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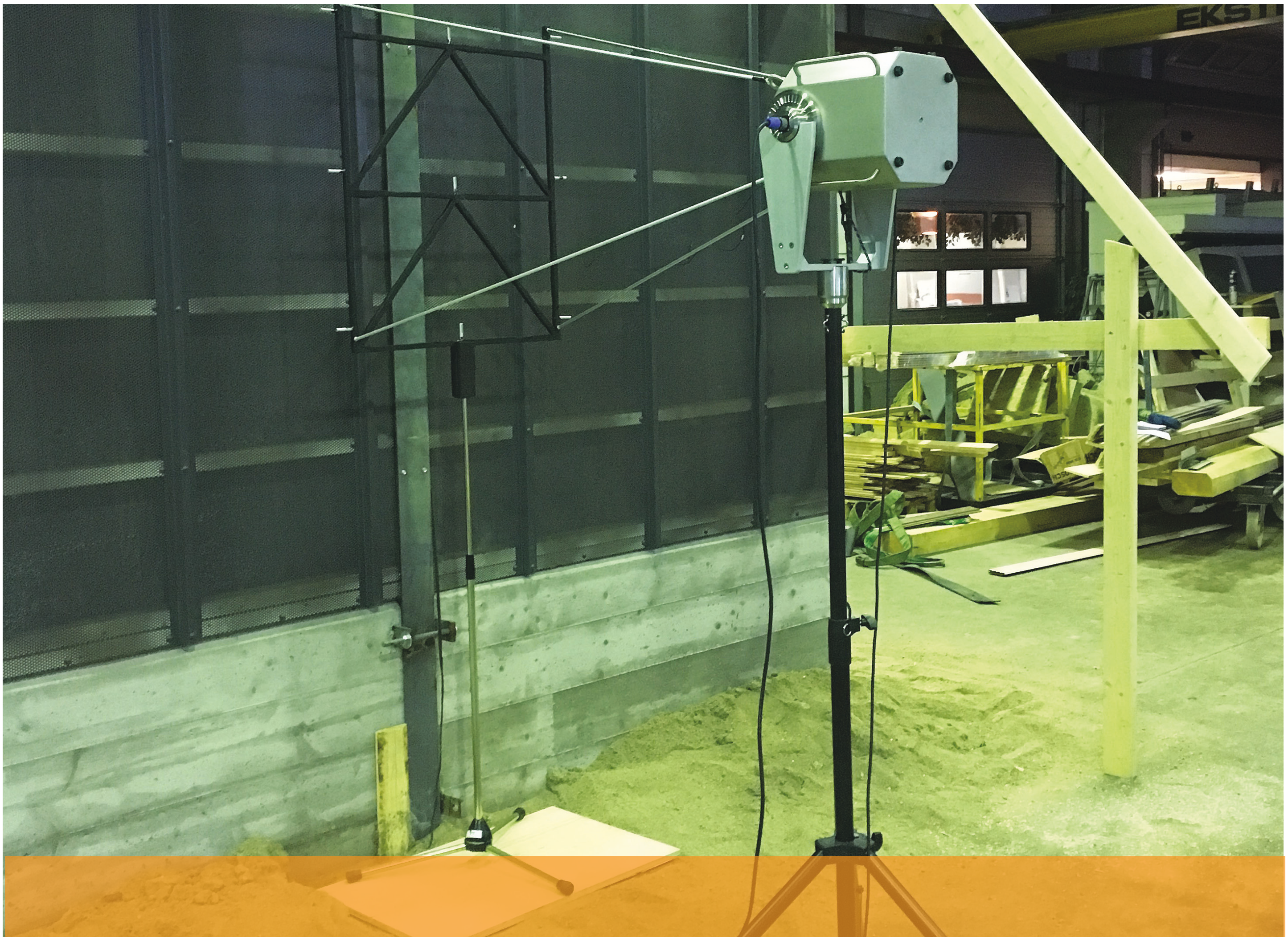
Sound reflection from different noise barriers



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Finnish Transport Agency
P.O.Box 33
FI-00521 HELSINKI, Finland
Tel. +358 (0)29 534 3000

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Summary

In this report, mainly the applicability of the standard SFS-EN 1793-5 (Road traffic noise reducing devices. Test method for determining the acoustic performance. Part 5: Intrinsic characteristics) was studied. In situ values of sound reflection under direct sound field conditions) to measure the sound reflection/ absorption of noise barriers were studied. In order to study the suitability the main targets were to clarify; the variation of the values between different types of structure, repeatability of the measurements, applicability to the periodic measurements of ageing effect and how these measured values can be applied in the quality requirements of Finnish Transport Agency.

Altogether almost thirty reflection measurements were carried out with different noise barrier structures and with their modifications. Single value of reflection/absorption of the studied noise barriers at frequency band 200–5000 Hz varied between 4–10 dB (the acoustically hard surfaced are not taken in to account). The values did not even deviate much, if they were calculated at frequency band 200–2000 Hz.

With modifications the effect of decorative wooden lathing on the results are studied. The effect of them on the results was slightly contradictory and needs some extra research to be done in the future. The lathings reduced absorption, if they were installed directly to the surface of the noise barrier and increased it, if they were not fixed directly to the surface.

With variations simulating changes due to ageing effects and their effect on the results were studied, too. For example the surface of one noise barrier was dirtied with sand and water. However, the effect of the dirtied surface remained smaller than expected, and needs more research later on. In addition, the decreasing of the absorption due to subsidence of the wool during time or other type of the decreasing of the absorption capacity was clearly noticeable.

Repeatability measurements carried out were limited. In those repeatability (or reproducibility) was measured taking in to account that in practice at different measurement times also the place or measuring angle can change a little bit. Repeatability considerations were also made based on calculations.

It was noticed in the study that comparisons between new measures with old absorption values measured in laboratory are not reasonable or appropriate, since the measuring methods differ greatly from each other.

