DOI: 10.61782/fa.2023.0218

ADVANCEMENT OF THE EUROPEAN METHOD FOR IN-SITU MEASUREMENTS ON ROAD TRAFFIC NOISE BARRIERS

M. Garai[1*] **P. Guidorzi**[1] **A. Osele**[2] **C. Costa**[2]
[1] 1 Department of Industrial Engineering, University of Bologna, Italy
[2] Autostrada del Brennero S.p.A., Trento, Italy

ABSTRACT

The EN 1793-5 and -6 method for measuring the intrinsic acoustic characteristics of noise barriers along motorways (a.k.a. Adrienne method) has been in use for many years and has proven to be robust and provide highly repeatable results. However, some aspects of the method can still be improved. For example, when measuring along a motorway open to traffic or when the entire length of the barrier needs to be evaluated, measurements need to be made quickly and efficiently; on the other hand, accurately positioning the equipment may be time-consuming. Therefore, Autostrada del Brennero and University of Bologna developed a frame for the measuring equipment, to be quickly transported on the test site and positioned with a crane truck. The first results seem very encouraging, however, a detailed study of the repeatability that can be expected during a full-day measurement session on the field is still lacking. This study has been done and is presented in this paper, where the new system is compared with the standard system used at University of Bologna to make the background study for EN 1793-5 and EN 1793-6. Repeated sequences of in-situ measurements have been done with both systems on the same noise barriers and the standard deviation of repeatability has been derived. It is concluded that the new rigid supporting frame has a better standard deviation of repeatability compared to a state-of-the-art equipment.

Keywords: *road traffic, noise barrier, Adrienne method, EN 1793-5, EN 1793-6*

[*]***Corresponding author***: massimo.garai@unibo.it

1. INTRODUCTION

Measurements of the intrinsic characteristics of noise barriers mounted along highways are carried out according to the standard EN 1793-5 [1] and EN 1793-6 [2], which involves the use of a sound source, a grid of 9 x 9 microphones, and a measurement and data processing unit. Such instrumentation requires some time to be mounted and positioned accurately for each individual measurement position; moreover, measurements often take place during the normal flow of high-speed motor vehicles. A system in which the microphones and the sound source are fixed on a single support, suspended above or in front of the surface of the panel to be measured by means of a movable arm was thus devised. In this way, at the price of using a little truck for the transport, a quick-to-use system is obtained. In addition, the relative position of the microphones and the sound source are rigidly fixed at the correct distance all the time, and bumpers (small wheels) allow the system to be placed against the surface of the barrier, for both reflection and insulation measurements, at the correct distance from the surface. A more detailed description of the suspended system developed by Autostrada del Brennero (manager of the A22 motorway) and University of Bologna (UNIBO) can be found in [3].
This study presents some series of sound insulation and sound reflection measurements repeated 10 times on the same panel of a road traffic noise barrier installed on the A22 motorway near Verona Nord (IT). The measurements were made both with the UNIBO measurement system (tested comparatively during an international round robin test [4], and therefore to be considered here as a "reference") and with the new suspended system supplied by A22, repositioning the system for each new measurement. As shown in the following, the fixed and stable spacing of all moving parts of the A22 system allows to obtain highly repeatable measurement results.

