12 to Table 9.12.

Table 9.12: Sound insulation indices at individual microphone positions for Barrier A, h_s = 2.0 m (average of left and right panels)

1/3 octave band centre frequency	Sound insulation indices SI for microphone positions P1-P9 & the mean								
	SI_1	SI_2	SI_3	SI_4	SI_5	SI_6	SI_7	SI_8	SI_9	SI
200	17.0	19.3	17.4	17.7	18.7	17.0	17.9	20.3	17.4	18.0
250	17.5	20.9	18.1	18.4	19.9	17.5	18.7	22.0	18.0	18.9
315	21.0	20.3	20.7	18.6	19.1	17.3	21.5	22.4	20.2	19.7
400	25.7	20.0	23.0	19.1	18.9	17.2	24.5	22.7	21.7	20.4
500	22.5	20.1	21.1	25.6	25.2	20.2	21.8	23.1	17.8	21.4
630	18.4	22.0	20.0	25.0	25.1	26.9	20.3	22.6	19.4	21.9
800	22.1	23.5	21.6	27.5	24.8	24.7	23.6	23.4	22.0	23.6
1000	21.7	21.9	21.7	22.4	22.6	23.6	25.4	20.9	21.9	22.3
1250	21.9	21.0	21.3	21.7	23.8	24.8	24.7	21.7	23.5	22.5
1600	21.5	21.2	19.7	24.3	25.2	23.9	22.5	21.1	23.1	22.4
2000	18.4	20.7	18.1	24.1	26.0	23.0	22.0	21.8	19.7	21.5
2500	12.8	18.8	13.0	23.1	25.1	23.3	16.7	20.9	13.8	18.0
3150	18.1	23.1	17.8	22.2	27.4	23.6	17.3	23.1	17.2	21.3
4000	20.9	21.8	18.4	23.3	30.4	23.1	22.4	26.3	18.3	22.5
5000	20.1	26.1	20.0	23.5	28.5	24.2	20.2	26.6	20.6	23.7
DL_{SI} (0.2-5 kHz)	19.6	21.2	19.4	22.4	23.2	21.9	21.6	22.0	19.8	21.4

Table 9.13: Sound insulation indices at individual microphone positions for Barrier B, h_s = 2.0 m

1/3 octave band centre frequency	Sound insulation indices SI for microphone positions P1-P9 & the mean								
	SI_1	SI_2	SI_3	SI_4	SI_5	SI_6	SI_7	SI_8	SI_9	SI
200	16.5	17.4	16.0	15.9	16.4	15.9	15.9	19.3	17.9	16.7
250	17.3	18.1	16.5	16.3	17.0	16.5	16.6	21.4	19.5	17.4
315	19.9	18.3	20.1	17.8	17.1	15.7	20.0	19.7	19.6	18.3
400	21.6	18.7	23.6	19.5	17.4	15.5	24.6	19.0	19.5	18.9
500	15.9	25.0	17.0	23.0	23.4	20.4	19.1	19.5	18.5	19.9
630	17.9	20.9	20.3	25.4	25.7	26.6	20.3	19.5	22.8	21.8
800	25.2	27.1	21.9	20.3	23.9	19.8	23.4	22.2	22.9	22.2
1000	23.1	24.7	21.5	21.9	25.9	25.3	24.0	25.9	23.2	23.8
1250	22.7	22.3	22.0	28.6	26.9	32.0	26.9	24.3	23.7	24.8
1600	20.6	25.9	22.4	26.2	24.5	25.7	21.9	20.0	21.1	23.0
2000	16.3	22.3	16.7	20.9	21.5	19.7	20.5	16.2	14.6	18.4
2500	12.0	20.3	11.3	23.8	25.2	26.7	15.9	17.8	14.5	17.3
3150	18.1	18.4	22.7	25.1	25.4	31.1	13.3	16.8	15.9	19.5
4000	24.7	24.3	16.9	25.7	25.4	23.0	20.0	22.7	15.8	21.6
5000	22.2	21.8	17.3	24.2	25.3	25.6	18.6	20.2	13.8	21.2
DL_{SI} (0.2-5 kHz)	18.8	21.9	18.7	21.6	22.3	21.0	20.2	20.2	19.0	20.7

Table 9.14: Sound insulation indices at individual microphone positions for Barrier C, h_s = 2.0 m

