Chapter

Approaches for Noise Barrier Effectiveness Evaluation based on *In Situ* "Insertion Loss" Determination

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Abstract

In situ evaluation of the effectiveness of noise barriers may be based on the assessment of their intrinsic or extrinsic characteristics. The evaluation of intrinsic characteristics is based on acoustic properties, such as noise barrier absorption or insulation. The evaluation of the extrinsic characteristics is based on the calculation of the barrier Insertion Loss, which is defined as the difference in the noise level before and after the installation of the barrier. Insertion Loss is calculated using two different approaches: the direct and indirect methods. The direct method is used when the barrier has not been installed yet or can be removed, while the indirect method is used when the barrier is already installed and cannot be easily removed. This chapter describes the different approaches used in the scientific literature for *in situ* evaluation of the effectiveness of noise barriers and discusses the noise attenuation levels obtained with each approach.

Keywords: diffraction, effectiveness, Insertion Loss, noise barriers, traffic noise

1. Introduction

1.1 Noise barriers: the ubiquitous solution to the road noise problem

Chronic exposure to environmental noise is a widespread problem around the world, causing significant impacts on human health and well-being. Road traffic is the predominant source of noise in urban areas and represents the second most important health risk factor after air pollution [1]. In Europe, it is estimated that about 20% of the total population is exposed to road traffic noise levels considered harmful to health [2]. Moreover, the problem is expected to become more severe in the next decades. In the European Union, the population exposed to high road noise levels is projected to rise both inside and outside urban areas over the next years due to urban growth and increased demand for mobility [3].

In the last decades, the introduction of more stringent environmental noise legislation has resulted in a series of noise abatement measures of varied nature. These included urban planning measures (such as the designation of noise-sensitive areas, or regulations on vehicle speed limits or traffic restrictions), measures to improve the acoustic performance of vehicles, pavements and buildings, and the construction of noise barriers. Currently, noise barriers have become frequent features along many roads and railways.

The history of noise barriers precedes the appearance of the first generation of environmental regulations in the World. The first documented noise barrier installed on a road was built in 1963 [4]. In the following years, several new design criteria and new materials for barriers were rapidly introduced. And so, the first lightweight barriers with an absorptive treatment on the panel surface date back to the early 1970s [5]. By 1975, Japan had already built noise barriers along 79 km of new highways [6], and the USA had installed about 57 km of barriers at certain types of highway projects [4].

In the 1960s and 1970s, the first research studies were initiated to analyze the acoustic properties of barriers and calculate noise attenuation levels. Probably the most famous of these studies was the Maekawa empirical chart of 1968 [7], as well as the formulations developed by other authors based on Maekawa's original proposal [8–12]. It was also during this period that the first regulations for noise management and abatement were adopted in countries such as the USA (1972), Canada (1973), Germany (1974) and Japan (1974).

Since the 1980s, many countries have adopted Environmental Impact Assessment (EIA) legislation that requires the evaluation of, among others, proposed road projects that are likely to have significant environmental impacts. As part of the EIA process, the project developer is required to evaluate road traffic noise and must determine appropriate mitigation measures to minimize its effects. Constructing a noise barrier is probably the most mentioned mitigation measure in EIAs conducted around the world [13]. As an example of the extensive use of these devices, it was estimated that the global production of noise barriers reached approximately 370 million m^2 in 2014 [14]. In the European Union, these devices have become the most prominent noise mitigation measure applied to major roads located outside residential areas [15]; in the USA, about 5700 km of barriers have been built to date [4].

Noise barriers have been made of many different materials and have taken many different forms over time. In the past, simple reflecting barriers made of concrete, masonry blocks, or earth berms were often used, but modern barriers tend to have absorptive treatments which minimize the level of reflected noise. In recent years, a number of innovative barriers are being developed, such as combined noise and safety barriers, low-height barriers, photovoltaic barriers, noise walls with titanium dioxide (TiO_2) coating, inox/corten steel barriers, or acoustic devices based on sonic crystals [16].

The growth in the use of noise barriers has also been coupled with a growing interest in their effectiveness as a tool to reduce noise pollution. The evaluation of this effectiveness is, however, a difficult task, given that these devices are placed outdoors under very varied conditions, with diverse barrier designs and locations, fluctuating noise sources, and changing environmental conditions. This chapter outlines the fundamentals of the acoustic performance of barriers, describes the main approaches for the evaluation of their effectiveness, as well as the main findings obtained in the studies conducted on the attenuation levels measured.