2. METHODOLOGY

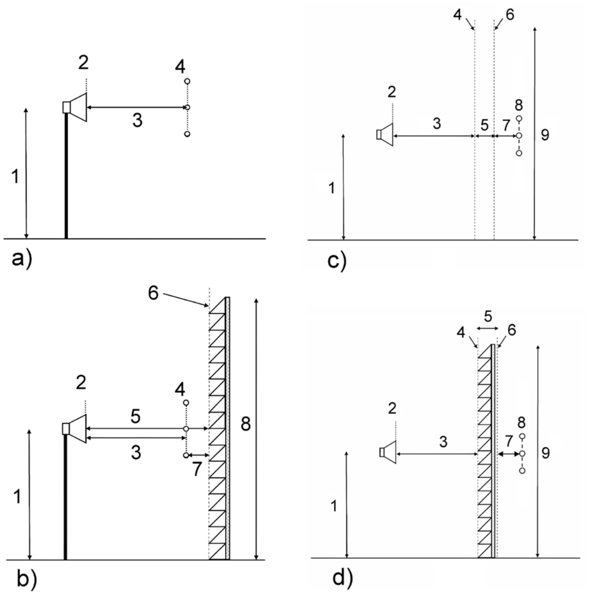


Figure 1. **a)** Free-field configuration for sound reflection measurement; 1: source height (h_S = 2 m); 2: sound source front; 3: source-microphone grid distance (1.25 m); 4: microphone antenna. **b)** Set up for sound reflection measurement in front of the noise barrier; 5: source-reference surface distance (d_S = 1.5 m); 6: barrier reference surface; 7: microphone grid-reference surface distance (d_M = 0.25 m); 8: barrier height h_B. **c)** Free-field configuration for sound insulation measurements; 1: source height (h_S = 2 m); 2: sound source front; 3: source-reference surface distance (d_S = 1 m); 4: barrier reference surface; 5: barrier thickness; 6: reference surface of barrier backside; 7: microphone grid-reference surface distance (d_M = 0.25 m); 8: microphone grid; 9: barrier height h_B; **d)** Set up for sound insulation measurements across the noise barrier.

2.1 Sound Reflection and Insulation measurements

The sound reflection measurement procedure follows the standard EN 1793-5 [1]. Two impulse response measurements are done, one in the free-field configuration and the other in front of the noise barrier, with the geometrical set up shown in Figure 1 a) and b). The sound insulation measurement procedure follows the standard EN 1793-6 [2]. Again, two impulse response measurements are done, one in free-field and the other across the barrier, following the configurations in Figure 1 c) and d). A detailed description of these measurement procedures can be found in refs [4]-[7]. Impulse responses were measured using an MLS signal, following the best practices described in refs [8]-[18].

2.2 Measuring equipment

The A22 measurement system consists of the following instruments: sound source Phon-X with its amplifier, PCB microphones model PCB 130F20, PCB microphone preamplifiers 480B21, RME Fireface UFX II audio interface, Projectlead Traveller Pro 2.0 computer, MCIRMS measurement software. The UNIBO measurement system uses: custom sound source based on Sica Z002601 loudspeaker (120 W, 8 Ω) and class D amplifier model ST CCA044V1, described in [7], PCB microphones model PCB 130F20, IEPE/ICP preamplifier TMP PS12A, MADI digital audio interface RME MADIface XT connected via coaxial cable (MADI protocol) to RME M-16 AD multichannel ADC converter, Projectlead Traveller Pro 2.0 computer, MCIRMS measurement software.

2.3 Weather conditions

Figure 2. Weather conditions measurement

During the entire measurement campaign, weather conditions were monitored using certified instrumentation to verify compliance with EN 1793-5 requirements and EN 1793-6 (see Figure 2). The following average values were measured during the day: air temperature 27 °C, relative humidity 52%, atmospheric pressure 102640 Pa, average barrier surface temperature 32.8 °C, maximum air speed 1.3 m/s.

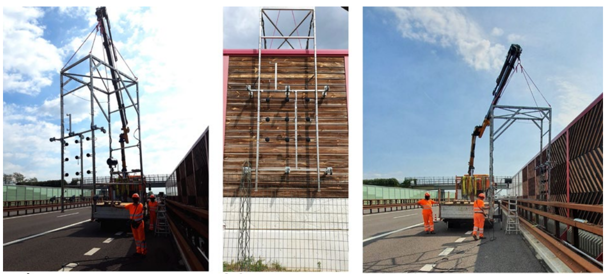
2.4 Noise reducing device under test

a) b)

Figure 3. A noise barrier during the measurements. a) road traffic side, b) backside

Figure 3 a) shows the surface of the noise barrier exposed to road traffic, which consists of a sound absorbing layer, thickness 120 mm, in thermo-regulated synthetic fibres of recycled polyester, protected by an acoustically transparent black fabric, and a series of decorative wooden slats mounted in a zig-zag pattern. The back side of the noise barrier, visible in Figure 3 b), consists of wooden boards. The front and back sides are connected by a pine wood frame with beams and uprights at a distance of 0.605 m. These acoustic elements are placed on a curb in porous concrete 0.50 m high. The total noise barrier height is 4 m.