1/3 octave band centre frequency	Sound insulation indices SI for microphone positions P1-P9 & the mean									
	SI_1	SI_2	SI_3	SI_4	SI_5	SI_6	SI_7	SI_8	SI_9	SI
200	16.1	20.9	19.1	17.4	19.1	16.4	15.5	17.7	15.2	17.3
250	16.8	22.6	20.0	18.2	20.1	16.5	16.1	18.7	15.4	17.9
315	21.0	19.8	24.1	20.9	17.7	17.5	19.3	17.9	16.7	18.9
400	26.1	19.0	26.4	23.1	17.0	18.0	23.2	17.7	17.6	19.4
500	14.4	30.0	15.2	17.9	26.7	16.4	17.0	22.4	15.8	17.9
630	19.1	21.2	25.4	15.7	20.0	26.5	15.4	15.5	24.1	18.7
800	27.7	20.6	20.6	26.7	25.1	20.7	25.3	22.9	20.2	22.4
1000	28.1	24.1	24.8	27.7	24.6	23.8	23.3	21.8	23.5	24.2
1250	26.8	25.7	26.0	27.6	22.7	26.5	24.9	20.4	26.2	24.3
1600	19.3	24.9	25.4	20.2	23.0	27.9	17.0	20.3	25.4	21.8
2000	22.0	22.7	21.1	28.8	26.3	23.5	22.5	26.2	20.7	23.6
2500	14.5	23.9	13.9	16.8	20.4	16.3	15.2	23.1	17.4	17.5
3150	13.6	22.9	18.9	16.9	19.5	22.0	20.5	21.1	24.0	19.3
4000	19.3	22.3	19.3	19.0	23.0	18.8	23.8	23.1	22.7	20.8
5000	21.9	27.8	24.1	20.9	25.5	19.0	25.5	28.0	20.1	23.0
DL_{SI} (0.2-5 kHz)	19.6	22.7	20.6	20.7	21.9	20.5	19.3	20.2	20.1	20.7

Differences up to the order of ±8 dB are again observed for individual frequencies/microphones comparing Barrier A (the average of the left and right panels) and B, and up to ±10 dB for Barrier A (the average of the left and right panels) and Barrier C. However, no specific microphone or specific frequency band is consistently the poorest. In terms of the single number ratings of sound insulation, the differences are ±3 dB between Barriers A and B as well as between Barriers A and C.

Comparing the spectral performance for the multi-panel configurations B and C alone, the differences in the sound insulation indices are generally less than 1 dB; the exceptions occur around the 500 and 630 Hz bands and around the 2 kHz band. Moving the height of the horizontal joint from 2.0 m to 2.5 m above ground appears to offer an increased sound insulation across some frequency bands, but this most likely due to the lower position being directly opposite the loudspeaker being directly opposite the joint. However, this is not reflected when comparing the spectral performance at individual microphone positions. In terms of the single number ratings, the differences are generally in the range ± 2 dB.

Conclusions and Recommendations

The results suggest that the full height single panel does not provide significantly better sound insulation than the designs comprising multiple panels with a horizontal joint. Shifting the position of the horizontal joint does not offer a consistent benefit in sound insulation performance over the full frequency range.

10 Suitability appraisal of the prEN 1793-6 test method for use on England’s strategic road network

The test methodology prescribed in CEN/TS 1793-5 and prEN 1793-6 has been applied in the current project both at the roadside and on purpose-built test-facilities. The following text assesses the suitability of the method for routine use and asset management on the Highways Agency’s strategic road network.

It is noted that further work is required to improve understanding of the reproducibility/ repeatability/uncertainties of the method and that at the current time, it is considered to early to be able to specify uncertainties/accuracies/ tolerances in specifications, tender documents, etc.

Overall, it is considered that the test methodology is well-suited for in situ application, is relatively straightforward to undertake with appropriate test apparatus (it is noted that specialist measurement and analysis systems are required) and, with care, can be used under a wide variety of site conditions, e.g. flat ground, embankments, etc. The nature of the acoustic signals used to provide the noise source means that measurements are unaffected by the presence of traffic, which is of particular importance when assessing barriers on the side of the motorway. The measurements can be performed on barriers at least 3 m in height without the results being affected by the presence of the safety barrier (as shown in Chapter 6). It is recommended that barriers lower than 3 m high should not be assessed unless there is no adjacent safety barrier.

It is considered that the method could in the future provide an important asset management tool to the Agency, although for this to be the case, the provision of a centralised, high quality database for measurement data will also be required (see Section 4.10).

Significantly, the factors that most affect the potential use of the method as a routine assessment/asset management tool are unrelated to the process of the method itself and are more practical/logistical issues. It is recognised that these have significant implications in terms of both the *scheduling* of assessments and in the *direct and indirect costs* associated with the physical undertaking of the assessments. The issues can be summarised as follows:

Road space and traffic management

The forward planning for undertaking in situ measurements is a significant factor since hard shoulder closures will always be required on motorways, meaning that measurements cannot generally be undertaken at short notice (the circumstances for testing on ‘A’ roads are considered later in the Chapter). Works require prior booking of both road space and traffic management, generally between 2-8 weeks in advance and road space cannot be granted when within 5 km of other works.