1.2 Acoustic performance of noise barriers

A noise barrier is a structure that obstructs the direct transmission of airborne noise produced by a source, such as road traffic, and redistributes the sound energy into several paths (**Figure 1**):

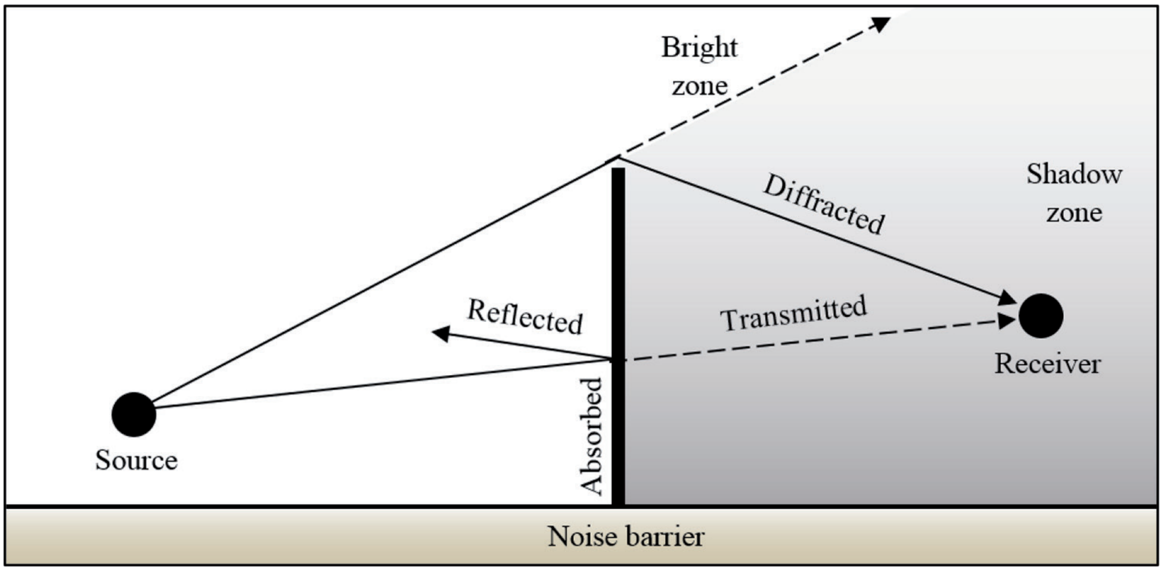

Figure 1.
The acoustic performance of a noise barrier (based on [17]).

- A reflected path, so that the noise wave reaching the exposed side of the barrier partly reflects on it. The barrier can also absorb other parts of the sound energy. Based on these acoustic properties, noise barriers are usually divided into two main groups: absorptive barriers, which are specifically designed to absorb part of the acoustic energy, and reflective barriers, from which noise is largely reflected (a special group consists of reactive barriers, which are devices that contain cavities or resonators).

- A transmitted path, so that the noise reaching the exposed side of the barrier transmits through the device itself. Therefore, the transmitted energy must be as low as possible.

- A diffracted path, over the top and around the ends of the barrier, so that the barrier acts as an obstacle to the noise propagation, diffracts noise waves, and then propagates to the protected side of the barrier with less energy. Noise diffraction is largely determined by the difference between the source-receiver direct path length and the extended path length due to the presence of the barrier.

Noise barriers cause an area of decreased sound energy behind the barrier (also called shadow zone) which is a combination of reflection, diffraction, and transmission losses. Due to the nature of sound, diffraction does not bend all frequencies uniformly: higher frequencies are diffracted to a lesser degree; lower frequencies are, by contrast, diffracted deeper into the shadow zone behind the barrier. As a result, noise barriers are generally more effective in attenuating the higher frequencies.

The acoustic performance of a noise barrier depends on a set of intrinsic and extrinsic characteristics [18]. Intrinsic characteristics refer to the properties of individual components of the barrier, such as the type, thickness, and design of the materials used. Extrinsic characteristics consider the attenuation of the barrier once it has been installed. These characteristics are mainly determined by a set of context-specific conditions, such as:

- The position of the barrier relative to the source and the receiver, and its effective height and length to block propagation paths.

- The nature of the noise source in terms of traffic volume, traffic speed, types of vehicles, and road pavement.

- The characteristics of the propagation medium, i.e., wind conditions, air temperature, and relative humidity.

- The nature of the terrain between the road and the receiver, i.e., interfering obstacles and the acoustic impedance of the ground surface.

These contextual properties largely determine the diffraction characteristics of the barrier and the global noise attenuation that can be achieved. The noise diffracted on the top and around the ends of the barrier is the most important factor limiting its acoustic performance [18].

1.3 Approaches for determining noise barrier effectiveness

Determining the effectiveness of noise barriers has attracted the attention of researchers for the past 40 years, and a wide variety of both mathematical and experimental approaches have been developed. Mathematical methods have been widely used to determine the diffraction properties of the barriers. These methods can be based on the boundary element method [19, 20], the finite element method [21, 22], and the finite difference method [23].

Experimental studies have been based on diverse approaches relating to (i) the assessment of perceived annoyance reduction efficiency of noise barriers [24, 25], (ii) the effects of noise barriers on the perception of urban soundscape quality [26], (iii) the measurement of noise attenuation based on scale model experiments [27, 28], and (iv) the measurement of the acoustic properties of full-scale barriers. The latter experiments have been the most reported in the literature, and have addressed the analysis of the effectiveness of barriers based on their various acoustic characteristics:

- Some research studies have addressed the intrinsic characteristics of barriers, such as sound absorption and insulation. Two types of measurement methods are commonly used to evaluate these properties: laboratory methods, using a diffuse sound field in a reverberation room, and *in situ* methods.

- Other studies assessed barrier performance by measuring its “Insertion Loss”, which is defined as the difference in sound pressure level before and after the barrier is constructed.

