RECENT ADVANCES IN NOISE BARRIERS TESTING, QUALIFYING AND STANDARDISATION

M Garai University of Bologna, Bologna, Italy

1 INTRODUCTION

The standardization activity inside CEN (European Standardization Committee) is giving an important contribution to the definition of the technical characteristics of noise barriers and related devices; new test methods have been purposely developed and validated. Sound absorption and airborne sound insulation in a reverberant sound field (like inside tunnels or deep trenches) are tested in laboratory using optimized versions of the ISO 354 and ISO 140-3 standards. The same properties can also be measured in a direct sound field, e.g. in situ on free standing noise barriers, thanks to a new method based on an impulsive technique with the use of a deterministic test signal. A similar technique can also be applied to characterise sound diffraction of “added devices” which may be placed on the top of noise barriers. The principles of these methods are presented here together with real life results.

Other standards dealing with non-acoustic performances (like mechanical resistance and fire reaction) and long term performances will be briefly presented, as they concern how to keep noise barriers and related devices performing correctly for many years. In the rail sector, new standards are in preparation about insertion loss and fatigue from dynamic loads due to passing trains. In the road sector, the existing standards make it possible to prepare a “declaration of conformity” of the device according to the European rules, which authorizes affixing the CE marking on products.

For the sake of generality, in this paper we will speak of the general class of noise reducing devices (NRD) including:

- noise barriers: NRD’s which obstruct the direct transmission of airborne sound emanating from road or railways; they may also span or overhang the noise source;
- claddings: NRD’s attached to a wall or other structure and reducing the amount of sound reflected;
- added devices: components added on the top of a noise barrier that influence the acoustic performance of the original NRD acting primarily on the diffracted energy.

NRD’s may include both acoustic and structural elements (e.g. panels and posts). NRD’s have “extrinsic” and “intrinsic” characteristics:

1. extrinsic characteristic: it is the acoustic effectiveness in reducing noise levels at a given receiver position; it is commonly called insertion loss (IL); it depends not only on the NRD itself, but also on the environment (given geometry, ground impedance, local atmospheric conditions, etc.);

2. intrinsic characteristics: they depends only on the device itself and not on the environment; they include sound absorption, airborne sound insulation, sound attenuation by diffraction of devices added on the top of acoustic barriers, etc.

The insertion loss qualifies the design of the work; the achievement of the predicted insertion loss is primarily a responsibility of the designer. The intrinsic characteristics belong to the product, rather than to the construction work, and are primarily a responsibility of the manufacturer and/or the installer.

2 ACOUSTIC CHARACTERISTICS

2.1 Insertion loss

The insertion loss is deemed to be the most important characteristics of a NRD. There exist many analytical methods to predict the IL of a given noise barrier (for a comprehensive review see Li and Wong[16]); on the other side, its assessment by measurements on site is much more difficult than expected, as it depends on many parameters; this partly explains why IL measurements are not yet standardised at an international level, apart for ISO 10487[1] which, on the other hand, has been rejected by CEN. The main reasons for the European disagreement are the poor reliability of the whole procedure and the lack of operational applicability on real sites[17]. Some countries tried to produce their own national standard, but it is clear that a robust, widely acknowledged international standard is needed. CEN/TC 256/SC 1/WG 40 put the item on its work plan. It is hoped that some advancement in the knowledge on the near field-far field connection could come from the QUIESST project (EU funded).

2.2 Sound absorption

Laboratory measurements of sound absorption, described in EN 1793-1[3] for the road sector, follow the principles of the EN ISO 354[2] test method, optimized for noise barriers or claddings for retaining walls or tunnels. A similar standard is under preparation for the rail sector. The test method in EN ISO 354 assumes a ***diffuse sound field*** (where all angles of incidence are equally probable) and is strictly valid only for flat absorbers; for example, green walls are out of the range of applicability of the standard; in particular, ISO 354 excludes devices which act as slightly damped resonators. Thus, EN 1793-1 should not be used to determine completely the intrinsic characteristics of sound absorption for noise reducing devices to be installed in non reverberant conditions, e.g. alongside highways or railways in open space; its range of applicability is limited to products to be installed inside tunnels or deep trenches or under covers.