According to the study the new method to measure single value of reflection/absorption is quite repeatable, although there were some slight variations in the reflection indices at narrower bands. Thus, the method is applicable to reflection measurement of noise barriers and periodic control measurements both for estimation of ageing effects. Preliminary thought, reflection/absorption control measurements may be carried out with noise barrier, the height of which is much lower than that 4 meter minimum height required by the standard. New measures can also be utilized in classification and choosing noise barriers in practice case by case. Measures cannot be used directly in noise propagation models, which are used to estimate the noise experiences of those living farther from the barrier.

The results of the study may be perhaps utilized, when the European standards EN 1793 -5 is developed further.

Abstract

The goal of this study was to produce general purpose information about the acoustic characteristics of noise barriers and to determine how changes in the measurement method affect the quality requirements of the Finnish Transport Agency.

The study was funded by the Finnish Transport Agency, Hansa Rakenne Oy, SEPA Oy and Urakointiasennus M. Rautio Oy. In the Finnish Transport Agency, the work was directed by Kari Lehtonen. Research was carried out and the report written by Pekka Sipari and Tero Jalkanen from VTT Expert Services Oy and Denis Siponen from Ades Oy.

In addition to this publication by the Finnish Transport Agency, the research results were reported in more detail in a report written by VTT Expert Services Oy.

Helsinki, May 2017

Finnish Transport Agency
Engineering and Environment Department

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1 Introduction

This study was a continuation of the Adrienne2012 and Adrienne2013 studies previously commissioned by the Finnish Transport Agency. The earlier studies measured the noise abatement capacity of noise barriers according to the EN 1793-6 standard [4]. The study also sought to bring our measurement competence up to the level required by accreditation and enable the Finnish Transport Agency to use the measurements in the SFS-EN 1793-5 test method as a quality requirement.

This study concentrated on reflectivity measurements according to standard SFS-EN 1793-5. Sound reflectivity measurements according to the standard were performed for various noise barrier structures manufactured by noise barrier manufacturers. The purpose of the measurements was to determine and assess the suitability of the SFS-EN 1793-5 method for measuring the sound reflectivity of noise barriers, the usability of the method for monitoring the effects of aging and the suitability of the measurement results for issuing quality requirements. This was achieved by surveying the general repeatability of the measurements by investigating the reflectivity values produced by different structures and by causing artificial aging on the noise barrier structures for example by making them wet or dirty. Another topic of investigation was the effect of decorative battens on the measurement results.

In addition, we reviewed literature on results obtained abroad and compared them with the results obtained in this study.

2 Objective of the study

The objectives of this study were the following:

1. To obtain competence for measurements compliant with EN 1793-5.
2. To obtain an overall idea of the results compared with the results given by EN 1793-2, in order for the Finnish Transport Agency to set quality requirements for sound reflection.
3. To provide information for the manufacturers on the sound absorption of their products, prototypes and variants.
4. To assess the effect of decorative battens, dirt, wetness in structures etc. on the results.

The following sub-goals were set in order to achieve the main goals:

- to investigate what reflectivity/absorption values are obtained using the SFS-EN 1793-5 method for noise barriers containing different structures,
- to assess the suitability of the method in cases where decorative battens are mounted on the surface of the noise barrier, and the effect of the battens on the values obtained,
- to investigate the repeatability of the measurement method, and
- to assess how the artificial changes made to simulate aging affect the results obtained, and, based on these results, assess the suitability of the measurements for follow-up measurements.

3 Literature review and background

The standards EN 1793-5 and 6 (Adrienne method) contain instructions for measuring the sound reflection index and sound insulation index of a structure. The methods are based on the evaluation of the transfer functions of the direct and reflected components of a signal coming from a signal source (reflection index) and the components that travel through the barrier and directly without the barrier (insulation index).

Methods compliant with the standards can be used for measuring the acoustic properties of noise barriers alongside roads as well as noise barriers erected indoors in a hall for measurement purposes.

Sound insulation measurements with an EN 1793-6 compliant method give results that correspond fairly well to the results of measurements compliant with EN 1793-2 made in a laboratory: – the acoustic performance ranking of the structures measured remains more or less the same even when the measurement method is changed. According to the standard, sound insulation is measured separately for both the acoustic element and the post. The global sound insulation rating calculated from these two results overemphasises the share of the post at longer distances from the barrier, considering that the measurement area is corresponds to an area approximately 0.8 metres wide.

Reflectivity measurements compliant with the EN 1793-5 standard measure the sound reflection indices *RI*. The reflection indices can be used to calculate a so-called single-number rating of reflectivity DL_{RI}, which, in spite of its misleading name, indicates sound absorption measurable in the field. A high DL_{RI} value means a high absorption of sound (or propagation through the structure) and low reflection. Literature contains comparisons of the DL_{α} value resulting from EN 1793-1 absorption measurements performed in a laboratory with the EN 1793-5 reflectivity/absorption value DL_{RI}.

Different results have been presented for field measurement standards EN 1793-5 (sound reflection) and EN 1793-6 (sound insulation) for over ten years. This study focuses primarily on the latest sources presented in the standard EN 1793-5 (/1/, /2/, /3/ and /4/). The review also touches the EN 1793-6 compliant sound insulation measurement performed in the field.

Studies by Garai and Guidorzi (/1/ and /2/) present results from reflection measurements conducted on the field in accordance with the new standards and compare them with the absorption results obtained from traditional laboratory measurements. Tables 1 and 2 in Chapter 4 present the single-number ratings for absorption/reflectivity obtained in laboratory and field measurements. The studies compare different noise barrier types. The studies do not describe the structure of the noise barriers or the measurement methods in detail, so it is impossible to compare them with the measurements conducted in this study. On the other hand, the results obtained gave a rough indication of the values that could be expected in this study.

The standard EN 1793-5 (/8/) sets limits for the repeatability and reproducibility of the method that can now be used for assessing the repeatability of the measurements performed in this study.