2.5 A22 Measurement systems

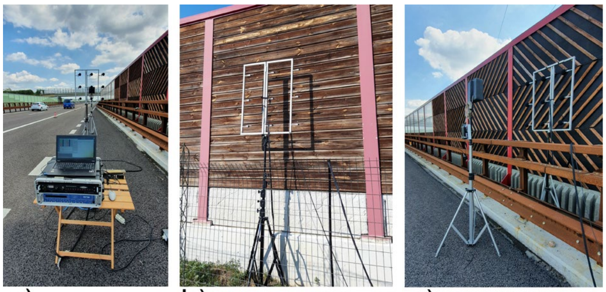


a) b) c)

Figure 4. Measurements with the A22 system: a) in the free-field, b) sound insulation, c) sound reflection

Figure 4 a) shows the suspended A22 measurement system [3], during the free-field measurement. Figure 4 b) shows the suspended system placed across the noise barrier from the top during the sound insulation measurement. Figure 4 c) shows the sound reflection measurement, for which the suspended stand is placed in front of the noise barrier side exposed to road traffic.

2.6 UNIBO measurement system



a) b) c)

Figure 5. Measurements with the UNIBO system: a) free-field, b) sound insulation, c) sound reflection

Figure 5 a) shows the UNIBO measurement system during free-field measurement. Figure 5 b) shows the microphone grid placed in front of the back side of the barrier, during the sound insulation measurement. Figure 5 c) shows the sound reflection measurement on the noise barrier side exposed to road traffic. The UNIBO system has been extensively tested, even under critical conditions [5] and for measurements on unconventional materials [6].

3. SOUND INSULATION MEASUREMENTS

Over a single day session, a series of 10 sound insulation measurements were taken with both systems on the same noise barrier field (one field includes the acoustic elements between two subsequent posts), repositioning the system each time, both for the measurement across the barrier and for the free-field one. An attempt was made, as far as possible, to place the loudspeaker-microphone grid system in exactly the same place close to the noise barrier each time, since imperfections or defects in mounting in different positions of the field could cause differences in the results and affect the repeatability test. A small discrepancy between the placements of the two systems was unavoidable, considering the criticalities of the measurement location, especially on the motorway side, while road traffic was flowing.

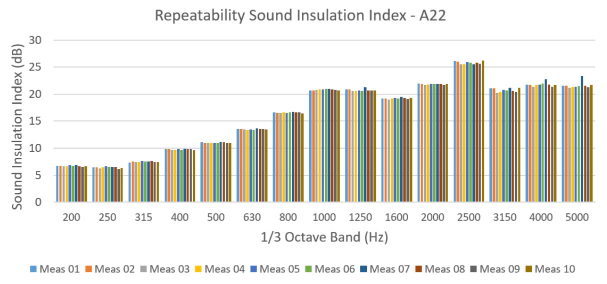


Figure 6. A22 Sound Insulation Index measurements

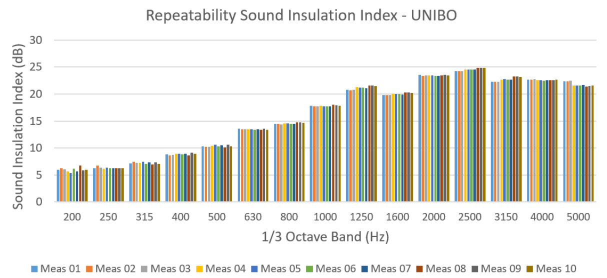


Figure 7. UNIBO Sound Insulation Index measurements

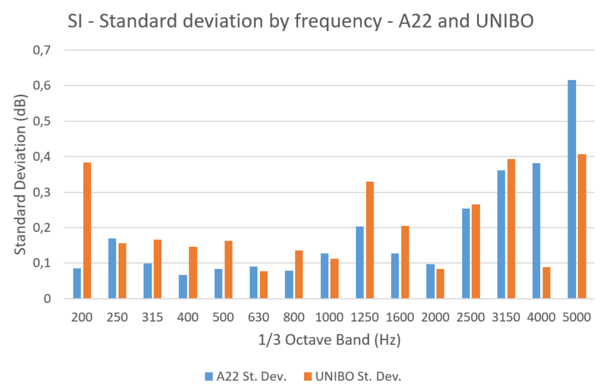


Figure 8. Standard deviation of Sound Insulation Index for the A22 and UNIBO measurements

Figure 6 shows the 10 Sound Insulation Index measurements made with the suspended A22 system and Figure 7 shows the 10 Sound Insulation Index measurements made with the UNIBO system. In both cases only minimal differences are observable due to the slight shifts between the measurement positions, revealing some inhomogeneities inside the acoustic elements. The results are presented in the one-third octave bands from 200 Hz to 5 kHz, as the lowest reliable frequency band is the 200 Hz one due to the size of the active surface [2].