It is anticipated that any conformity-of-production type measurements would be performed within the traffic management scheme under which the barrier is installed; however, as has been observed in this study, even this is not always possible since the measurements may obstruct safe access/passage through the TM by other users.

Health and safety requirements/training for the individual Highways Agency Areas are an additional factor that can impact upon the scheduling process.

The need for traffic management also has cost implications for routine monitoring. The costs of TM have been observed to vary from one Area to another by a significant amount. The ability to cancel TM without any financial penalty when measurements have to be postponed due to adverse weather (as has frequently been the case during the current project) is considered crucial if the method is to be used routinely.

Access and working space

Access to both sides of the barrier as well is required to perform the measurements. Clear working space is also required to provide a safe working environment for the measurement team and to minimise the occurrence of parasitic reflections within the measurement time window.

A high percentage of barriers on the network have no easy access to the rear of the barrier, e.g. via emergency access gates, preventing assessment. Even where access is available either through access gates or round the end of the barrier, this can often be obstructed by undergrowth; environmental assessments may be necessary to determine the likely impacts of clearance. This has both scheduling and cost implications.

The visual inspections undertaken for this project have identified that at sites where the barriers have been in place for some time, trees, bushes and undergrowth frequently grow right up against the barrier. Again, environmental assessments may be required before any work can be carried out.

It is noted that it appears common practice to plant trees behind newly installed barriers to reduce visual intrusion in the medium-long term. If routine assessments of sound insulation performance are to be carried out on the network, such practices might have to be reviewed or regular maintenance of vegetation be carried out.

Site conditions

Based on site conditions experienced within the current project, the undertaking of measurements on barriers with a height of 4 m or greater using the same loudspeaker/ microphone heights as during product certification cannot always be easily achieved, particularly when the ground behind the barrier is either not flat or at a different level to the road. However, it is considered that this problem could be overcome with careful selection/design of measurement apparatus. Some of the sites tested in the current project have required the measurement team to use safety lines/harnesses to secure both themselves and the measurement apparatus.

Application of the method at non-motorway sites

The present study has been restricted to motorway locations with hard shoulder working. Based on the observations above, it is considered that further investigations are required to assess the feasibility of using the method for the assessment of barriers on non-motorway roads where hard shoulders are less common and any verge space between the running lanes and noise barriers is limited. This is because lane closures are unlikely to be granted for such work during daytime hours. The considerations regarding road space and access will still be applicable.

11 Conclusions and recommendations

Presently, timber barriers are one of the most common mitigation measures against noise arising from traffic on England's strategic road network (SRN). Barriers installed on the SRN must not only fulfil their acoustic function and structural design requirements in accordance with the Highways Agency's Specification for Highway Works, but also maintain their performance for a reasonably long life. The Agency's technical design guide, HA 66/95 (Highways Agency *et al.*, 2001), stipulates that all types of noise barriers, including acoustic timber screens, should remain serviceable for 40 years and not require maintenance for 20 years.

Currently, the Agency's specifications require that the acoustic performance of any barriers to be installed on the SRN must have been assessed, as appropriate, in accordance with EN 1793-1 and EN 1793-2 which assess sound absorption and airborne sound insulation respectively. However, these are only concerned with the acoustic performance of the barriers when new, and are unsuitable for in situ application or for routine assessments of acoustic durability.

The Agency therefore commissioned TRL to undertake a study of timber noise barriers on the SRN using recently developed methods for performing in situ (roadside) assessments of airborne sound insulation, as prescribed in the forthcoming standard EN 1793-6. The objective was to provide indications on the long-term acoustic durability of different types of timber noise barrier which might be used in future Agency specifications and for CE marking.

In undertaking this task, the work has also highlighted a range of other key issues associated with the practical application of the method at the roadside and its potential future use by the Agency as an asset management tool, as well as deficiencies in the Agency's current asset management strategies.

The following conclusions and related recommendations, guidance and advice have been drawn from the findings and results of the study.

Initial data availability and asset management

The selection process highlighted that the level of location and technical information held by any single source was highly variable and that there is little consistency between the data sources. This lack of data hindered the selection of candidate barriers for roadside testing and meant that it was not possible to identify all sites prior to the commencement of the measurement programme.

The selection procedure highlighted the lack of a comprehensive, centrally held database of noise barrier records within the Highways Agency. The existing Agency asset management record system EnvIS already provides the necessary mechanism for such a database.

It is recommended that any future revision of EnvIS should, as a minimum, include the addition of suitable noise-barrier related fields covering all aspects of location, design and performance.

The acoustic durability of timber noise barriers

Whilst, the selection of roadside barriers assessed in the test programme is only a limited sample of all of the barriers installed on the SRN, the ages of the barriers suggests that there has been a shift in the last 5-6 years in terms of the type of barrier being installed. This shift suggests a decline in the installation of single-leaf reflective barriers with either double-leaf reflective of sound absorptive barriers becoming the preferred choice.