The Quiesst 2012 Guidebook to Noise Reducing Devices Optimisation discusses the optimisation of noise barriers (/3/). The guidebook contains many clear and useful graphics that illustrate the propagation of noise at a general level. The guidebook also discusses the usability of the measurement results in the modelling of noise both in the near and far field.

Neither the literature sources nor the standard give instructions on how local authorities should apply the measurement results in practice. The intention is not to give any limit values, but, for example, to use noise modelling to select a noise barrier structure that meets the applicable requirements.

4 General information on the reflection and absorption of sound

The absorption coefficient (measured according to EN 1793-1) is the ratio of sound power hitting an obstacle to the sound power absorbed by the obstacle (Figure 1). An absorption coefficient measured in a laboratory can be used for determining the sound reflection coefficient *r* by subtracting the absorption coefficient α from 1, i.e. ($r = 1 - \alpha$). In principle, the reflection coefficient is closely related to the reflection index *RI* (measured according to EN 1793-5). It could be said that the value 1- *RI* corresponds to the absorption and sonic power that passes through the noise barrier in a reflectivity measurement. The reflection coefficient and also the reflection index are calculated as the ratio of sound power hitting an obstacle to the sound power reflected from it. However, these figures differ considerably from each other in terms of the sound field of the measurement situation and sound propagation. In addition to differences in the measurement of transmission and reception levels themselves and the processing of the results, the main differences are:

- In a laboratory, the sound field is diffuse (i.e. sound hits the surface from every direction at approximately the same sound power), whereas in field measurements, the sound source generates a virtually direct sound wave (the sound signal hits the surface fairly perpendicularly, and is also reflected fairly perpendicularly).
- In absorption measurements performed in a laboratory, most of the sound power passing through the structure does not affect the measurements, whereas in reflection measurements conducted in the field, the sound power passing through the structure might affect the reflectivity results depending on the structure.
- Absorption measurements in a laboratory measure the average sound absorption of two wall element halves and one post, whereas the reflectivity measurements in the field measure a circular area 4 metres in diameter.

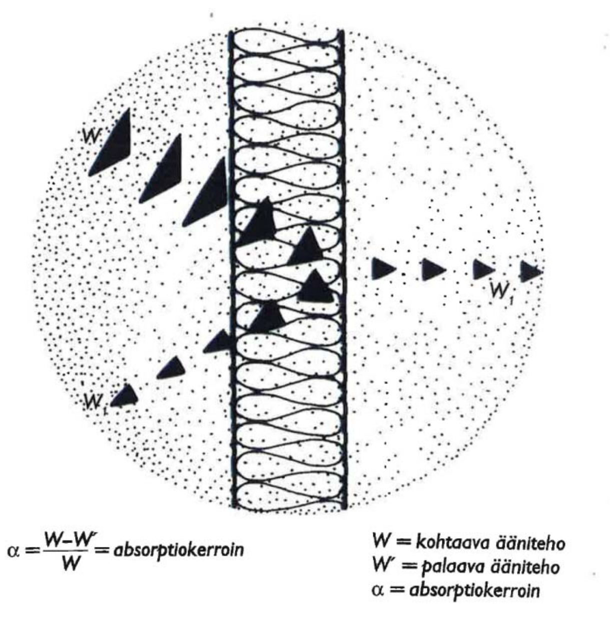

Figure 1. Transmission of sound as it meets an obstacle.

The EN 1793-5 field measurement method has been found to be sensitive to the (acoustic) impedance of the structure of a noise barrier, which means that it emphasises the resonant frequencies of the structure and its surface. The EN 1793-5 method gives a good indication of how sound is reflected from a structure to its immediate vicinity /1/.

The DL_α value obtained from EN 1793-1 absorption measurements performed in a laboratory is often compared with the DL_{RI} value obtained from EN 1793-5 measurements, since their formulas are similar and they both describe absorption. Tables 1 and 2 were obtained from literature, and it can be seen that no general correlation has been found between the DL_α and DL_{RI} values. On the other hand, for perforated metallic cassettes filled with glass wool, the DL_α value seems to be three to four times the DL_{RI} value. It cannot be concluded from the results whether the ratio also applies to other types of metallic cassettes than those measured.

Table 1. Single-number ratings for absorption coefficient and reflectivity (frequency range 100–5,000 Hz/laboratory measurement and frequency range 250–5,000 Hz/field measurement) /1/.

Sample	Type	α_w [dB] lab. 100 to 5k Hz	DL_α [dB] lab. 100 to 5k Hz	DL_α [dB] lab. 250 to 5k Hz	DL_{RI} [dB] outdoors 250 to 5k Hz
CON1	Concrete	0.75	9	10	6
CON2	Concrete	0.65	6	7	4
CON3	Concrete	0.90	10	12	4
CON4	Concrete	0.65	5	6	3
CON5	Concrete	0.50	5	5	2
CON6	Concrete	0.20	1	1	0
MET1	Metal	1.00	20	20	5
MET2	Metal	1.00	18	20	5
MET3	Metal	0.95	16	20	5
MET4	Metal	0.15	0	0	0
MET5	Metal	0.95	8	9	4
MET6	Metal	0.95	19	20	6
MET7	Metal	0.95	13	20	5
RES1	Resin	0.80	8	9	4
ACR1	Acrylic	0.10	0	0	0
MIX1	Met./Acr.	0.60	4	4	3
WOOD	Wood	0.65	8	8	4

Table 2. Single-number ratings for absorption coefficient and reflectivity (frequency range 100–5,000 Hz/laboratory measurement and frequency range 250–5,000 Hz/field measurement) /2/.

	Road traffic spectrum		High speed train spectrum	
Barrier type	DL_α [dB] Laboratory	DL_{RI} [dB] In situ	DL_α [dB] Laboratory	DL_{RI} [dB] In situ
Metallic cassettes filled with rock wool (2000)	20	7	20	9
Metallic cassettes filled with glass wool (2005)	20	6	20	8
Timber/Metal cassettes filled with glass wool (2005)	20	5	20	7
Concrete panels with a porous side (2001)	5	1	7	3
Concrete panels with a porous side (2005)	—	2	—	3
Framed acrylic sheets (1999)	0	0	0	1
Framed acrylic sheets and concrete panels (2005)	—	−1	—	0

5 Measurements performed and the measurement programme

The measurement programme consisted mostly of reflectivity measurements. Some sound insulation measurements were also conducted. The measured structures A…E and the results of reflectivity measurements are presented in Table 3.