Table 1. Standard deviation values, in dB, after 10 measurements and repeatability s_r after EN 1793-6 [2]

1/3 Octave Band (Hz)	A22 SI St. Dev.	UNIBO SI St. Dev.	EN 1793-6 SI s_r
200	0.09	0.38	1.70
250	0.17	0.16	1.03
315	0.10	0.17	1.21
400	0.07	0.15	1.14
500	0.08	0.16	1.20
630	0.09	0.08	1.28
800	0.08	0.14	1.47
1000	0.13	0.11	1.97
1250	0.20	0.33	1.83
1600	0.13	0.21	1.88
2000	0.10	0.08	0.97
2500	0.25	0.27	0.93
3150	0.36	0.39	1.53
4000	0.38	0.09	2.50
5000	0.62	0.41	2.22

Figure 8 and Table 1 show the standard deviation values of the 10 measurements shown in Figures 6 and 7, distinct for each measurement system and one-third octave frequency band. For both systems, quite low values are observed, generally less than 0.5 dB, with some slight increase at the extreme frequency bands. These results are also smaller than the standard deviation of repeatability obtained in the QUIESST project [4] and reported in EN 1793-6 [2] (see last column of Table 1). This confirms the high repeatability of sound insulation measurements with the two system described here.
The single-number ratings DL_{SI} in the 200-5000 Hz one-third octave bands were calculated for each measurement with the two systems, see Figure 9 and Table 2. There is a slight difference between the results of the two systems, however smaller than 1 dB in all one-third octave bands. This may be due to the not perfectly coincident measurement positions, as highlighted above, but an excellent repeatability of the single-number rating DL_{SI} for both systems is shown, with a standard deviation of 0.06 dB, visible in Table 2 and Figure 10. This small standard

deviation is well below the value found by the international round robin [4] of 1.03 dB.

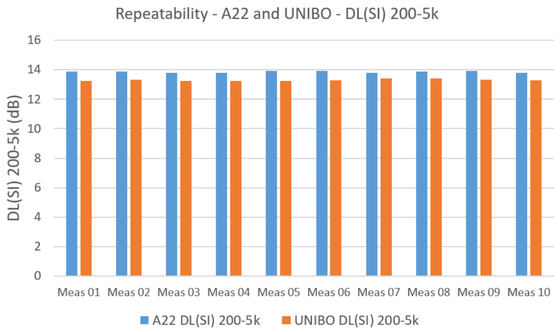


Figure 9. Values, in dB, of DL_{SI} in the 200-5000 Hz frequency bands after 10 measurements with the A22 and UNIBO measurement systems

Table 2. Standard deviation values, in dB, of DL_{SI} in the 200-5000 Hz frequency bands after 10 measurements; see Figure 9

	A22 DL_{SI} 200-5k (dB)	UNIBO DL_{SI} 200-5k (dB)
Meas 01	13.88	13.23
Meas 02	13.89	13.33
Meas 03	13.78	13.23
Meas 04	13.81	13.23
Meas 05	13.91	13.25
Meas 06	13.94	13.29
Meas 07	13.78	13.39
Meas 08	13.89	13.39
Meas 09	13.93	13.31
Meas 10	13.81	13.27
Mean	13.86	13.29
St. Dev.	0.06	0.06

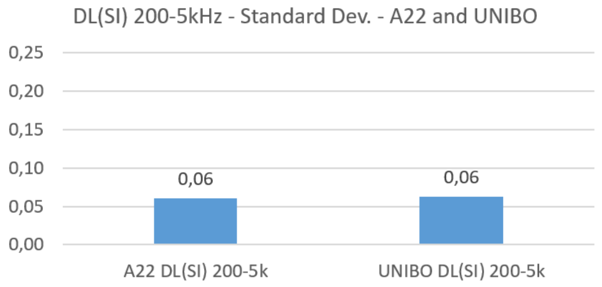


Figure 10. Standard deviation DL_{SI} 200-5kHz for the ten A22 and UNIBO measurements