In order to test NRD in a ***direct sound field***, in France the AFNOR NF S 31-089[7] was developed. It is based on the transient signal produced by a blank gunshot, processed with an analysis window 2,9 ms long (implying a low frequency limit of about 350 Hz); the high frequency limit depends on the depth *e* of surface irregularities and the sound speed *c*:

$$f_{max} = \frac{c}{4e} \qquad (1)$$

A big step forward came from the European research project *Adrienne*[20] which produced innovative methods for testing the sound reflection/absorption and the airborne sound insulation characteristics of noise reducing devices ***in situ***. These methods are now included in the technical specification CEN/TS 1793-5[8]. The *Adrienne* method is based on the recovering of an acoustic impulse response close to the barrier under test[18]. A loudspeaker is placed facing the traffic side of the noise reducing device and a microphone is placed between the sound source and the device under test (Figure 1).

With the loudspeaker emitting a transient sound, the microphone receives both the direct sound pressure wave traveling from the sound source to the device under test and the sound pressure wave reflected (including scattering) by the device under test. The power spectra of the direct and the reflected components, corrected to take into account the path length difference of the two components, gives the basis for calculating a quantity called sound reflection index[8]. The sound reflection index is calculated using the signal subtraction technique[19, 20] that requires an exact reproduction of the time signals for both the direct and (direct + reflected) components.

Measurements must be repeated at nine incidence angles for a flat sample; for non-flat or non homogeneous samples, the number of measurements to average is increased[8].

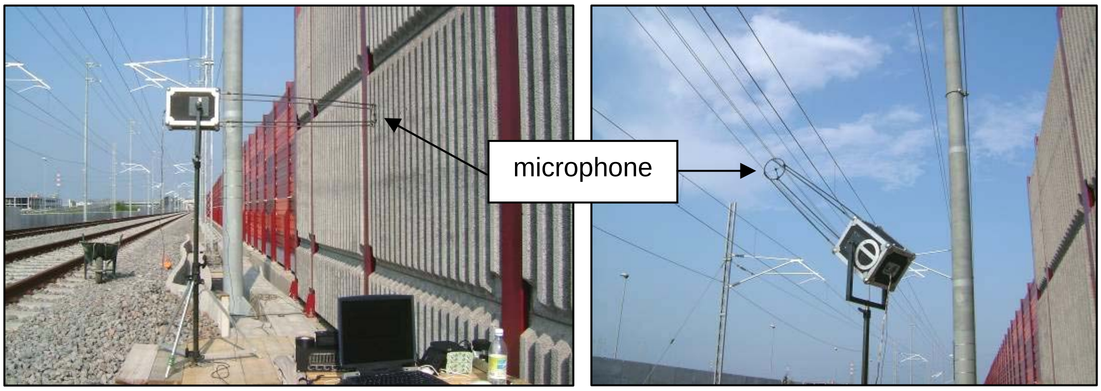

Figure 1. Reflection index measurement set-up in front of a non flat noise reducing device: reflected components measurements (left) and "free-field" (incident) component measurement (right).

The low frequency limit is inversely proportional to the width of the analysis window and depends also on its shape; for an Adrienne window 7,9 ms wide this limit is about 160 Hz [18, 20, 21]. The angle averaging influences this limit: it is the reason why, in CEN/TS 1793-5 [8], it is limited to 90° ± 0° below 200 Hz, ± 10° at 250 Hz, ± 30° at 315 and 400Hz, and ± 40° over 400 Hz.

Figure 2 shows the reflection index - measured following CEN/TS 193-5 - of a non flat noise barrier which is impossible to test in the reverberation room, because of its volume, and also using the AFNOR standard, because eq. (1) gives a high frequency limit of about 430 Hz.