The methods for *in situ* evaluation of barrier effectiveness are described below, with a particular emphasis on those based on the determination of Insertion Loss.

2. In situ tests for evaluating intrinsic characteristics of noise barriers

A substantial part of the scientific literature on the evaluation of the acoustic properties of noise barriers has been based on the *in situ* evaluation of their intrinsic characteristics.

Figure 2.
Measurement according to the "Adrienne" method (left) [30] and "QUIESST" method (right) [31].

In Europe, *in situ* tests for measuring intrinsic characteristics have been based on standardized methods such as AFNOR 31089 [29], the European projects "Adrienne" [30] and "QUIESST" [31], and more recently the EN 1793-4, 5 and 6 standards [32–34].

The measurement system consists of a fixed source (loudspeaker) reproducing a maximum length sequence (MLS) signal [30, 31] or a gunshot [29]. With these kinds of signals, the impulse response of an acoustic system can be obtained. In addition, background noise is eliminated [35]. Then a microphone is located behind the barrier to measure noise transmission or/and in front of the screen to measure noise reflection (**Figure 2**).

These methods are focused on the measurement at the near field (placing the microphones close to the surface to be measured) since, according to the standards, the lower power of the waves reflected, the difficulty of discerning between emitted and reflected sound, and the influence of background noise, make it really difficult to obtain meaningful results more distance [30, 31]. For this reason, some researchers prefer to extrapolate reflectivity data measured in the near field toward the effect in the far-field.

However, other researchers based on the standard EN 1793-4 [32], where receiver microphones are placed 2 m behind the barrier (see **Figure 3**), have situated the receiver microphones at greater distances from the screen (from 10 to 40 m) [36] considering these distances better to estimate the real IL.

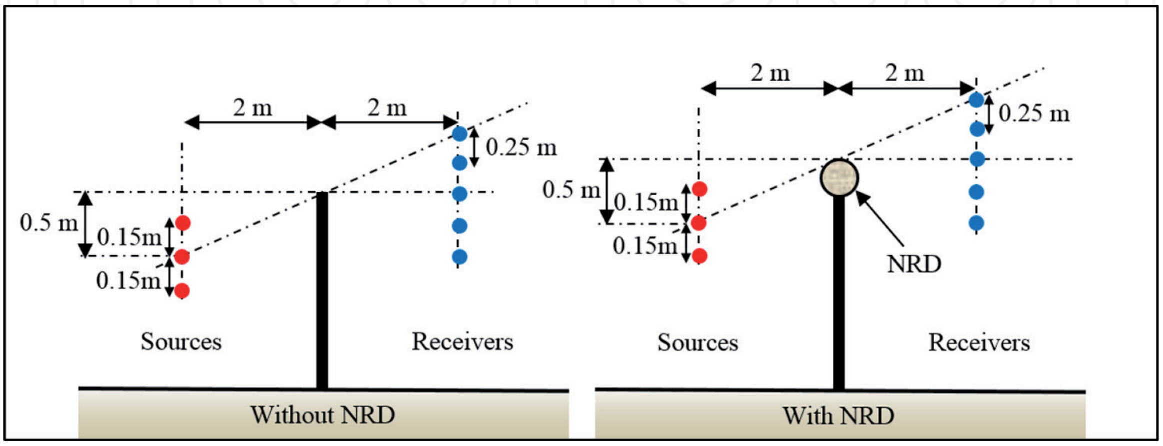

Figure 3.
Standard 1793-4 microphone location (based on [32]).

In addition, according to Kim et al. [36], since the European test methods are based on an impulsive signal, they could be eliminating the influences of reflected sounds by ground and any other objects around the test area. So that, methods such as conventional Japanese and Kim et al. use traffic signal for their measurements.

3. In situ tests for determining noise barrier Insertion Loss

Part of the research studies conducted to date has been based on the evaluation of the effectiveness of barriers on the calculation of Insertion Loss (IL), which is defined as the difference in the noise level before and after the installation of the barrier [37]. The IL is an extrinsic characteristic of noise barriers, depending mostly on the site geometry, meteorological conditions, ground impedance, and the relative positions of the noise source and the receiver [17]. These factors are in general not independent of each other, so the total IL cannot be calculated by the addition of partial insertion losses [17].

The international standard ISO 10847:1997 [37] establishes two methods of in situ IL measurement and calculation; direct and indirect measurement methods:

- The direct method is used when the barrier has not been installed yet or can be removed. The noise level is measured before and after the installation of the barrier to determine the IL. In this method, it must be ensured that measurements before and after the installation of the barrier are performed under equivalent weather and traffic conditions.

- The indirect method is used when the barrier is already installed and cannot be removed. In this case, an estimated “before” noise level is obtained by the measurement at a site that is considered equivalent to the study site.

The American standard ANSI/ASA S12.8-1998 [38] describes an additional “indirect predicted” method, which uses measurements at the site with a barrier to determine "after" noise levels, and a traffic noise prediction model to predict “before” levels at the same site without the barrier.