4. SOUND REFLECTION MEASUREMENTS

Similar to the results presented in the previous section, a series of 10 sound reflection measurements were made with both systems on the same noise barrier field, repositioning the system each time, both for the measurement close to the noise barrier and for the free-field one. Again, an attempt was made to place the loudspeaker-microphone grid system in exactly the same position in front of the noise barrier each time, as far as possible. It should be noted that the non-flat surface, due to the zig-zag mounted wooden strips, makes the result highly sensitive to the exact positioning of the microphones. Since the described tests were related to the repeatability of the measurement system, 10 measures were taken at the (presumed) same point of the barrier with both systems without making measurement series at other positions; it would not have been possible to make these additional series with both systems on the same day for time reasons, whereas dividing the measurements over several working days would have increased the uncertainties due to external factors such as temperature, humidity and air speed.

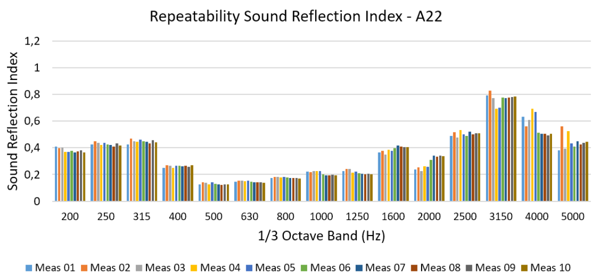


Figure 11. A22 Sound Reflection Index measurements

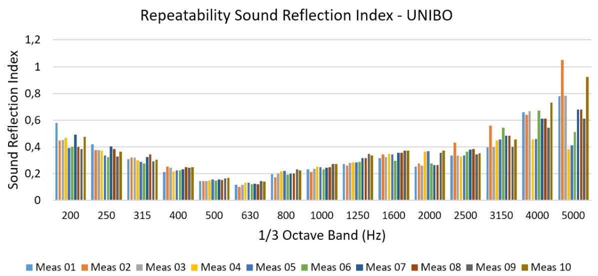


Figure 12. UNIBO Sound Reflection Index measurements

Figure 11 reports the 10 Sound Reflection Index measurements made with the suspended A22 system and Figure 12 shows the 10 Sound Reflection Index measurements made with the UNIBO system. Again, some differences are observable between the measured values obtained with the two measurement systems due presumably to an imperfect overlap of the measurement positions. These differences are more pronounced than for the sound insulation measurements due to the non-flat surface of the barrier; in fact, the wooden slats influence the high frequency sound reflected toward the microphones. It is also possible to observe a higher variance, especially in high frequency, in the data measured by UNIBO compared to the A22 system, which keeps always fixed the distance between the loudspeaker and the microphones, installed on the suspended structure.

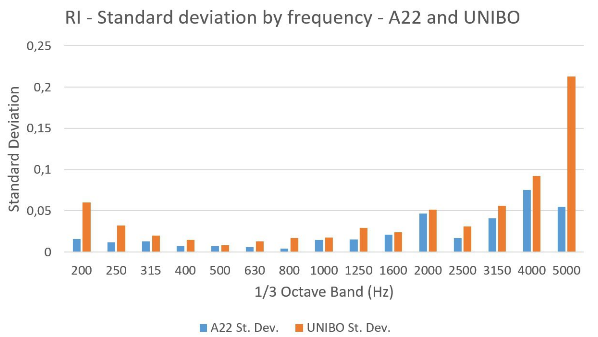


Figure 13 Standard deviation of the Sound Reflection Index for the A22 and UNIBO measurements

Figure 13 and Table 3 show the standard deviation values of the 10 measurements shown in Figures 11 and 12, distinct for each measurement system and one-third octave frequency band. For both systems, quite low values are observed, with an increase at high frequency due to the effects of the non-flat wooden slats. These results are also smaller than the standard deviation of repeatability obtained in the QUIESST project [4] and reported in EN 1793-5 [1] (see last column of Table 3). This confirms the high repeatability of sound insulation measurements done with the two measurement systems described here, with a slightly higher performance (lower data variability) of the suspended A22 system.