It was not possible to restrict the assessment to barriers of a common, consistent design and construction. Panel widths/post separations were observed to vary from barrier to barrier, with a range of 2.4-3.0 m. Post thicknesses and panel constructions also varied significantly.

The final candidate barrier group to be assessed using the Part 6 method comprised 18 single-leaf reflective barriers (14 roadside and 4 test facility), 5 double-leaf reflective barriers (3 roadside and 2 test facility) and 8 single-leaf sound absorptive barriers (6 roadside barriers and 2 test facility barriers). In addition, the results have been supplemented with data from previous TRL studies using the same test method.

At the conclusion of the project, taking into account cancellations resulting from unsuitable weather conditions and the unavailability of road space, the following numbers of roadside barriers have been assessed: 11 single-leaf reflective, 4 sound absorptive barriers and 2 double-leaf reflective barriers.

In the absence of confirmed data for the majority of roadside barriers, assumptions have been made regarding the initial sound insulation performance based on discussions with industry experts. Where these barriers were site assembled constructions, the changes in acoustic performance over time suggest the possibility that the real initial performance is likely to have been less than observed in laboratory certified panels of the same design.

Overall, the results would suggest that for single-leaf reflective barriers, any degradation in acoustic performance occurs during the first 5 years after construction. Depending upon the initial performance, this decrease appears to be of the order of 4-7 dB. Performance would appear to remain relatively stable thereafter for at least the next 5 years, the limit of the current dataset. Similarly, the results for sound absorptive barriers suggest an average decrease in sound insulation performance of 7 dB after 5 years, although in this case the scatter of measurement results is significant. There is insufficient data to define more robust relationships for either type of barrier. Additionally, there is insufficient data to draw conclusions in relation to double-leaf reflective barriers.

The effect of safety barriers on roadside prEn 1793-6 measurements

Based on the results of measurements taken on the TRL noise barrier test facility, it is concluded that the presence of a safety fence has no significant effect on the acoustic performance of a noise barrier when assessed in accordance with EN 1793-6.

As such, it is considered that the EN 1793-6 test method can be applied at the roadside without modification on barriers *with a minimum height of 3.0 m*, without the need to temporarily remove or modify any safety fence installed in close proximity to the noise barrier.

The effect of moisture content on early life sound insulation performance

Measurements show that the moisture content levels in pressure treated timber can decrease by as much as 25% as a result of drainage/evaporation of water in the preservative in the first 3-4 weeks after treatment. In that same time period, the airborne sound insulation performance, DL_{SI}, assessed in accordance with prEN 1793-6 reduces by approximately 8-10 dB as a result of this effect. Similar changes in performance are likely to be observed when testing in accordance with EN 1793-2.

These changes could have a potentially significant effect on the performance rating of the barrier when described using the B and D classes in Part 2 and 6 respectively, potentially resulting in inappropriate noise barriers being selected for installation under current Highways Agency procurement conditions.

It is recommended that future certification of timber noise barrier products in accordance with either prEN 1793-6 or EN 1793-2 should not be taken until at least 4 weeks after the timber from which the barrier is manufactured has been treated with preservative.

The effect of variations in certification and in situ assessment geometry

For each of the barrier configurations assessed, whilst there is variation between the one-third octave band spectra for the different measurement heights, in each case the difference in the single number ratings (calculated using a reduced frequency range of 0.32-5.0 kHz) was observed to be less than 1 dB.

Based on these results, it is concluded that the effects of using a reduced height h_s for the loudspeaker and microphone array are negligible. However, this may not be the case for multi-element barriers where there are no seals used at the horizontal joint between panels. Care should therefore be exercised when selecting the measurement height for in situ assessment depending upon the design of the noise barrier.

Suitability of the test method for use on England's strategic road network

Overall, it is considered that the test methodology defined in prEN 1793-6 is well-suited for in situ (roadside) application, is relatively straightforward to undertake with appropriate test apparatus and, with care, can be used under a wide variety of site conditions. Measurements are unaffected by varying levels of traffic and can be performed on barriers at least 3 m in height without the results being affected by the presence of the safety barrier. It is recommended that barriers lower than 3 m high should not be assessed unless there is no adjacent safety barrier.

Based upon practical experience at the roadside, it appears that positioning of the test apparatus with an accuracy of ±10 mm should be readily achievable during free-field measurements. Once the position of the axis between the loudspeaker and microphone P5 has been determined on the faces of the barrier for the transmission measurements, positioning of the test apparatus with an accuracy of ±10 mm should be readily achievable.

It is considered that the method could provide an important asset management tool to the Agency, although for this to be the case, the provision of a centralised, high quality database for measurement data will also be required.