The ISO standard specifies general criteria for in-situ measurement of barrier IL including microphone positions, noise source conditions, and acoustic environments of the measurement sites. It also suggests generic principles for ensuring that sufficiently equivalent conditions are maintained between “before” and “after” measurements to permit reliable determination of barrier IL. The noise descriptor recommended is A-weighted equivalent sound pressure level. The materialization of the general criteria suggested by ISO has been resolved in different ways in studies based on both the direct and indirect methods.

3.1 Direct measurement method

The direct method described in the ISO 10847 standard is the approach to be used when the barrier has not been installed yet or can be removed. The method requires measurements before the barrier has been constructed to determine “before” levels and measurements at the same site after construction to determine “after” levels. According to US Federal Highway Administration (FHWA) [17, 39] this method ensures identical site geometric characteristics but also requires equivalent “before” and “after” meteorological and traffic conditions that may be difficult to reproduce. These meteorological equivalence conditions include wind, temperature, humidity, and cloud cover. In case of strong winds, "before" and "after" measurements should be avoided.

The factors to be considered in the determination of the measurement sites and procedures are briefly described below:

3.1.1 Noise emission source

The ISO standard recommends the traffic itself as the sound source for the "before" and "after" measurements. Using traffic noise signal has the advantage of measuring the signal which is wanted to evaluate. However, the fluctuations in traffic may affect the accuracy of the results, so that the measurement period must be taken into consideration.

3.1.2 Microphone locations

The standard recommends the use of a reference microphone, which allows for calibration of "before" and "after" measured levels and helps to consider variations in the characteristics of the noise source [17, 39].

When the reference microphone is used, it is placed in most cases according to the ISO standard, i.e., at a point on a vertical plane including the barrier, and at a height, at least, 1.5 m above the barrier edge. When the barrier is located less than 15 m from the near road lane, the microphone may be placed at 15 m from the center of the road lane, and at a height such that the line-of-sight angle between the microphone and barrier top, as measured from the center of the near road lane, is at least 10° (**Figure 4**) [17].

Microphone location at receiver positions depends on the study objectives since the location of the microphones (distance from the barrier, height above the ground) are determinants to establish diffraction effects. In some studies, a single microphone is located at a height of 1.5 m above the ground. The most common situation is, however, to place microphones at different distances and heights [17, 39–41] for a better understanding of the performance of the shadow zone (**Figure 5**).

3.1.3 Measurement period

A range from 2 to 30 min is the usual sampling period for measurements. When weather conditions are fluctuating, longer sampling periods, such as 1 or 24 h, could be more accurate [17]. It has been suggested [40] that 2-min measurements, as specified in the standard, are too short for a stable and reliable evaluation of sound pressure levels. The optimal measurement periods are 15–30 min, as longer periods

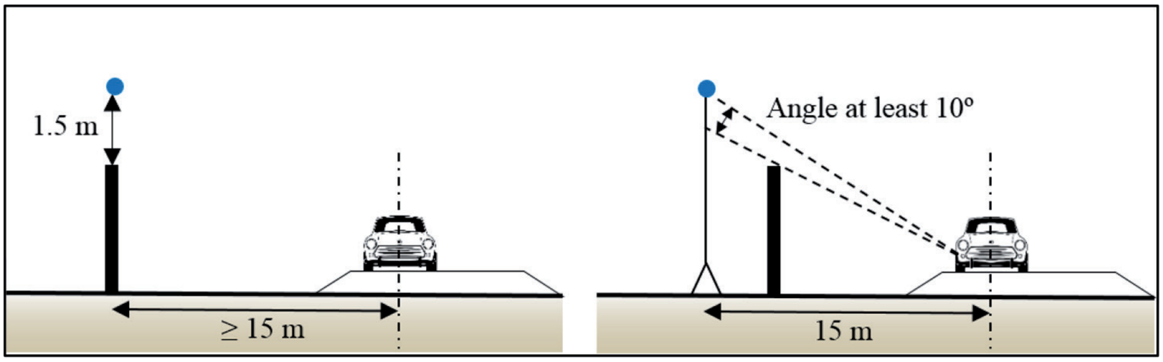

Figure 4.
Alternative positions for reference microphones—blue circle—(based on [17]).