Table 3. Standard deviation values, in dB, after 10 measurements and repeatability s_r after EN 1793-5 [1]

1/3 Oct Band	A22 RI St. Dev.	UNIBO RI St. Dev.	EN 1793-5 SI s_r
200	0.02	0.06	0.08
250	0.01	0.03	0.08
315	0.01	0.02	0.08
400	0.01	0.01	0.07
500	0.01	0.01	0.07
630	0.01	0.01	0.09
800	0.00	0.02	0.10
1000	0.01	0.02	0.09
1250	0.02	0.03	0.10
1600	0.02	0.02	0.12
2000	0.05	0.05	0.11
2500	0.02	0.03	0.11
3150	0.04	0.06	0.12
4000	0.08	0.09	0.15
5000	0.06	0.21	0.17

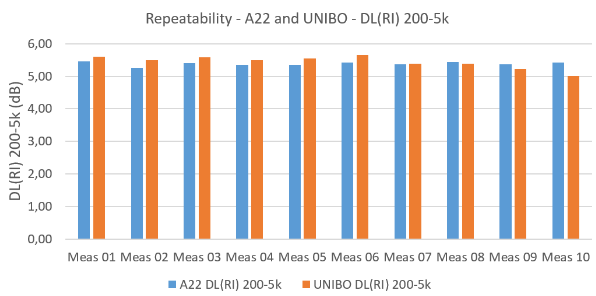


Figure 14. Values, in dB, of DL_{RI} in the 200-5000 Hz frequency bands after 10 measurements with the A22 and UNIBO measurement systems

Table 4. Standard deviation values, in dB, of DL_{RI} in the 200-5000 Hz frequency bands after 10 measurements; see Figure 14

	A22 DL_{RI} 200-5k (dB)	UNIBO DL_{RI} 200-5k (dB)
Meas 01	5.45	5.61
Meas 02	5.27	5.49
Meas 03	5.41	5.59
Meas 04	5.35	5.50
Meas 05	5.35	5.54
Meas 06	5.42	5.66
Meas 07	5.38	5.38
Meas 08	5.44	5.39
Meas 09	5.38	5.22
Meas 10	5.43	5.02
Mean	5.39	5.44
St. Dev.	0.05	0.20

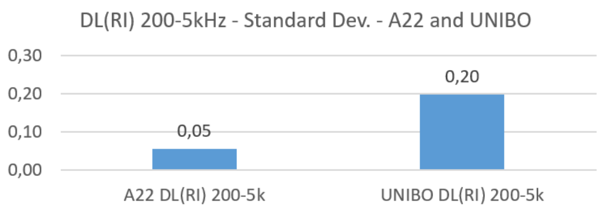


Figure 15. Standard deviation DL_{RI} 200-5kHz for the ten A22 and UNIBO measurements

The single-number ratings DL_{RI} in the 200-5000 Hz frequency range have been calculated for each of the measurements made with the two systems, see Figure 14 and Table 4. A slight difference between the results with the two systems, less than 0.5 dB in all 1/3 octave bands, is observed, due to unavoidable small shift among the nominally identical measurement positions, as in the previous case. Excellent repeatability is shown also for the DL_{RI} values in the 200-5000 Hz frequency range for both systems, with a standard deviation of 0.05 dB for the A22 system and 0.20 dB for the UNIBO system, as visible in Table 4 and Figure 15. The values for both systems are largely less than the value found by the international round robin [4] of 0.54 dB.

5. CONCLUSIONS

The presented work shows an excellent repeatability of measurements made on the same field (post-to-post) of an installed noise barrier with the two measurement systems in use at A22 and UNIBO. For both Sound Insulation Index and Sound Reflection Index and both measuring equipments, the standard deviation among repeated measurements is significantly lower than the values obtained from the international round robin test [4]. The A22 system allows measurements on a large number of fields to be obtained quickly, combined with increased accuracy and greater repeatability due to the firm connection between loudspeaker and microphone grid.
These findings support the extensive use of the EN 1793-5 and EN 1793-6 method to evaluate the installed noise barrier on site, which can be used for quality control and long-term performance assessment of the material and installation quality, as attempted for example in [19]. Further research will be devoted to develop a statistically sound procedure to sample a representative set of noise barrier fields, thus avoiding the need to test all fields of a long noise barrier, and to assess the relative advantages and disadvantages of the quick method proposed in [7] versus of the standard method shown here.