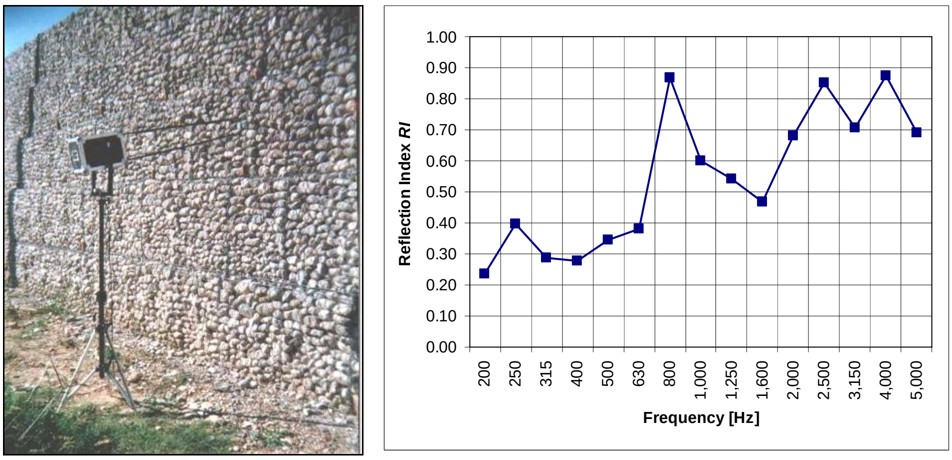

Figure 2. A non flat noise barrier (left) and its sound reflection index (right).

2.3 Airborne sound insulation

Laboratory measurements of airborne sound insulation, described in EN 1793-2[5] for the road sector, follow the principles of the EN ISO 140-3[4] test method, optimized for noise barriers which can reasonably be assembled inside the testing facility described in EN ISO 140-3 (again, devices like green walls are excluded). A similar standard is under preparation for the rail sector. The test method in EN ISO 140-3 assumes a ***diffuse sound field*** (where all angles of incidence are equally probable). Thus, EN 1793-2 should not be used to determine the intrinsic characteristics of airborne sound insulation for noise reducing devices to be installed in non reverberant conditions, e.g.

alongside highways or railways in open space; its range of applicability is limited to products to be installed inside tunnels or deep trenches or under covers.

The *Adrienne* method (CEN/TS 1793-5[8]) is designed to test NRD's in a ***direct sound field***. Using it, a loudspeaker is placed facing the traffic side of the noise reducing device; a microphone grid (9 positions or scanning points) is placed on the opposite side. The loudspeaker emits a transient sound wave that is partly reflected, partly transmitted and partly diffracted by the NRD (Figure 3). The microphones receive: the transmitted sound pressure wave, traveling from the sound source through the NRD to the grid, and the sound pressure waves diffracted by the edges of the NRD. The power spectra of the direct and the transmitted components, at each microphone position, give the basis for calculating the outdoor sound transmission loss, which has been called sound insulation index[8]. The final sound insulation index is the logarithmic average of the nine results. A set of nine measurements must be repeated in front of the acoustic elements and in front of a post.

Comparisons between field and laboratory results show a quite acceptable correlation for sound reflection (r = 0,89) and a very good correlation for sound insulation (r = 0,97 for acoustic elements; r = 0,93 for posts): existing differences can be explained with the different sound fields, averaging techniques and mounting conditions between the outdoor and laboratory tests[22, 23, 24].

Figure 3. Sound insulation index measurement set-up in front of a transparent noise barrier: transmitted components measurements (left) and "free-field" (incident) component measurement (right).

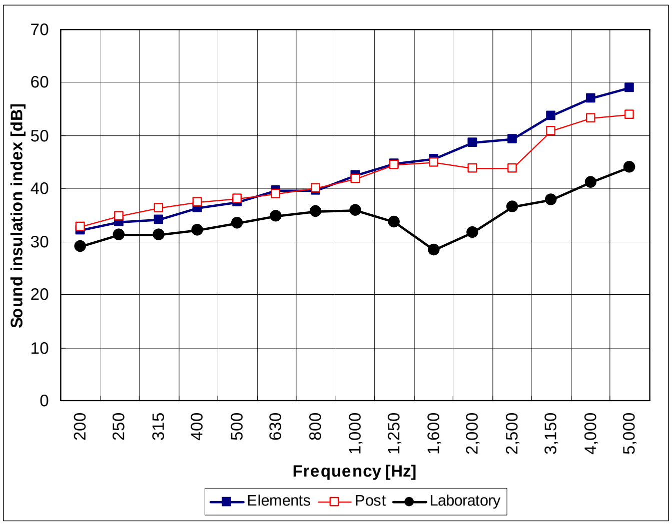

Figure 4. Sound reduction index, measured in the laboratory according to EN 1793-2, and sound reflection index, measured in situ according to CEN/TS 1793-5, of PMMA sheets on metallic frame.