Preliminary reflectivity measurements were made in the VTT Expert Services Oy's reverberation room, using its uncoated concrete wall and a concrete wall larger than 4 x 4 m coated with 40 mm of polyester wool. In addition, a similar measurement of a hard and reflective surface was performed for structure D (solid sheet metal surface behind the noise barrier). Measurements conducted at the noise barrier manufacturers' premises were conducted in industrial halls. The structures studied were located in the middle of the hall so that reflections from the surrounding hall structures would not affect the results.

The measurements investigated structures with different absorption. Structures A, C, D and E had a perforated sheet metal surface and functioned as cavity resonators (Helmholz resonators). Structure B functioned as a disc resonator. This group also includes the measurements made from the rear side of structure E. A total of 32 measurements were made, of which 5 were sound insulation measurements and the rest were reflection measurements.

The sound insulation and reflectivity measurements were conducted for basic structures according to the standards EN 1793-5 and EN 1793-6. The EN 1793-5 methods were used to determine the reflection indices and single-number ratings for reflectivity/absorption of noise barriers and their variations.

Decorative battens are sometimes required by the client to be mounted on the surface of a noise barrier to improve its appearance and reduce the potential for graffiti. The purpose was to determine how the DL_{RI} value stated in the manufacturer's performance declaration should be altered to account for the use of battens. The battens were installed directly onto the noise barrier surface or approximately 20–30 mm above it. These measurements were made for structures B, D and E.

Repeated measurements were only carried out for structure D. For this structure, a repeated measurement was carried out at exactly the same measurement point and also by displacing the measuring equipment laterally by 50 mm and changing its angle (3.6° and 7.2°) to the surface of the noise barrier. Standard SFS-EN 1793-5 does not require reflectivity measurements of the posts. However, the present measured some posts for reflectivity to determine whether the results differ substantially from the results of the elements themselves. This enabled the repeatability of the measurement method to be assessed also based on the post measurement results and calculations made over various frequency ranges.

The impact of ageing phenomena was studied with structure D. The ageing phenomena studied were the possible settling of wool and the effects of dirt on the surface. The latter was investigated by wetting the surface of the noise barrier and applying sand to it. The loss of absorption ability of the wool was also investigated by reducing the initial 100 mm deep wool layer by half.

The measured structures and their results are presented in more detail in Chapter 6, Table 3.

6 Results of the reflectivity measurements and discussion of the results

6.1 Single-number ratings

The single-number rating for sound reflectivity DL_{RI}, dB (200–5,000 Hz), is presented in Table 3 below.

Table 3. The structures measured and their sound reflectivity results for the frequency range 200–5,000 Hz, dB. The results in parentheses have been calculated for the frequency range 200–2,000 Hz for comparison purposes.

Measurement number	**Structure**	**DL_{RI} (dB)** **element/post**
1	Tested structure / Measurement of an acoustically hard wall	1.5 (1.5)
2	Tested structure / Hard wall + 40 mm polyester wool	3.7 (3.5)
3–4	Basic structure A + perforated sheet metal 0.6 mm, perforation diameter 4 mm, perforation ratio 30 % (of entire area)/ air gap 98 mm /50 mm cement-bonded particle board/dense wood fibre cement board	4.6 (4.6) / 4.9 (4.9)
7–8	Basic structure B wood wool cement board / air gap 98 mm / wood wool cement board / wood fibre cement board	3.5 (3.6) / 3.2 (3.1)
9–10	Basic structure B + horizontal battens (22 mm air gap to surface of board), coverage approx. 30%	5.6 (5.9) / 4.5 (4.4)
11–12	Basic structure C + perforated sheet metal 0.6 mm, perforation diameter 2 mm, perforation ratio 25% (of total area)/ air gap 60 mm / wool 90 mm/polymer composite board	5.1 (5.1) / 5.5 (5.5)
13–14	Basic structure D, perforated sheet metal 1 mm, perforation diameter 3 mm, perforation ratio 30% (of total area) / no air gap / polyester wool approx. 90 mm / aluminium 3.5 mm	10.1 (10.0) / 8.4 (10.8)
17	Basic structure D, vertical square battens mounted on surface of the sheet metal, mounting interval 100 mm, 50x50 mm, coverage 50%	6.8 (7.3)
18	Basic structure D, (square battens), repeated reflectivity measurement / displacement by 50 mm	6.8 (7.6)
19	Basic structure D, triangular vertical battens, mounting interval 100 mm, 50x35x35 mm, coverage approx. 50%	7.1 (8.1)
20–21	Basic structure D, triangular vertical battens, repeated reflectivity measurements using different angles (3.6° and 7.2°)	7.1 (7.9) and 7.0 (7.9)
22	Basic structure D, vertical square battens, mounting interval 100 mm, 28x50 mm, coverage approx. 28%	7.2 (7.5)
23	Basic structure D, repeated measurement of reflectivity after battens removed	10.3 (10.2)
24	Basic structure D, wool wetted with water, sand added to surface of the wool	9.6 (10.3)
25	Basic structure D, approximately 1 mm more sand added to the surface	8.7 (9.1)
26	Basic structure D, air gap of approximately 45 mm behind the perforated sheet metal, and 45 mm wool instead of 90 mm	5.4 (5.4)
27	Basic structure D, height of wool reduced by 15%	7.4 (7.4)
28	Basic structure E, perforated sheet metal 1 mm, perforation diameter 4 mm, perforation ratio 20% / air gap 15 mm / wool 75 mm / solid sheet metal, measurement from the front side (perforated sheet metal)	5.1 (5.9)
30	Basic structure E, solid sheet metal 1 mm / wool 75 mm / air gap 15 mm 75 mm / perforated sheet metal, measurement from the back side (solid sheet metal)	1.6 (1.6)
31	Basic structure E, horizontal battens 50x50 mm, mounting interval 100 mm (30 mm air gap to board), 50% coverage, measurement from the front side (perforated sheet metal)	5.5 (6.2)
32	Basic structure E, horizontal battens 50x50 mm, mounting interval 100 mm (30 mm air gap to board) on the backside, 50% coverage, measurement from the back side (solid sheet metal)	1.9 (1.9)