6. REFERENCES

[1] EN 1793-5:2016/AC:2018 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.

[2] EN 1793-6:2018/A1:2021: 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.

[3] M. Garai, P. Guidorzi, A. Osele, C. Costa. On-site check of the intrinsic acoustic characteristics of noise barriers: preliminary results on the Italian A22 highway. Forum Acusticum, Dec. 2020, Lyon, France, pp.431-437, doi: 10.48465/fa.2020.0090.

[4] M. Garai, E. Schoen, G. Behler, B. Bragado, M. Chudalla, M. Conter, J. Defrance, P. Demizieux, C. Glorieux, P. Guidorzi: "Repeatability and

reproducibility of in situ measurements of sound reflection and airborne sound insulation index of noise barriers", Acta Acustica united with Acustica, vol. 100, pp. 1186-1201, 2014.

[5] M. Garai, P. Guidorzi: "Sound reflection measurements on noise barriers in critical conditions", Building and Environment, vol. 94, no. 2, pp. 752-763, 2015.

[6] F. Morandi, M. Miniaci, P. Guidorzi, A. Marzani, M. Garai, "Acoustic Measurements on a Sonic Crystals Barrier", Energy Procedia, vol. 78, pp. 134-139, 2015.

[7] P. Guidorzi and M. Garai: "A Low-Cost System for Quick Measurements on Noise Barriers in Situ", IEEE Transactions on Instrumentation and Measurement, vol. 71, pp. 1-14, 2022, Art. no. 6503714, doi: 10.1109/TIM.2022.3218037.

[8] J. Borish, and J. B. Angell, "An Efficient Algorithm for Measuring the Impulse Response Using Pseudorandom Noise" J. Audio Eng. Soc., vol. 31, no. 7/8, pp. 478-488, 1983.

[9] D. D. Rife, J. Vanderkooy, "Transfer-function measurement with maximum-length sequences", J. Audio Eng. Soc., vol. 37, no. 6, pp. 419–444, 1989.

[10] D. D. Rife, "Modulation Transfer Function Measurement with Maximum Length Sequences", J. Audio Eng. Soc., vol. 40, no. 10, pp. 779-790, 1992.

[11] J. Vanderkooy, "Aspects of MLS measuring systems", J. Audio Eng. Soc., vol. 42, no. 4, pp. 219-231, 1994.

[12] E. Mommertz, "Angle-dependent in-situ measurements of reflection coefficients using a subtraction technique", Applied Acoustics, vol. 46, no. 3, pp. 251–263, 1995.

[13] M. Vorländer, M. Kob, "Practical aspects of MLS measurements in building acoustics" Applied Acoustics, vol. 52, no. 3-4, pp. 239-258, 1997.

[14] J.L. Nielsen, "Improvement of Signal-to-Noise Ratio in Long-Term MLS Measurements with High-Level Nonstationary Disturbances", J. Audio Eng. Soc., vol. 45, no. 12, pp. 1063-1066, 1997.

[15] M. Vorländer, E. Mommertz, "Guidelines for the application of the MLS technique in building acoustics and in outdoor measurements", in Proceedings Inter-Noise 97, pp. 1457-1462, August 1997.

[16] G. Stan, J.J. Embrechts, D. Archambeau, "Comparison of Different Impulse Response Measurement Techniques", J. Audio Eng. Soc., vol. 50, no. 4, pp. 249-262, 2002.

[17] D. Ćirić, "Comparison of influence of distortion in MLS and Sine Sweep technique", in 19th International Congress on Acoustics, paper RBA-07-020, September 2007.

[18] P. Robinson, N. Xiang, "On the subtraction method for in-situ reflection and diffusion coefficient measurements", J. Acoust. Soc. Am., vol. 127, no. 3, EL99, 2010.

[19] A. Fuchs, M. Conter, R. Wehr, "Proposal for an in-situ approval testing and quality assurance procedure for assessing sound reflection properties of noise barriers", in Proc. 24th International Congress on Sound and Vibration, ICSV 2017, Paper ID 728, July 2017.