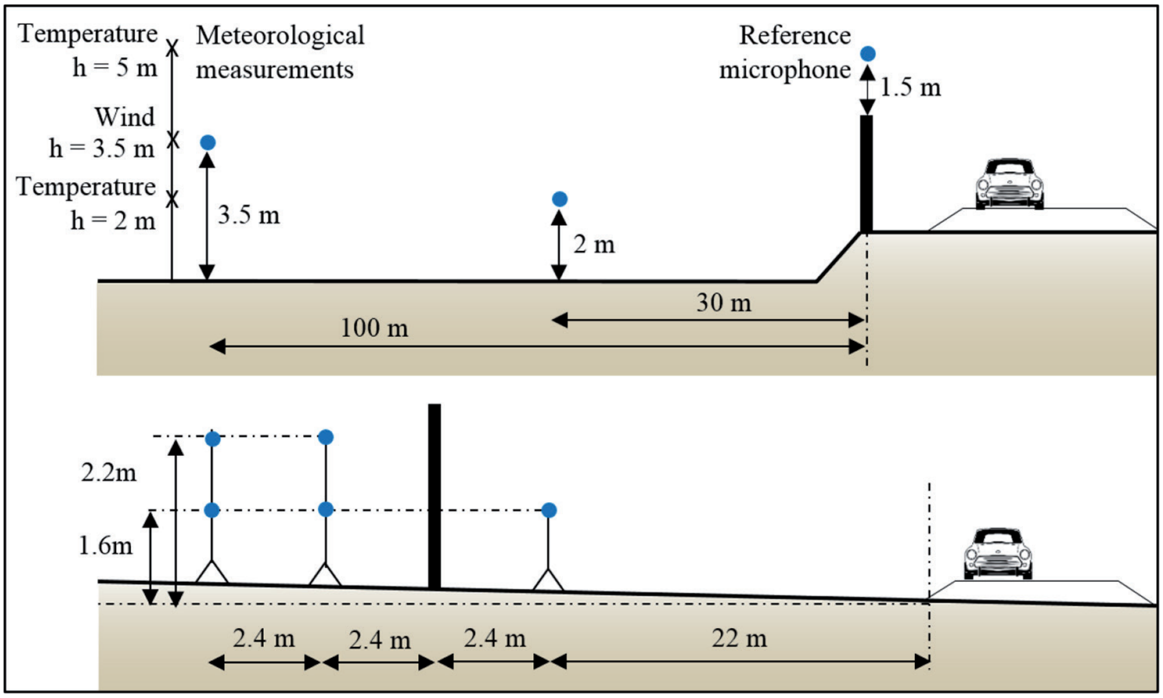

Figure 5.
Measurement microphones in the study of Anfosso-Lédée et al. [40] (above) and Parnell et al. [41] (below).

would possibly introduce atmospheric changes [40]. However, other researchers [41] established a 10 min measurement period.

The FHWA suggests avoiding measurements when wind speed exceeds 17 km/h or while raining since raindrops generate noise and tire noise increases on wet pavements. The Agency also recommends avoiding measurements when traffic flow is congested since the traffic noise level will be lowered, making it more difficult to evaluate the IL.

3.1.4 Main findings

There is a lack of evidence on the effectiveness of barriers based on the direct method. In the study conducted by Anfosso-Lédée et al. [40], the authors suggest that it could be due to the poor applicability of the method since it took 3 years for his team to complete the measurements due to the time waited for the installation of the barrier and the difficulty to find the equivalence of traffic, weather conditions, and ground impedance.

The experiment was based on measurements at 30 m and 100 m from the barrier (or where the barrier was supposed to be installed) (**Figure 5**). The measurements "before" took place in 1996, and the measurements "after" (when the barrier was already installed) were implemented from June 1998 to August 1999. Results showed IL values range from 4 to 8 dB(A) at 100 and 30 m from the road.

Parnell et al. [41] constructed a new barrier 80 m long and 2.4 m high and measured, with and without the barrier, at a distance of 2.4 m in front of the barrier and 2.4 and 4.8 m behind the barrier (**Figure 5**). Results of the experiment showed a 6–8 dB(A) difference in measurements "before" and "after" the barrier installation.

3.2 Indirect measurement method

The indirect method is, according to ISO 10847:1997, the approach to be used when the noise barrier has already been installed and cannot be removed for measurements.

In this case, an estimated "before" noise level is obtained by the measurement at a site that is considered equivalent to the study site. To ensure consistency of results, the "before" and "after" measurements should be performed simultaneously.

The indirect method is the only practicable approach in the case of most new roads, where the noise barriers have been installed during road construction, and therefore it is not possible to obtain a "before" measurement under normal traffic conditions. The primary advantage of using this method is that it ensures the same environmental conditions (meteorological and traffic conditions), so this method, as highlighted by some authors [17, 42], would be preferred over the direct measurement method.

The use of the indirect method involves the identification of another measurement site that is deemed to be equivalent. For these equivalent sites, a close match is required in emission characteristics, relative positions of source, barrier and receiver, acoustic performance of ground surface, terrain profile, interfering obstacles, reflecting surfaces, and meteorological conditions. The factors to be considered in the determination of the measurement sites and procedures are briefly described below.

3.2.1 Selection of equivalent sites

According to ISO 10847:1997, the "before" site must have a terrain profile, interfering obstacles, and reflecting surfaces equivalent to those of the real barrier site within a sector extending 60° on either side of the line connecting the receiver positions towards the source position, so that similar noise propagation can be achieved.

It is also necessary to ensure the equivalence of ground surface, which refers to the acoustic impedance of the ground along the source-receiver propagation path (i.e., acoustic characteristics of soil coverage, such as paved soil, vegetation on loose or packed soil, gravel, etc.) (**Figure 6**). The standard ISO additionally requires that

Figure 6.
An example of "after" and equivalent "before" locations at one of the sites studied by the authors in Spain (aerial photograph from Iberpix, OrtoPNOA 2020 CC-BY 4.0 scne.es).

the environment in the region within 30 m behind and to the side of the receiver positions shall be similar.