In the results with single-number ratings, sound reflection/absorption is presented as a single numeric value, DL_{RI}, which takes into account a range of frequencies by using traffic noise weighting compliant with the standard EN 1793-3 (/10/). To facilitate comparison, the values in Table 3 are shown to one decimal place. The standard requires the results to be rounded to the nearest integer, but this could result in a difference of up to 1 dB in the integer results, even if the difference in decimals were only 0.1 dB.

Measurements 1 and 30 show that a hard concrete surface and a steel surface gave the same result, 1.5 dB.

Measurements 3–4, 11–12 and 13–14 on structures perforated on the surface, with a perforation ratio of approximately 30%, gave a result of approximately 5 dB when the internal structure consisted of a wood wool cement board, and approximately 10 dB, when the internal structure consisted of porous wool throughout the structure. Measurement 28, where the perforation ratio was approximately 20% and the wool amounted to around 80% of the thickness of the cassette, gave a result of about 5 dB.

The effects of battens were investigated in different structures. According to measurements 17–22, battens mounted directly on the surface of perforated sheet metal and covering 50% of the surface area reduced the result of measurements 13–14 from 10 to 7 dB. This was expected, since the battens covered the sound-absorbing holes and the vibration of the perforated sheet metal was already dampened by the wool to begin with. According to measurements 28 and 30–32, wooden battens mounted above the surface of the noise barrier (solid or perforated sheet metal) and covering 50% of it had little effect. On the other hand, in measurements 9–10, battens mounted above the surface of a solid wood wool cement board and covering 30% of it increased the result of measurements 3–4 from 3.6 dB to 5.6 dB. This result may have been caused by the battens and their wooden supports beneath them dampening the vibration of the board, which was not already dampened by other materials in the element.

The repeatability of measurements was studied in several measurement sequences. In measurement 18, the measurement location was moved by 50 mm. In measurements 20-21, the measurement angle was changed from that of the initial measurement. These measurements sought to determine the repeatability of measurements in field conditions, where the location of the meter might vary at different measurement times. The single-number reflectivity/absorption result did not change (Figure 3). Based on the measurement results, it can be concluded that the measurements are fairly repeatable in the frequency range of 200–2,500 Hz also in field conditions. Measurement 23 was carried out after the battens had been removed. The result was the same as the result obtained in measurement 13, before the installation of the battens (Figure 6). Repeated measurements include measurement series 3–4, 11–12, etc. that were partially conducted at the location of the element and post, and they too gave uniform results.

Measurements 24–27 investigated the effects of aging by means of deforming the wool artificially or by making the surface of the noise barrier dirty or wet. The results of these measurements were compared with structure D – a 100 mm thick cassette with 90 mm polyester wool board behind a perforated aluminium sheet. Measurements 24 and 25 indicate that the dirt and wetness on the surface of the noise barrier reduced the result of measurement 13–14 (10.1 dB) to 8.7 dB, depending on the amount of sand (max. 1 mm). Thus, contrary to what was expected, the effect of dirt and water in this test setup is minor.

Halving the thickness of the wool, resulting in a 45 mm deep cavity behind the perforated sheet metal, reduced the value obtained in measurement 13 (10.1 dB) to 5.4 dB in measurement 26. This was caused by the fact that the absorption capacity of the wool was reduced and the wool did not dampen the vibration of the perforated sheet metal. In measurement 27, the height of the wool was reduced by 15% in every 200 mm cassette. The result fell from 10.1 dB to 7.4 dB.

6.2 Observations concerning different frequencies and repeatability

For all structures, the reflection of sound was determined according to EN 1793-5, separately for all 1/3 octave bands of the frequencies. The results can be stated as follows:

- In measurement 13 and 14, the measurement location, angle and the measured structure stayed the same, but the results differed in the frequency range 2,000-5,000 Hz, although the DL_{RI} value was the same.
- In measurements 17-21, changing the measurement location or angle when measuring a battened surface did not change the DL_{RI} value, but the results differed from each other in the frequency range 2,000-5,000 Hz (Figure 2).
- In measurements, 13, 17 and 19, the shape of the battens did not change the DL_{RI} value, but there were differences in the results in the frequency range 1,600-5,000 Hz. The differences show as individual spikes in certain frequencies within the range.
- In measurements 13, 26 and 27, reducing the amount of wool inside the cassette increased the sound reflection index *RI* (and worsened the DL_{RI} value); the DL_{RI} value worsened considerably in frequencies less than 1,000 Hz (Figure 3).
- In measurements 13, 24 and 26, wetting the wool and making it dirty increased the sound reflection index in the frequency range 800-5,000 Hz (Figure 4).