Significantly, the factors that most affect the potential use of the method as a routine assessment/asset management tool are unrelated to the method itself and are more practical/logistical issues relating to road space availability, traffic management, and levels of vegetation behind the barrier. These will have significant implications in terms of both the *scheduling* of assessments and in the *direct and indirect costs* associated with the physical undertaking of the assessments.

The present study has been restricted to motorway locations with hard shoulder working. Further investigations are required to assess the feasibility of using the method for the assessment of barriers on non-motorway roads where hard shoulders are less common, any verge space between the running lanes and noise barriers is limited and the opportunities for daytime lanes closures are unlikely.

11.1 Recommendations: Addressing gaps in current knowledge

The following proposals for further work are made on the basis of the above conclusions.

- A comprehensive network survey of barriers installed on the SRN should be undertaken to determine data for the characteristics outlined in Section 4.10, namely barrier type and construction, location and information on what the barrier is protecting, the date of installation and details of the installation scheme, the date of the acoustic element manufacture (if significantly different from date of installation), details of the manufacturer and/or installer, initial acoustic performance characteristics, monitored acoustic performance characteristics, and physical condition reports.

  Where necessary, historical Agency records should be reviewed to determine the date of installation. It is noted that Part 6 performance data is unlikely to be unavailable for existing barriers. In such cases, the initial performance based on the current laboratory tests should be stated.

  It is recommended that a revision of the EnvIS database be undertaken to include fields for the storage of this information, so that comprehensive data can be held centrally within the Agency.

- A review of current HA procurement procedures and liaise with barrier manufacturers is recommended to establish whether the implied shift from the use of single-leaf reflective to absorptive or double-leaf reflective barriers is real and commonplace and restricted to the motorway part of the SRN or whether it is common across the whole of the SRN, i.e. motorways and trunk roads.

- An investigation is recommended to determine whether Agency contract requirements or specification requirements can be introduced to encourage wider use of prefabricated noise barrier products in order to improve build quality and ensure value for money.

The following recommendations address technical issues that have arisen as part of the current research and which would potentially enhance the application of the Part 6 method.

- The current study has been restricted to the assessment of noise barriers installed on the motorway part of the Strategic Road Network. It is recommended that an assessment be undertaken to evaluate the practicalities of performing Part 6 assessments on non-motorway roads, where hard shoulders are less common, any verge space between the running lanes and noise barriers is limited and lane closures are unlikely to be granted during daytime hours.

- At the current time, it is considered to early to be able to specify uncertainties/accuracies/ tolerances in specifications, tender documents, etc. Further work is required to improve understanding of the reproducibility/

repeatability/uncertainties of the method, although it is expected that information on these issues will result from the European 7th Framework project QUIESST.

Acknowledgements

The work described in this report was carried out in the Noise and Vibration Group of the Transport Research Laboratory. The authors is grateful to the following individuals: Mike Ainge who carried out the technical review and auditing of this report; Kate Avery, Ruth Mellon and Dani Myers for organising the tests and assisting with the practical measurements; Mike Ainge, Katharine Boddington, Clare Harmer, Shaneen Khambata, Jenny Vestey, Matthew Muirhead, Louise Morris, Adam Parrett and Geraldine Trufil-Fulcher for assisting with the practical measurements; Michelle Clifton for assisting with the test site selection; Peter Walters; David White and staff at Charles Ransford and Sons Ltd;

References

Adrienne Research Team (1998). *Test method for the acoustic performance of road traffic noise reducing devices, Final Report.* SMT Project MAT1-CT94049.

BSI (1986). *BS 6579-5:1986. Safety fences and barriers for highways. Part 5: Specification for open box beam safety fence (single height).* London, UK: British Standards Institution.

BSI (1987). BS 4072-2:1987. *Wood preservation by means of copper/chromium/arsenic preparations. Part 2: method for timber treatment.* London, UK: British Standards Institution.

BSI (1998a). *BS 1793-1:1998. Road traffic noise reducing devices - Test method for determining the acoustic performance. Part 1: Intrinsic characteristics of sound absorption.* London, UK: British Standards Institution.

BSI (1998b). *BS 1793-2:1998. Road traffic noise reducing devices - Test method for determining the acoustic performance. Part 2: Intrinsic characteristics of airborne sound insulation.* London, UK: British Standards Institution.

BSI (1998c). *BS 1793-3:1998. Road traffic noise reducing devices – Test method for determining the acoustic performance. Part 3: Normalised traffic noise spectrum.* London, UK: British Standards Institution.

BSI (1999). BS 4072:1999. *Copper/chromium/arsenic preparations for wood preservation.* London, UK: British Standards Institution.

BSI (2003a). *BS CEN/TS 1793-5:2003. Road traffic noise reducing devices – Test method for determining the acoustic performance. Part 5: Intrinsic characteristics of in situ values of sound reflection and airborne sound insulation.* London, UK: British Standards Institution.