The main difficulty of the method is that an adjacent equivalent site may not always be available, especially in dense urban areas [17, 40]. As an example, a study conducted in Spain [42], which was based on an initial sample of 84 measurement sites, had to reject 54 potential locations due to various causes; the main cause was the different acoustic environment at the "before" and "after" positions due to significant differences in terrain profile and the presence of other noise sources.

3.2.2 Noise source

Most of the indirect method-based studies use road traffic as a noise source. The ISO standard proposes that naturally occurring road noise should be used as the sound source equivalence for the “before” and “after” measurements. The use of traffic noise has the obvious advantage of representing the natural source, but also the disadvantage of describing fluctuations in traffic volume, speed, and composition that may affect the accuracy of the results.

The use of artificial noise sources is infrequent and is used only when it is not possible to use traffic noise in equivalent conditions. This artificial point source may be based on a loudspeaker that reproduces traffic noise [20] or a regulated artificial signal such as pink noise [43].

3.2.3 Microphone locations

One of the key factors in the use of the indirect method is that the locations of the microphones relative to the noise source at the "before" and "after" positions should be identical, in terms of distance from the road and height above the road [39]. Some authors suggest the use of a reference microphone [17, 39], which, as mentioned before (Section 3.1.2) takes into account the effect of possible fluctuations of the noise source.

Only a few studies have considered the use of the reference microphone [39, 44], so it is understood that the rest of the studies assume that possible traffic fluctuations during the measurements are not expected to significantly affect the results.

The location of the receiver microphones varies according to the purpose of the study. The choice of these locations is sometimes determined by the possibility of finding equivalent locations at the "before" site.

In most studies, microphones are placed at regular distances from the barrier (5, 10, 15 m), or corresponding to incremental doublings of the distance (e.g., 7.5, 15, 30 m) [42, 44]. Some studies determine IL levels by placing a single microphone in the near field behind the barrier, at distances of 1–5 m [20, 43, 45, 46]. The most common height for the microphone is 1.5 m, although there are studies that consider additional heights, which are similar to or higher than the barrier height (e.g., 2, 4, 6 m). Both the distances and incremental heights of the microphone positions are intended to better understand the performance of diffraction shadow zones (**Figure 7**).

There is no general standard for receiver locations. The ISO standard proposes general criteria that are a very general characterization of the open space behind the barrier [47]. In recent years, the European Committee for Standardization adopted the CEN/TS 16272-7:2015 standard for railway noise barriers [48], which recommends nine locations for receiver microphones. These microphones are located at a distance of 7.5, 12.5, and 25 m away from the lines, and at a height of 3.5, 6, and 9 m

