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NOISE BARRIERS: WHAT REALLY MATTERS AND WHAT DOESN'T?

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ABSTRACT

After more than 40 years spent designing and optimizing noise barriers for land transport, it is worth noting that many of the important factors determining their performance are still underestimated or even neglected.
The purpose of this paper is to review all the factors that determine the actual performance of noise barriers in reducing noise around roads and railways.
Those factors are : the physical phenomena (sound emission, sound propagation, sound reflection, sound diffraction and airborne sound transmission), the sound emission characteristics (vehicle type), the dimensions (height, length, volume, source / receiver relative positions, frequency domain, time scale), the shape of the objects, the sound propagation medium (air, weather conditions, ground effect) and, late but not least, the intrinsic performances of the barriers (sound absorption, airborne sound insulation, intrinsic sound diffraction).
All those factors are influencing the final insertion loss performance, each one can have a major influence ... or not: it all depends on the context in which it is used.
That's the reason why it is so important to not underestimate or neglect any relevant factor: this paper will focus on several points too often neglected or poorly considered.

Keywords: *noise barriers, ground transport, insertion loss*

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1. INTRODUCTION

Road and rail noise barriers have been used around the world since the early 1970s. Since then, a great deal of research and development has gone into their ability to reduce ambient noise, but one thing has never changed: the laws of physics. Thanks to the advent and increasing power of computers, transport noise modelling has evolved enormously since the 1980s. However, as of today, we are not yet able to completely model ground transport noise as it actually is, i.e.: moving vehicles, each with multiple and different noise sources (location, directivity, spectrum, time evolution) and multiple bodies continuously interacting with many other objects during the sound propagation process. The main reason is that, however complex they may be, models too often fix one or more parameters that may be considered less important in common cases, but which may be essential in others.
The objective of this paper is to review several factors that determine the ability of noise barriers to reduce road and railway noise in inhabited environments.

2. KEY FACTORS RULING NB PERFORMANCE

Key factors are the physical phenomena, the sound emission characteristics, the dimensions, the shape of the objects, the sound propagation medium and the intrinsic performances of the barriers themselves. : all those factors rule the final insertion loss at any single receiver position depending on the context in which the noise barrier is used.
In all those factors, one is common to all the others: the sound wavelength / frequency.
Fig. 1 presents the Normalized 1/3rd octave band spectra for both road traffic noise as described in [1] and rail traffic noise as described in [2] from 100 to 5.000 Hz; the part below 100 Hz for road traffic noise is derived from [3].

The spectra are relative to the primary (left) axis in dB, while the corresponding wavelengths are displayed on the same graph, but relative to the secondary (right) axis in m.

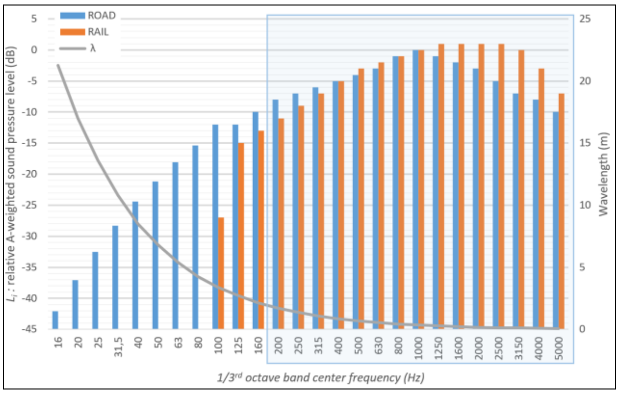

Figure 1. Normalized A-weighted noise spectrum for Road and Railway noise, wavelength / frequency.

Main part of the A-weighted emitted energy is concentrated in the frequency range (200 - 5.000 Hz): for road noise, frequencies below 200 Hz represent 4% (-15 dB) of the total spectrum, and 1% (-20 dB) for train noise.
These spectra play an important role in the sound propagation process, which is highly dependent on wavelength.

2.1 Physical phenomena

The aim of this paper is not to recall well-known facts, but what should be better considered for an even better control of the performance of ground transport noise barriers.