Figure 4 shows the airborne sound insulation of a noise barrier made of PMMA sheets on metallic frame measured in the laboratory and in situ. In the first case the diffuse sound field gives rise to the coincidence effect (sharp dip at 1600 Hz); which doesn't exist in the second case. The single-number ratings are DL_R = 33 dB in the laboratory, DL_{SI} = 40 dB on site.

2.4 Intrinsic diffraction

Part of the market of traffic noise reducing devices is constituted of products designed to be added on the top of noise reducing devices and intended to contribute to sound attenuation, acting primarily on the diffracted sound field; these products are called "added devices". CEN/TS 1793-4[9] is the only international standard to qualify them.

The added device under test is installed on a reference wall. A loudspeaker emits a transient sound wave that travels toward the device under test and is partly reflected, partly transmitted and partly diffracted by it (Figure 5). The microphone array placed on the other side of the wall receives both the transmitted sound pressure wave traveling from the sound source through the wall and the sound pressure wave diffracted by the top edge, including the added device under test. If the measurement is repeated without anything between the loudspeaker and the microphones, a direct free-field wave can be acquired. The power spectra of the direct and the top-edge diffracted components, at each microphone position, give the basis for calculating the *diffraction index*. The whole procedure is carried out twice: one with, and one without the added device placed on the reference wall (keeping the same total height). The *diffraction index difference* is then calculated: this is the relevant characteristic of the added device under test. For a complete qualification, the reference wall must be made both reflective and covered with a sound absorbing lining[9, 25].

Figure 5. Sound diffraction index measurement on a prototype added device placed on a reference wall in the sound absorbing configuration.

2.5 Single-number ratings

For classification purposes, a single-number rating following a normalized road or rail noise spectrum can be calculated for sound absorption, airborne sound insulation or intrinsic diffraction (for the road spectrum see EN 1793-3[6]). The use of single-number ratings is solely for the purposes of comparing the overall performance of noise barriers and related devices, irrespective of local conditions, road or rail traffic composition and road or track type. However, presentation of results in one third octave bands may be more informative than single-number ratings when selecting products.

3 NON ACOUSTIC CHARACTERISTICS

Apart safety concerns, NRD's are exposed to a range of forces due to wind, air pressure caused by passing traffic (vehicles or trains), and self weight. They may also be subjected to shocks caused by stones or other debris thrown up by passing vehicles/trains and, for roads in some countries, the dynamic force of snow clearance devices. The deflections caused by such loads during the working life should not reduce the acoustic performance of NRD's. In order to correctly select new NRD's to be installed along roads, EN 1794-1[10] provides criteria to categorise NRD's according to basic mechanical performance under standard conditions of exposure, irrespective of the materials used. A range of conditions and optional requirements is provided to allow for the wide diversity of practice within Europe.

Moreover, NRD's should not support the spread of fire from adjacent brushwood, should not reflect light in such a way as to prejudice the visual capabilities of vehicles or train drivers, should be made from materials which do not emit dangerous smokes or release breakdown products which might in time have adverse effects on the environment (either as the result of natural or industrial processes, or as the result of fire). Finally NRD's should allow a means of escape by road/rail users and access by operatives in the event of an emergency. EN 1794-2[11] provides criteria and test methods to categorise NRD's according to the above mentioned characteristics. CEN experts are also thinking about a fire reaction test more demanding than the brushwood fire test in EN 1794-2.

EN 1794-1 and EN 1794-2 are for the road sector; similar standards are in preparation for the rail sector, including also electrical ground connection of components (for safety issues) and dynamic load due to passing trains and fatigue.