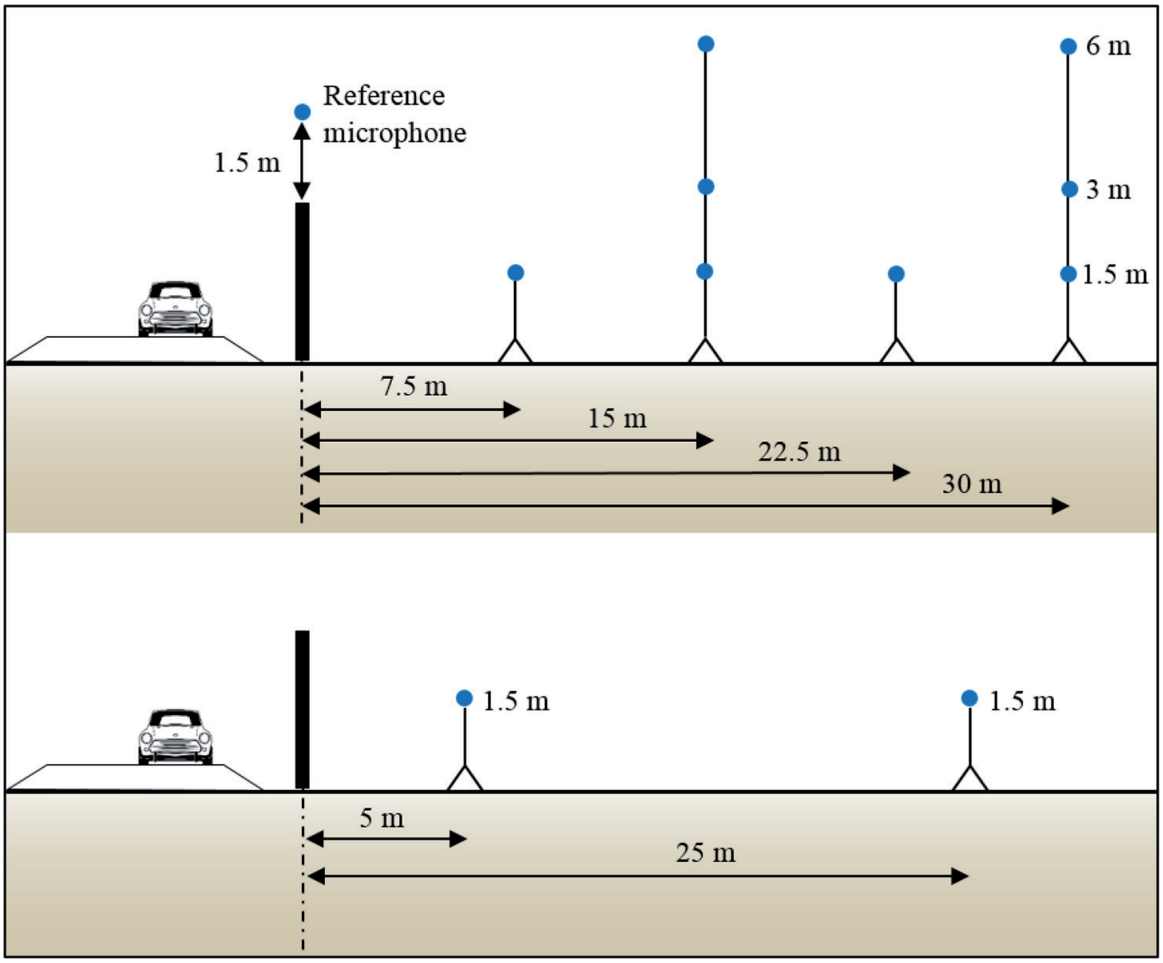

Figure 7.
The experimental design of studies based on the indirect method depends on the purpose of the study. Above, a microphone distribution is intended to better understand the pattern of the shadow zone [44]. Below, microphone distribution to measure IL levels at a distance at which real receivers are located (near the building facade) [42].

above the ground. However, this standard does not appear to be in use in studies relating to the measurement of Insertion Loss at railway noise barriers [47].

3.2.4 Measurement period

The selection of the measurement period should first consider when to measure along the daily time. One of the factors to be taken into consideration concerns favorable weather conditions, in particular wind speed and direction. The preferred conditions are for daily periods when low wind or calm is expected. Some studies [42] have conducted measurements in the period after peak traffic time in order to find dense but fluid traffic conditions, where traffic fluctuations are less prominent. In most of the studies, the "before" and "after" measurements have been undertaken simultaneously to ensure the same environmental conditions (i.e., background noise, traffic, and meteorological conditions).

The duration of the measurements in studies based on the indirect method depends on the nature of the noise source. In the case of studies using an equivalent artificial noise source, the duration of measurements is usually short (such as 2 min) in accordance with the ISO standard [43]. In the case of road traffic noise, the period is usually long enough to ensure the representativeness of the spectrum of the traffic noise. In practice, measurement duration in most studies ranges from 10 to 30 min, and the most common value is 15 min. Some studies [17] have suggested using longer periods (such as 1 h, or a day) when noise variations are expected to be substantial, but these longer periods do not seem to be used in practice.

In other studies [39, 49] the procedure consists of measuring noise levels, wind speed and direction, and temperature lapse rate for a 4-h block of time in 1-min increments. Thus, the results are broken down into short periods and continuous equivalent levels and meteorological conditions are individually determined for each short period. This procedure anticipates the problem of *a priori* considering possible fluctuations in the meteorological conditions of the site.

Occasionally [42], the choice of the measurement duration was based on traffic variations at the time of sampling. Thus, measurements were prolonged until the observed variation in the sound level meter did not vary more than a certain value (such as 0.1 dB(A)) over a certain time period (at least 1–2 min).

3.2.5 Main findings

The results obtained in the different research studies conducted revealed moderate Insertion Loss values of the noise barriers. Attenuation values obtained in the near field, at distances from the barrier of 5–7 m, and heights above ground of 1.2–1.5 m, range between 7 and 10 dB(A) [20, 42, 44–46, 50]. Insertion Loss levels are higher at shorter distances from the barrier, such as 1 m [43]. The IL values at comparable greater distances from the barrier (20–30 m) tend to decrease to values of 3–5 dB(A) [40, 42, 44], although one study reports much higher attenuation levels of up to 10 dB(A) at intermediate distances (15 m) [51]. Attenuation levels measured at greater distances (up to 100 m) tend to decrease slightly [40].

These results seem to indicate that the barrier attenuation levels are, above a certain distance, clearly lower than expected. It is, however, generally assumed that an effective noise barrier typically reduces noise levels by about 5–10 dB(A) [16, 44]. Effectiveness usually depends on its dimensions, material type, and location relative to the source and receiver positions. In the dimensioning of the barrier, the contribution to the total sound field of the components diffracted around the top and side edges are the key elements to determine the minimum barrier height/length for which the influence of the side edges diffraction may be neglected.

The best noise reduction effect is in the frequency range of 250–4000 Hz, at which the traffic noise is dominant. The average value of Insertion Loss for the octave bands between 250 Hz and 4 kHz ranges from 4 to 9 dB(A) [42, 50]. Noise abatement reaches a maximum at 4000 Hz, and the smallest reductions are encountered for the lowest frequencies (**Figure 8**) [42, 50, 52].

The type of barrier material does not appear to have a significant effect on attenuation levels [42, 51]. The differences found are rather related to locational factors, such as the distance from the barrier to the source (or receiver). Thus, the Insertion Loss measured at earth berms is lower than at noise walls because the top edge of the barrier is usually further away from the source and/or receiver positions.