2.1.1 Sound emission / Sound emission characteristics

Today, we model noise emission very well, both for road vehicles and trains: noise spectra are becoming increasingly relevant and include the road surfaces or the railway track characteristics. Models also consider the location of the different noise sources and, to a certain extent, their directivity.
However, the *movement* of vehicles in 3D space and in time is very rarely considered, while it conditions the spatiotemporal effects: those effects can be very important, e.g.: interactions between the body of the vehicles themselves and/or with nearby obstacles as noise barriers (see 2.1.3 further on).
Those effects are most complex with road traffic: numerous vehicles of different types and body shapes randomly located and all interacting with each other in different ways.

2.1.2 Sound propagation

Sound propagation, whatever in the noise barrier close field or in the far field, is probably one the best modelled phenomenon but, once again, almost all the models neglect the vehicles movements.

2.1.3 Sound reflection / interactions

Sound absorbing noise barriers represent more than 75 % of the barriers installed in EU countries. Sound absorbing materials are not only used to limit the 1st order of reflections toward some sensitive locations but can also be very efficient to reduce *multiple reflections*.
Multiple reflections between parallel walls or barriers are well integrated into the models, as in CNOSSOS-EU [4].
However, interactions between the vehicle's bodies and/or with nearby obstacles as barriers are still too rarely and too simply considered in road noise (to some extent, it is better done in railway noise). This effect was introduced several decades ago [5, 6].
Fig. 2 shows the effect of interactions: it details the 1-minute-long pass-by noise level L(t) when a truck is passing in front of a receiver without any noise barrier, with a *perfect* sound-absorbing barrier, with a *perfect* reflecting one, and then with a usual sound-absorbing one[1]. In this figure, calculations are done assuming *incoherent moving noise source*. Interactions significantly degrade the barrier's performance, especially when the truck passes in front of the barrier, what could even result in an increase of L(t) compared to the situation in the open field.

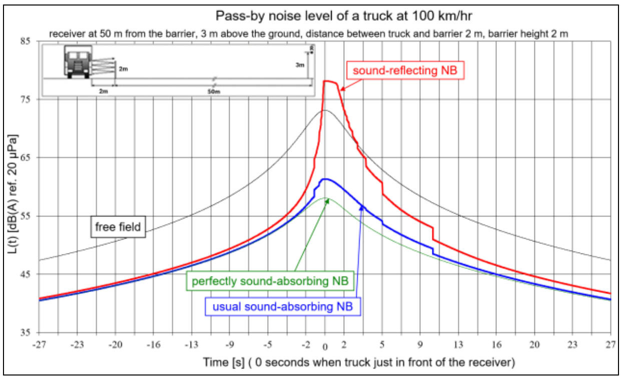

Figure 2. effect of multiple reflections on the pass-by noise of a truck (*no interferences*).

[1] The actual acoustic performance of conventional absorbent noise barriers is now well characterized thanks to standardized test methods (see 2.2 -Intrinsic performances).

Fig. 3 shows the same pass-by but now considering *coherent moving noise sources* instead of incoherent ones. The reality is not one of these two isolated cases, but a combination of both.: a noise source at instant *t* is incoherent with the one at instant *t+1* but remains coherent with all its own reflections. This combination is virtually ignored in all the models used to date.

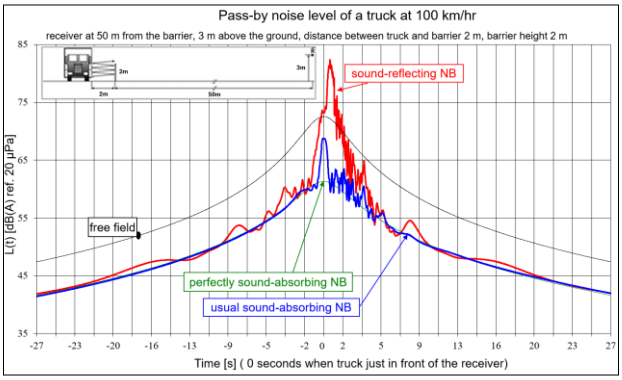

Figure 3. effect of multiple reflections on the pass-by noise of a truck (w/*interferences*).