BSI (2003b). BS EN 8417:2003. *Preservation of timber: Recommendations.* London, UK: British Standards Institution.

BSI (2004). *BS EN 14389-2:2004. Road traffic noise reducing devices – Procedures for assessing long-term performance. Part 2: Non-acoustical characteristics.* London, UK: British Standards Institution.

BSI (2005). *BS EN 14388:2005. Road traffic noise reducing devices – Specifications.* London, UK: British Standards Institution.

BSI (2007). *BS EN 14389-1:2007. Road traffic noise reducing devices – Procedures for assessing long-term performance. Part 1: Acoustical characteristics.* London, UK: British Standards Institution.

CEN (2010). *prEN 1793-6:2010. Road traffic noise reducing devices - Test method for determining the acoustic performance. Part 6: Intrinsic characteristics – In situ values of airborne sound insulation under direct field conditions [Working draft].* Brussels, Belgium: European Committee for Standardisation.

European Commission (2002). Directive 2002/49/EC of the European Parliament and of the Council relating to the assessment and management of environmental noise. *Official Journal of the European Commission*, L189/12. Brussels, Belgium: Commission of the European Communities.

Garai, M. and Guidorzi, P. (2000). European methodology for testing the airborne sound insulation characteristics of noise barriers in situ: Experimental verification and comparison with laboratory data. *Journal of the Acoustical Society of America* 103(3) pt1.

Garai, M. and Guidorzi P. (2008). In situ measurements of the intrinsic characteristics of the acoustic barriers installed along a new high speed railway line. *Noise Control Engineering Journal* 56(5), 342-355.

Highways Agency (undated #1). Manual of Contract Documents for Highway Works, Volume 1, Series 100: Preliminaries [online]. [Accessed May 2010]. Available from World Wide Web: http://www.standardsforhighways.co.uk/mchw/vol1/pdfs/series_0100.pdf

Highways Agency (undated #2). *Manual of Contract Documents for Highway Works. Volume 1, Series 300: Fencing* [online]. [Accessed May 2010]. Available from World Wide Web: http://www.standardsforhighways.co.uk/mchw/vol1/pdfs/series_0300.pdf

Highways Agency (undated #3). *Manual of Contract Documents for Highway Works. Volume 1, Series 2500: Special Structures* [online]. [Accessed May 2010]. Available from World Wide Web:
http://www.standardsforhighways.co.uk/mchw/vol1/pdfs/series_2500.pdf

Highways Agency (undated #4). *Manual of Contract Documents for Highway Works. Volume 2, Series NG 2500: Special Structures* [online]. [Accessed May 2010]. Available from World Wide Web:
http://www.standardsforhighways.co.uk/mchw/vol2/pdfs/series_ng_2500.pdf

Highways Agency (1996). *Trunk Road Maintenance Manual. Volume 2: Routine and Winter maintenance code.* London: The Stationary Office.

Highways Agency (2003). *Area Management Memo No. 43: Prioritisation of category 2, 3 and 4 noise mitigation sites, 18th December 2003* [online]. [Accessed May 2010]. Available from World Wide Web:
http://www.highways.gov.uk/aboutus/documents/AMM_2043_2003.pdf

Highways Agency (2006). *Design Manual for Roads and Bridges. Volume 2, Section 2, Part 8: Requirement for road restraint systems (TD 19/06)* [online]. [Accessed May 2010]. Available from World Wide Web:
http://www.standardsforhighways.co.uk/dmrb/vol2/section2/td1906.pdf

Highways Agency (2007). *Interim Advice Note 84 Part 1: Highways Agency environmental information system* [online] [Accessed May 2010]. Available from World Wide Web: http://www.standardsforhighways.co.uk/ians/pdfs/ian84.pdf

Highways Agency (2009). *Network management manual, Version 1, Amendment 8, Part 2: Asset management records* [online]. [Accessed May 2010]. Available from World Wide Web:http://www.ha-partnernet.org.uk/minisite/PNET_UI/NMM/V1%208%20Part%202.pdf

Highways Agency, Scottish Office Development Department, Welsh Office and Department Of The Environment for Northern Ireland (1985). *Design Manual for Roads and Bridges. Volume 2, Section 2, TD19/85: Safety fences and barriers [online].* [Accessed May 2010]. Available from World Wide Web: http://www.highways.gov.uk/aboutus/documents/annex_3(2).pdf

Highways Agency, Scottish Executive Development Department, National Assembly For Wales and Department For Regional Development (2001a). *Design Manual for Roads and Bridges. Volume 10, Section 5, Part 1: Design for Environmental Barriers (HA 65/94)* [online]. [Accessed May 2010]. Available from World Wide Web: http://www.standardsforhighways.co.uk/dmrb/vol10/section5/ha6594.pdf.