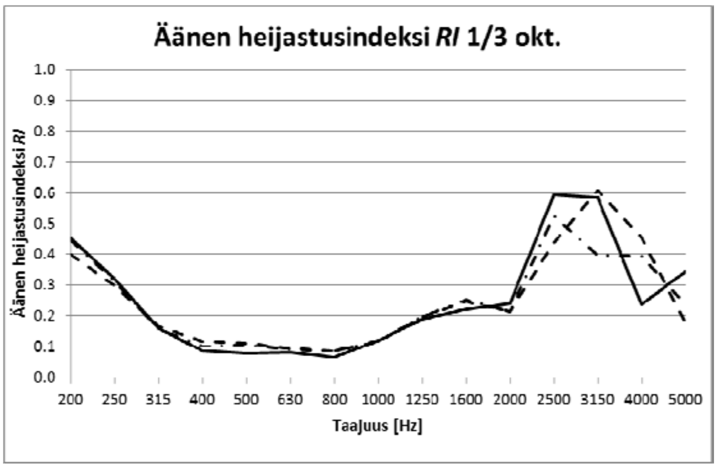

Figure 3. *Assessment of the repeatability of the measurements: effect of the measurement angle. Noise barrier with triangular battens. Perpendicular measurement number: 19 = continuous line, angle 3.6°; measurement 20 = dashed line and angle 7.5°; measurement 21 = dash-dot line). In all measurements,* $DL_{RI} = 7$ *dB*

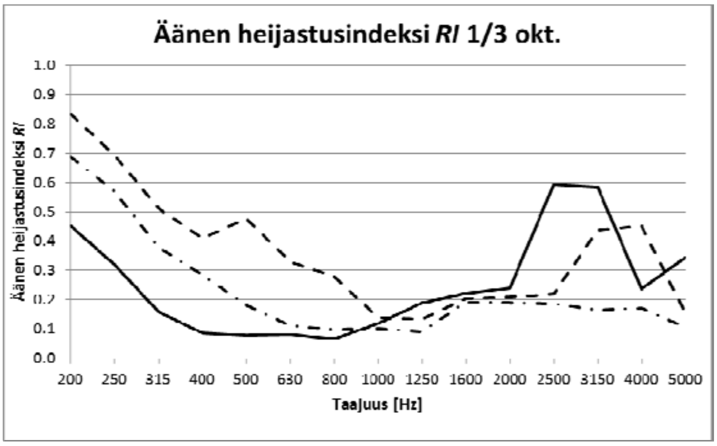

Figure 4. *Effect of the amount of wool. Measurement number: 13 = continuous line DL_{RI} = 10 dB, measurement number 26, wool thickness 45 mm = dashed line, DL_{RI} = 5 dB; measurement number 27 = height of 90 mm thick wool reduced by 15%) DL_{RI} = 7 dB.*

Obvious spikes were detected in the reflection coefficients especially at frequencies over 2,000 Hz, particularly when measuring posts and battenings. In addition, the results of individual microphone locations diverge in frequencies over 2,000 Hz. The reason for this phenomenon could not be identified (Figure 5).

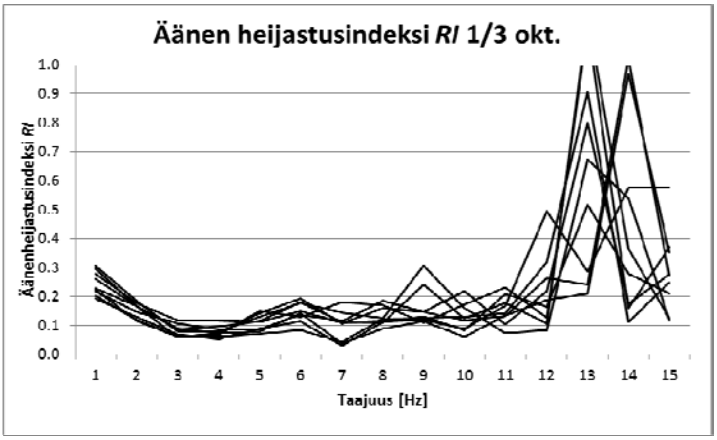

Figure 5. *Reflection indices by microphone locations in measurement 18, where the noise barrier contained a surface-mounted square battening.*

The values in parenthesis in Table 3 are those that would be obtained by calculating the DL_{RI} value over the frequency range 200–2,000 Hz. The result is somewhat more repeatable than the value calculated for the whole frequency range, which itself is fairly well repeatable when measured with the same device. This is due to the road noise spectrum weighting used.

Figure 6 shows the results of measurement 13 and the repeated measurement (number 23). As can be seen, the measurement results are very similar. This shows that the repeatability of the measurements is good, even when the divergence in individual microphone points might be substantial.

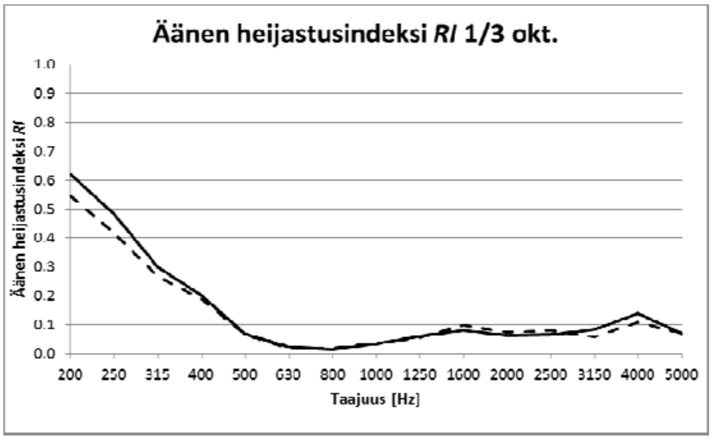

Figure 6. *Assessment of measurement repeatability. In both measurements, DL_{RI} = 10 dB (measurement number: 13 = continuous line and measurement number 23 = dashed line).*

6.3 Comparison between the laboratory and field measurement methods

Figure 7 presents a comparison between the sound reflection index (EN 1793-5) and the reflection coefficient calculated from the absorption results of the laboratory measurement method (EN 1793-1). The figure shows that the laboratory measurement (EN 1793-1) yields a fairly high DL_{α} value compared to the DL_{RI} value produced by the field measurement method, This is due to the low frequencies in particular. Since the nature of the absorption measurement performed in a laboratory is completely different from that of the reflectivity measurement, it is not possible to determine a general relationship or difference between the DL_{RI} value and the DL_{α} value obtained from laboratory measurements.