3.1 Dynamic loads and fatigue

In EN 1794-1 for the road sector, the air pressure caused by passing vehicles is treated like a static load. The situation is more severe for high speed railways lines. It has been experienced that the shock waves produced by passing trains (se Figure 6 [26]) induce vibrations into the whole noise barrier which, in extreme cases, may cause panel detachments with consequent safety risks. Therefore CEN/TC 256/SC 1/WG 40 decided to tackle this problem at 360°, drafting:

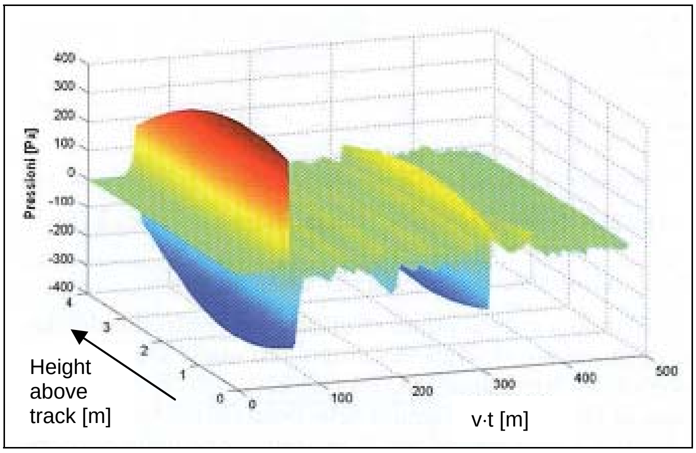

Figure 6. Three-dimensional view of the pressure distribution on aluminum panels caused by a train running at 290 km/h. Distance of the noise barrier from the nearest track: 4,32 m (after ref.[26]).

- a calculation method for dynamic loading due to passing trains, including the amplification factor due to the interaction of the input air pressure wave produced by passing trains with the natural frequency of the noise barrier (Eurocodes don't fully cover this issue, but a German guideline is available[12]);

- various test methods, in order of increasing complexity, including both the flexural and bending effects, local tests on small elements as well as global tests on a complete wall portion, and evaluation of fatigue resistance as a function of he number of cycles.

3.2 Long term durability

NRD's alongside roads and rails should not only fulfill their acoustic and structural design requirements, but also maintain their performance during the required working life. This point is not easy to assess, as NRD's can be made from different combinations of different materials, each one possibly reacting in different manners to ageing. Specific standards have been released, regarding acoustic (EN 14389-1[13]) and non-acoustic characteristics (EN 14389-2[14]). In particular, the increasing use of CEN/TS 1793-5[8] recommended in EN 14389-1[13] could be of great help in order to understand how ageing influences the actual in-situ acoustic performances.

In the revision and extension to the rail sector of above mentioned standards, it is planned to take into account also the resistance to vandalism, the systems and products (chemicals) to remove graffiti, the electrical insulation against currents inducted in the ground by the train power traction and the corrosion due to electricity, ozone, etc..

4 RELATION WITH OBLIGATORY REQUIREMENTS

In the road sector, all standards are recalled in EN 14388[15], which is a harmonized standard (hEN). This means that it meets the requirements of a mandate (M/111) given to CEN by the European Commission under the EU Construction Products Directive (89/106/EEC) and therefore compliance with EN 14388 confers a presumption of fitness of a noise reducing device for the intended uses, as indicated; this establishes the conditions for the CE marking, obligatory from 1st May 2007.
In the rail sector, EN standards should conform to Technical Specifications for Interoperability (TSI), which in turn specify the essential requirements expressed in the relevant Directives, but can also express the state of the art, laying down a code of practice widely acknowledged by Railways Authorities.

5 CONCLUSIONS

The acoustics characteristics of noise barriers and related devices can be evaluated using laboratory tests in a diffuse sound field and the *Adrienne* methodology in a direct sound field. Non acoustic characteristics are as important as the acoustic ones and can be evaluated by laboratory tests or calculation methods.

The standardization work began about 20 years ago in the road sector, which has now a complete package of standards and CE marking of products, and is now entering the rail sector. Two European research projects, one past ADRIENNE) and one current (QUIESST), provide the background research. Topics to be covered in the future include: reliable measurement of insertion loss, evaluation of dynamic loads due to passing trains and related fatigue effects, better evaluation of reaction to fire.

Overall, the European qualification system for noise barriers and related devices can be considered the most advanced in the world.

6 REFERENCES

1. ISO 10847, Acoustics – In situ determination of outdoor insertion loss of acoustic barriers of all types. (1997).
2. EN ISO 354, Acoustics - Measurement of sound absorption in a reverberation room. (2003).