Highways Agency, Scottish Executive Development Department, National Assembly For Wales and Department For Regional Development (2001b). *Design Manual for Roads and Bridges. Volume 10, Section 5, Part 2: Environmental barriers: Technical Requirements (HA 66/95)* [online]. [Accessed May 2010]. Available from World Wide Web: http://www.standardsforhighways.co.uk/dmrb/vol10/section5/ha6695.pdf

Highways Agency, Transport Scotland, Welsh Assembly Government and the Department for Regional Development (2007). *Design manual for roads and bridges. Volume 3, Section 2, Part 4: Inspection of highway structures (BD 63/07)* [online]. [Accessed May 2010]. Available from World Wide Web: http://www.standardsforhighways.co.uk/dmrb/vol3/section1/bd6307.pdf

Morgan, P. A. (2010). *Technical annex to PPR490: The acoustic durability of timber noise barriers on England's strategic road network.* Crowthorne: Transport Research Laboratory.

NRA (2009). *Manual of Contract Documents for Road Works. Volume 1: Specification for roadworks* [online] [Accessed May 2010]. Dublin, Ireland: National Roads Authority. Available from World Wide Web: http://www.nra.ie/RepositoryforPublicationsInfo/file,16134,en.pdf

UKAS (2009). *National Highways Sector Schemes for quality management in highway works: 2C- For the design, supply, installation and repair of environmental barriers (structural) for infrastructure works (NHSS 2C)* [online] [Accessed May 2010]. Feltham: United Kingdom Accreditation Service. Available from World Wide Web: http://www.ukas.com/library/Technical-Information/Pubs-Technical-Articles/Pubs-List/NHSS%202C%20July%202009.pdf

Walters, P. G. (2010). Private communication with Peter Walters, 21st January 2010.

Watts, G. R. (1997). In situ method for determining the transmission loss of noise barriers. *Applied Acoustics* 51(4), pp. 421-438.

Watts, G. and Morgan, P. (2005). *Validation of BS CEN/TS 1793-5 for the measurement of the airborne sound insulation of timber noise barriers* (PPR 040). Crowthorne, UK: Transport Research Laboratory.

Watts, G. and Surgand, M. (2001). *Sound transmission tests on M20 noise barriers for Union Railways, October 2001* (PR/SE/385/2001). Crowthorne, UK: Transport Research Laboratory.

Glossary of terms and abbreviations

ADRIENNE	Project Acronym: Test method for the acoustic performance of road traffic noise reducing devices
BSI	British Standards Institution
CE	Conformité Européene (European Conformity), as in “CE marking”
CEN	European Committee for Standardisation, Brussels, Belgium
Defra	Department for Environment, Food and Rural Affairs
DMRB	Design Manual for Roads and Bridges
EC	European Commission
EnvIS	Environmental Information System
EU	European Union
HAPMS	Highways Agency Pavement Management System
ISO	International Organisation for Standardisation
MA	Managing Agent
MCDRW	Manual of Contract Documents for Road Works, Ireland
NHSS	National Highway Sector Scheme
NMM	Network Management Manual
NRA	National Roads Authority, Ireland
OBB	Open Box Beam (Safety Fence)
Part 1	EN 1793:1. Road traffic noise reducing devices - Test method for determining the acoustic performance. Part 1: Intrinsic characteristics of sound absorption
Part 2	EN 1793:2. Road traffic noise reducing devices - Test method for determining the acoustic performance. Part 2: Intrinsic characteristics of airborne sound insulation
Part 5	EN 1793:5. Road traffic noise reducing devices – Test method for determining the acoustic performance. Part 5: Intrinsic characteristics of in situ values of sound reflection and airborne sound insulation
Part 6	prEN 1793:6. Road traffic noise reducing devices - Test method for determining the acoustic performance. Part 6: Intrinsic characteristics – In situ values of airborne sound insulation under direct field conditions
PSA	Public Service Agreement
QUIESST	Project acronym: Quietening the environment for a sustainable surface transport (www.quiesst.eu)
SHW	Specification for Highway Works
SMIS	Structures Management Information System
SRN	Strategic Road Network
TM	Traffic Management

TRL	Company Name: Transport Research Laboratory
TRMM	Trunk Road Maintenance Manual
UKAS	United Kingdom Accreditation Scheme