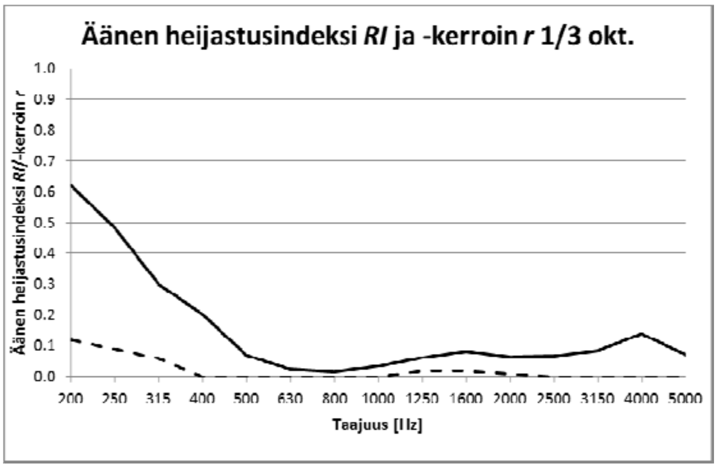

Figure 7. *Measurement 13: sound reflection index RI measured according to EN 1793-5 (solid line) and the sound reflectivity coefficient r ($r=1-\alpha$) of a corresponding noise barrier measured earlier with the EN 1793-1 compliant laboratory method (dashed line). DL_{RI}=10 dB and DL_{α}=15 dB.*

Figure 8 presents the DL_{RI} value of Table 2 as a bar graph. The results of sound reflection measurements have been found to differ markedly from the DL_{α} values obtained in a laboratory. In addition, when the method changes, the ranking of the structures changes. Based on the comparisons made, it can be concluded that there is no direct correlation between the results obtained by the laboratory and field methods.

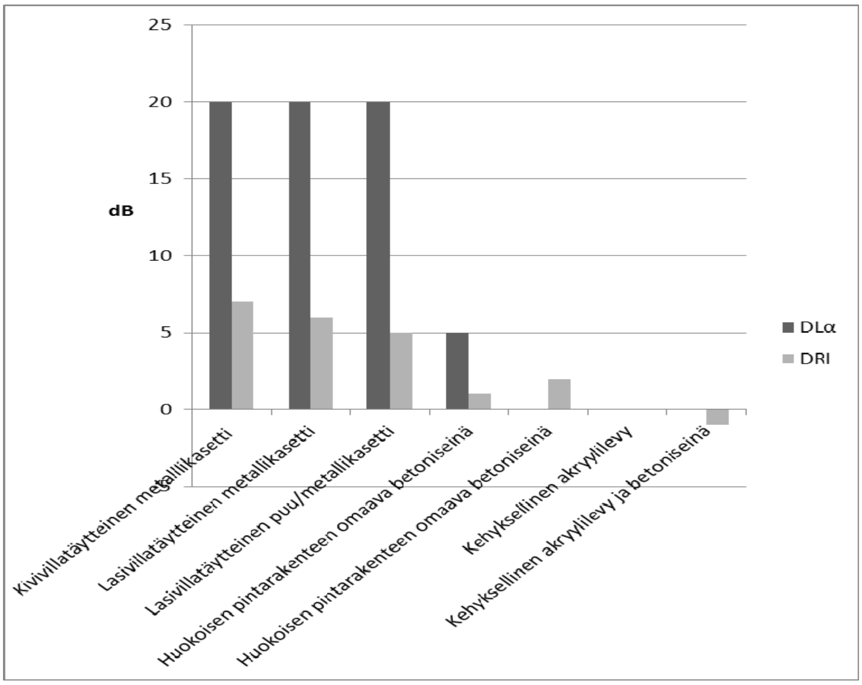

Figure 8. *Sound reflection/absorption values in Table 2 measured according to method EN 1793-5 and EN 1793-1.*

7 Measurement of insulation

The insulation of structures of A, D and E was measured according to standard EN 1793-6. The results are shown in Table 4. The results indicate that the insulation of the structures studied is typical for noise barriers. It is not known to what extent the sound penetrating the barrier affects the sound reflectivity results.

Table 4. Measured structures and results of sound insulation in dB.

Measurement number		**Insulation** $DL_{SI,E}$ (dB)	**Insulation, post** $DL_{SI,P}$ (dB)
5–6	Basic structure A + perforated sheet metal 0.6 mm, perforation diameter 4 mm, perforation ratio 30 % (of entire area)/ air gap 98 mm /50 mm cement-bonded particle board/dense wood fibre cement board	32	29
15–16	Basic structure D, perforated sheet metal 1 mm, perforation diameter 3 mm, perforation ratio 30% (of total area) / no air gap / polyester wool approx. 90 mm / aluminium 3.5 mm	28*	21
29	Basic structure E, perforated sheet metal 1 mm, perforation diameter 4 mm, perforation ratio 20% / air gap 15 mm / wool 75 mm / solid sheet metal, measurement from the front side (perforated sheet metal)	34	

* in a previous laboratory measurement, the result obtained for the same noise barrier was $DL_R = 28$ dB (A)

8 Conclusions

With the exception of measurements made for acoustically hard surfaces, the DL_{RI} values varied between 4–10 dB. Different barrier types differed considerably from each other in terms of reflectivity.

The results of the current measurements differ partially from the results presented in the literature, especially for well-absorbing noise barriers with a perforated sheet metal surface, for which the DL_{RI} values obtained in this study were high. It is likely that the structures presented in the literature differ from those measured in this study.

Reflectivity measurements conducted using the EN 1793-5 method differed considerably from absorption measurements conducted in a laboratory setting. The new method gives more precise information on the behaviour of the structure with regards to the reflection of sound in the near field. The DL_{RI} values obtained with the EN 1793-5 method should not be compared to the values obtained from laboratory measurements.