3. EN 1793-1, Road traffic noise reducing devices — Test method for determining the acoustic performance — Part 1: Intrinsic characteristics of sound absorption. (1997).
4. EN ISO 140-3, Acoustics – Measurement of sound insulation in buildings and of building elements – Part 3: laboratory measurements of airborne sound insulation of building elements. (1995).
5. EN 1793-2, Road traffic noise reducing devices — Test method for determining the acoustic performance — Part 1: Intrinsic characteristics of airborne sound insulation. (1997).
6. EN 1793-3, Road traffic noise reducing devices — Test method for determining the acoustic performance — Part 1: Normalized traffic noise spectrum. (1997).
7. AFNOR NF S 31-089. Code d'essai pour la détermination de caractéristiques acoustiques d'écrans installés en champ libre. (1990).
8. CEN/TS 1793-5, Road traffic noise reducing devices — Test method for determining the acoustic performance — Part 5: Intrinsic characteristics - In situ values of sound reflection and airborne sound insulation. (2003).
9. CEN/TS 1793-4, Road traffic noise reducing devices — Test method for determining the acoustic performance — Part 4: Intrinsic characteristics - In situ values of sound diffraction. (2003).
10. EN 1794-1, Road traffic noise reducing devices — Non-acoustic performance — Part 1: Mechanical performances and stability requirements. (1998).
11. EN 1794-2, Road traffic noise reducing devices — Non-acoustic performance — Part 2: General safety and environmental requirements. (1998).
12. DB Richtlinie 804.5501A05, Lärmschutzwände Vereinfachtes Verfahren Druck-Sog-Einwirkung.
13. EN 14389-1, Road traffic noise reducing devices — Procedure for assessing long term performance — Part 1: Acoustical characteristics. (2007).
14. EN 14389-2, Road traffic noise reducing devices — Procedure for assessing long term performance — Part 2: Non-acoustical characteristics. (2004).
15. EN 14388, Road traffic noise reducing devices — Specifications. (2005).
16. K.M. Li, H.Y. Wong, "A review of commonly used analytical and empirical formulae for predicting sound diffracted by thin screen", Appl. Acoust. 66 45-76. (2005).
17. F. Anfosso-Ledée, V. Steimer, P. Demizieux, In situ methods for the characterisation of road noise barriers efficiency, Proc. Inter-Noise 2000, 646-651. Nice (2000).
18. M. Garai, "Measurement of the sound-absorption coefficient in situ: the reflection method using periodic pseudo-random sequences of maximum length", Appl. Acoust. 39 119-39. (1993).
19. E. Mommertz, "Angle-dependent in-situ measurements of reflection coefficients using a subtraction technique", Appl. Acoust. 46 251-263. (1995).
20. Adrienne Research Team, Test methods for the acoustic performance of road traffic noise reducing devices - Final report, European Commission - DGXII - SMT Project MAT1-CT94049. (1998).
21. M. Garai, P. Guidorzi, Experimental verification of the European methodology for testing noise barriers in situ: sound reflection, Proc. Inter-Noise 2000, 477-482. Nice (2000).
22. M. Garai, P. Guidorzi, "European methodology for testing the airborne sound insulation characteristics of noise barriers in situ: experimental verification and comparison with laboratory data", J. Acoust. Soc. Am. 108(3) 1054-1067. (2000).
23. G. Watts, P. Morgan, "Measurement of airborne sound insulation of timber noise barriers: Comparison of in situ method CEN/TS 1793-5 with laboratory method EN 1793-2", Appl. Acoust. 68 421–436. (2007).
24. M. Garai, P. Guidorzi, "In situ measurements of the intrinsic characteristics of the acoustic barriers installed along a new high speed railway line", Noise Control Eng. J. 56(5) 342-355. (2008).
25. M. Garai, P. Guidorzi, Using CEN/TS 1793-4 to develop an acoustically effective added device for road traffic noise barriers (invited paper), Proc. 19th I.C.A, Paper ENV-06-004-IP. Madrid (2007).
26. L. Evangelista, A. Vittozzi, G. Silvestri, "Valutazione teorico-sperimentale del comportamento delle barriere antirumore su linee ad alta velocità", Ingegneria Ferroviaria 1/2009 35-51. (2009).