3.3 Equivalence of direct and indirect methods

There is little evidence of equivalence of the results obtained with the direct and indirect methods. In the only study conducted to date evaluating the IL of the same site (the same noise barrier) using both methods [40], the results reveal that the direct and indirect methods are not equivalent. The observed differences range from

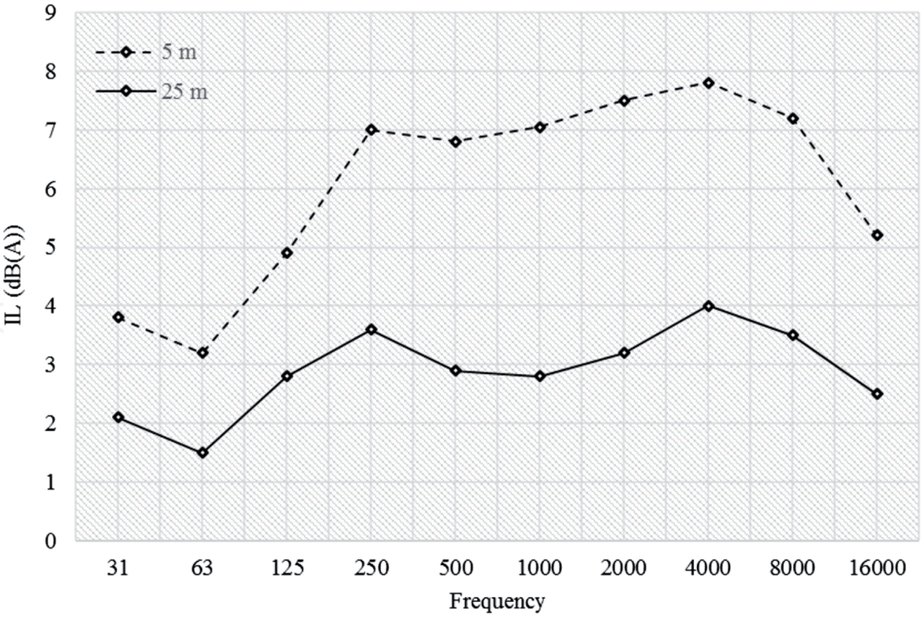

Figure 8.
An example of Insertion Loss levels in the range of frequencies of the octave bands at two distances (5 and 25 m) from the noise barrier [53].

−2 dB(A) to +4 dB(A). The causes of these differences were attributed in the study to variations in wind conditions (wind speed and direction) and vertical temperature gradient. The effect of microphone positions and other environmental factors on noise levels measurements also needs to be better known.

4. Conclusions

The amount of literature on the effectiveness of noise barriers has not provided sufficient evidence on the actual attenuation achieved by these devices, and there is uncertainty over the noise reduction capabilities of existing barriers. The methods described in the ISO 10847:1997 standard have drawbacks that make it difficult to obtain reliable attenuation measurements.

The direct method ensures identical propagation characteristics since the source of noise, the barrier, and the receiver are at the same positions, but the equivalence of source and meteorological conditions may not be fully satisfied. The indirect method ensures that the same local weather and traffic conditions are maintained, but the equivalence of terrain profiles, obstacles, and ground surface conditions may not be fully achieved. In addition, the usage of provisions of the ISO standard sometimes is complicated when at the site point exists a relatively high background noise level, or adverse meteorological conditions [54].

According to the ISO standard, the recommended method is the direct method, although most studies have been based on the indirect method because the barriers were installed during road construction, and therefore it was not possible to obtain equivalent "before" measurements.

The ISO standard provides generic methods for determining Insertion Loss at receiver locations. However, there are no universally acknowledged receiver positions for measurements. It is important to note that barriers are relatively ineffective at some distance from the road. The effective distance range is limited to a few tens of meters, so it is unclear that many receivers can benefit from barrier attenuation. Many of the studies conducted have calculated Insertion Loss levels at barrier near-field distances, so the noise reduction capabilities of barriers were only partially assessed. The IL levels measured at comparable greater distances from the barrier (20–30 m) were, in most cases, very moderate. This supports the argument that the barrier attenuation levels are, above a certain distance, clearly lower than expected.

Additionally, the ISO standard specifies measurements of equivalent continuous A-weighted sound pressure levels to calculate the attenuation of the barrier. However, A-weighting tends to underestimate the effects of low-frequency noise [47]. Several studies have highlighted that A-weighting does not adequately consider the perceived annoyance produced by predominantly low-frequency noise. This is the case of road traffic noise, which is characterized by the wide variability in the relative level of low-frequency noise [25, 55]. Noise barriers increase the relative level of low-frequency of noise on the shielded side of the barrier. Thus, the attenuation in A-weighted measured levels level may overestimate the estimated reduction in perceived annoyance due to the increase in the relative level of low-frequency sound [47].

In summary, the literature has described some critical points about the applicability and reliability of ISO methods. These points were dealing with (i) the reliability of results (i.e., direct IL measurements obtained at different moments, and indirect IL measurements obtained at equivalent locations), (ii) the equivalence of results of direct and indirect methods, (iii) the nature of the indicator used (A-weighted levels), and (vi) the relevance of operational factors such as weather conditions, traffic fluctuations, ground impedance, and background noise.

The effect of these factors on noise levels measurements needs to be better known. More research studies in this domain are required to bring improvements in measurement methods.

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