Glossary of units and symbols

Δf_i	Width of the j^{th} one third octave frequency band (CEN/TS 1793-5 and prEN 1793-6)
ρ	Density (kg/m^3)
A	Cross-sectional area of noise barrier panel
dB	Decibel
c	Speed of sound in air
$d_i(t)$	Geometrical spreading correction factor for the reference free-field component (CEN/TS 1793-5)
$d_k(t)$	Geometrical spreading correction factor for the transmitted component at the k^{th} scanning point (CEN/TS 1793-5)
DL_R	Single number rating of sound insulation in dB (EN 1793-2)
DL_{SI}	Single number rating of sound insulation in dB (CEN/TS 1793-5 and prEN 1793-6)
$DL_{SI,G}$	Global single number rating of sound insulation (the average of measurements on a panel and a post) in dB (prEN 1793-6)
$DL_{SI,E}$	Single number rating of sound insulation for panels/acoustic elements (the average of measurements on a panel and a post) in dB (prEN 1793-6)
$DL_{SI,P}$	Single number rating of sound insulation for posts (the average of measurements on a panel and a post) in dB (prEN 1793-6)
f	Frequency
f_c	Critical frequency
F	Fourier transform
$h_i(t)$	Incident reference component of a free-field impulse response (CEN/TS 1793-5)
$h_{ik}(t)$	Incident reference component of the free-field impulse response at the k^{th} scanning point (prEN 1793-6)
$h_{tk}(t)$	Transmitted component of the impulse response at the k^{th} scanning point (CEN/TS 1793-5 and prEN 1793-6)
j	Index of the j^{th} one-third octave frequency band (between 100 Hz and 5 kHz)
k	Wavenumber = (2πf/c)
L_i	Relative A-weighted sound pressure level, in dB, of the normalised traffic noise spectrum as defined in BS EN 1793-3 for the corresponding ith one third octave band
m_1, m_2	Sample masses for determination of moisture content: m_1 = wet mass; m_2 = dry mass (grams)
MC	Moisture content (percent)
n	Number of scanning points (CEN/TS 1793-5 and prEN 1793-6)

R_i	Sound reduction index in the i^{th} one-third octave band, determined in accordance with EN 1793-2
SI_j	Sound insulation index in the j^{th} one-third octave band, determined in accordance with EN 1793-5 and prEN 1793-6
t_B	Noise barrier thickness (CEN/TS 1793-5 and prEN 1793-6)
t	Thickness
$U(\Omega)$	Shape factor correction
$w_i(t)$	Reference free-field component time window, using an Adrienne temporal time window (CEN/TS 1793-5)
$w_{ik}(t)$	Reference free-field component time window, using an Adrienne temporal window, at the k^{th} scanning point (prEN 1793-6)
$w_{tk}(t)$	Time window, using an Adrienne temporal window, for the transmitted component at the k^{th} scanning point (CEN/TS 1793-5 and prEN 1793-6)

The acoustic durability of timber noise barriers on England's strategic road network

Timber noise barriers are one of the most common mitigation measures against traffic noise on England's Strategic Road Network. They are required not only to fulfil their acoustic function and structural design requirements in accordance with Highways Agency specifications, but also to retain their performance for a reasonably long life. The Agency's technical design guide, HA 66/95, stipulates that noise barriers should remain serviceable for 40 years and not require maintenance for 20 years.

Currently the Agency requires acoustic performance to have been assessed using recognised, standardised laboratory tests (EN 1793-1:1998 and EN 1793-2:1998) as appropriate to the barrier type. However, the Agency's specifications are only concerned with the performance of the barriers in new condition.

This report presents the results of a study commissioned by the Agency to investigate the acoustic durability of timber noise barriers on the network. This has been achieved through a programme of in situ measurements using recently developed test methods described in the forthcoming standard prEN 1793-6:2010 to determine airborne sound insulation characteristics.

The report also presents results from measurements to assess the impacts of moisture content on screening performance, the influence of panel design/geometry and factors affecting the practical roadside application of the prEN 1793-6 test method.

Other titles from this subject area

PPR040 Validation of BS CEN/TS 1793-5 for the measurement of the airborne sound insulation of timber noise barriers. G R Watts, P A Morgan. 2005

PPR216 An innovative dynamometer: free running rollers to provide a potential cheap representative roadside emission procedure. S Latham. 2007

PPR262 Primary NO2 emissions from road vehicles in the Hatfield and Bell Common Tunnels. P G Boulter, I S McCrae and J Green. 2007

PPR267 A review of instantaneous emission models for road vehicles. P G Boulter, I S McCrae and T J Barlow. 2007

PPR268 An evaluation of instantaneous emission models. T J Barlow, P G Boulter and I S McCrae. 2007

Price code: 4X

ISSN 0968-4093

TRL
Crowthorne House, Nine Mile Ride
Wokingham, Berkshire RG40 3GA
United Kingdom

T: +44 (0) 1344 773131
F: +44 (0) 1344 770356
E: enquiries@trl.co.uk
W: www.trl.co.uk

Published by

IHS
Willoughby Road, Bracknell
Berkshire RG12 8FB
United Kingdom

T: +44 (0) 1344 328038
F: +44 (0) 1344 328005
E: trl@ihs.com
W: http://emeastore.ihs.com

ISBN 978-1-84608-883-4

9 781846 088834

PPR490