The DL_{RI} values calculated according to the standard over the entire 200–5,000 Hz frequency range differed hardly at all from the corresponding values calculated over the frequency range 200–2000 Hz. This can be explained by the weighting of the road noise spectrum used in the calculation of the single-number rating for reflectivity, which markedly reduces the effective power of high frequencies. Based on the results, the DL_{RI} value seems fairly repeatable from 200 Hz to up to approximately 5,000 Hz, despite the unexpectedly large divergence in the results of individual measurement points. The reasons for the irregularities in the reflection measurements at certain frequencies cannot be explained based on these measurements. On the other hand, the deviations did not markedly affect the results. In the future, attempts should be made to improve the reliability of results at higher frequencies, if anomalies are detected. The correctness of the result could then be assessed by calculating the reflection also over a narrower frequency range (e.g. 200–2,000 Hz).

The measurements can be regarded as repeatable and reproducible. Based on the measurements conducted in this study, it can be concluded that the new EN 1793-5 standard is a suitable method for measuring the sound absorption of noise barrier elements. It brings out the differences between the different noise barrier structures sufficiently clearly. Compared to the previous measurement method, the figures produced by the new method are coarser, and are therefore an improvement on the sometimes excessively precise assessment based on laboratory measurements.

The CE marking requires that the minimum height of the barrier to be measured is at least 4 metres. The new measurement method and its results can also be used for e.g. monitoring the effects of aging of a sound barrier, including barriers less than 4 metres high. However, if the barrier height is less than 4 metres, the monitoring requires a separate initial measurement. During the warranty period, the values measured from, e.g., a 3-metre high barrier that has been used for 5 years should not be compared directly to the results obtained by the manufacturer during CE marking certification.

The effects of various decorative battens were also slightly contradictory, especially regarding the increased absorptive effect of battens elevated from the surface. The result depends on, among other things, whether the vibration of the perforated sheet metal is somehow prevented already before the battens are mounted. This matter requires further study. Further studies are also needed to determine the effects of surface soiling and waterlogging of wool, since their effect was surprisingly small in the current test setup. Furthermore, the actual effect of reflected noise on the noise level at various distances and frequencies should be investigated in more detail.

The new reflectivity standard EN 1793-5 does not require the measurement of the posts. This is a correct approach, since the effective area of the post is low. By contrast, the sound insulation standard EN 1793-6 requires the post to be measured. Future development of European noise barrier standards should carefully consider whether the global value should be omitted, since it is might be slightly incorrect (in overemphasising the post) and give rise to false conclusions. For example, with respect to follow-up measurements and assessments, the results of the sound insulation performance of a noise barrier element and an individual post are sufficient as separate results (if including the post section as part of the measurements and follow-up). On the other hand, measuring the sound insulation of an entire post section is questionable, since small defects in workmanship (such as a gap between the post and the element) can be given too much importance in assessments (the significance of the sound insulation capacity of a post is low when the sound field is investigated even slightly further away from the sound field). In addition, it would be beneficial for further development if the standard provided clear direction regarding the application of the measurement values.

The results given by the EN 1793-5 method are not directly applicable to studies investigating the adverse effects of noise on residents further away from the noise barrier. This also applies to absorption values determined in a laboratory setting. Furthermore, the adverse effects for residents might be best described by noise modelling.

Old laboratory results and the resulting minimum requirements for sound absorption in noise barriers cannot be used as the basis when issuing new requirements based on the EN 1793-5 measurement method. However, various minimum requirements can nevertheless be set based on field measurement results and the resulting single-number rating DL_{RI}, for example by using category limits 4, 6, 8 and ≥ 10 dB. For noise reflected from the surface of the barrier to the near field (assuming that the phase of the reflected wave is different from the phase of the sound wave hitting the barrier), these values correspond to a total increase of 1.5 dB, 1 dB, 0.6 dB and 0.4 dB of noise from the perspective of an observer slightly further away from the noise barrier.

In the Finnish Transport Agency's Guideline 'Tien meluesteiden suunnittelu' [Designing Noise Barriers for Roads], a sound barrier is considered to be noise-absorbing when its EN 1793-1 compliant DL_{α} value is at least 8 dB. It is not possible to define a EN 1793-5 compliant DL_{RI} limit that products exceeding a DL_{α} value of 8 dB – and those products only – would exceed. Moreover, the performance ranking of products in EN 1793-5 compliant tests is not the same as in EN 1793-1 compliant tests.

Sources

/1/ GARAI M., GUIDORZI P. “Experimental verification of the European methodology for testing noise barriers in situ: sound reflection” (invited paper), Proc. Inter-Noise 2000, Nice, France, 477-482 (2000)

/2/ GARAI M., GUIDORZI P. In situ measurements of the intrinsic characteristics of the acoustic barriers installed along a new high speed railway line. Noise Control Eng. J. 2008, 56 (5) pp. 342–355

/3/ QUIESST. (2012). Guidebook to noise reducing devices optimisation [Online]. Accessed October 2014; Available from the World Wide Web:
http://www.quiesst.eu/images/stories/guidebook_JPC_19_nov_2012_MC_CD_MG_logos.pdf

/4/ QUIESST. Final procedural report on WP4 activities: Including public database of European NRD, data analysis and definition of NRD families. Available from the World Wide Web, 2012 [[Online], Accessed October 2014
http://www.quiesst.eu/images/QUIESST_D4.3_MS4.2.pdf

/5/ EN 1793-1, Road traffic noise reducing devices - Test method for determining the acoustic performance - Part 1: Intrinsic characteristics of sound absorption

/6/ EN 1793-2, Road traffic noise reducing devices - Test method for determining the acoustic performance - Part 2: Intrinsic characteristics of airborne sound insulation under diffuse sound field conditions

/7/ EN 1793-4, Road traffic noise reducing devices - Test method for determining the acoustic performance - Part 4: Intrinsic characteristics - In situ values of sound diffraction

/8/ EN 1793-5, Road traffic noise reducing devices - Test method for determining the acoustic performance - Part 5: Intrinsic characteristics - In situ values of sound reflection under direct sound field conditions

/9/ EN 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 sound field conditions

/10/ EN 1793-3, Road traffic noise reducing devices - Test method for determining the acoustic performance – Part 3: Normalized traffic noise spectrum

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