The longer the vehicles, the larger their bodies and the closer they are to barriers, the greater the interactions: this happens with the loudest vehicles, i.e.: trucks.
With trains (long and continuous bodies very close to), noise barriers design should definitely consider interactions and shapes effects, e.g.: design studies of High-Speed Train noise barriers (see Fig.4 [7]).

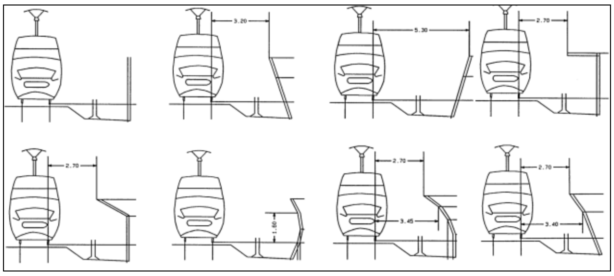

Figure 4. Specific designs for HST noise barriers.

2.1.4 Sound diffraction

Some trivial evidence important to recall…
As long as reflections (2.1.3) and transmission (2.1.5) are *adequately managed* as a function of its height, diffraction determines the IL performance of a noise barrier.

Noise barriers are used as *obstacles* to sound propagation. Given the wavelengths involved in traffic noise (see Fig. 1), when the wavelength is much less than the height of an obstacle, the obstacle acts fully and drastically reduces the energy diffracted at its top (Fig. 5).

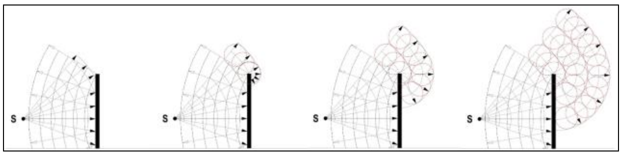

Figure 5. Diffraction with a wavelength that is much less than the height of the obstacle.

Conversely, when the wavelength is of the same order as or greater than the height of the obstacle, it can no longer be considered a real obstacle: the wave literally 'jumps' over it (see Fig. 6).
Whereas in building acoustics, one considers frequencies down to 50 Hz, in environmental acoustics, the dimensions of the *obstacles to the sound propagation* must be correctly considered in relation to the wavelength of the noise.

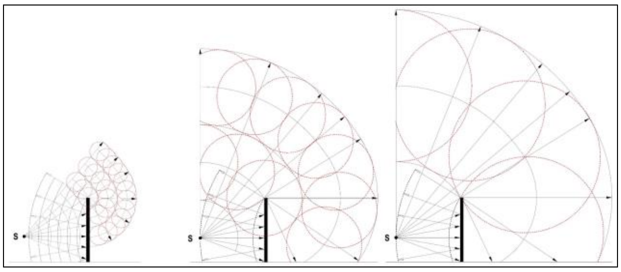

Figure 6. Diffraction with increasing wavelengths.

At 50 Hz, the wavelength is almost 7 m. With wavelengths this order of magnitude, usual noise barriers as 3 mH or 4 mH cannot be considered as real obstacles to sound propagation: only buildings can be. This will be important to remember when considering the significance of the *lowest reliable frequency limit* of the standardized test methods to characterize the intrinsic sound characteristics (see 2.2 further on).

2.1.5 Sound transmission

The noise perceived within the protected side of a noise barrier corresponds to the sum of the energy diffracted at its top *and* the one transmitted through, but how important can transmission be in the final barrier IL?

A *common* rule of thumb is: *"The effect of transmission is negligible as long as the single-number rating of airborne sound insulation performance DL_{SI} is 15 dB higher than the targeted ΔL_{Aeq} performance (obtained only by diffraction)"*: $DL_{SI} > \Delta L_{Aeq} + 15$ dB.

Fig. 7 shows what becomes the *effective* IL if a barrier has a *theoretical* IL of 8, 12 or 15 dB[2] when transmission occurs as a function of its intrinsic airborne sound insulation DL_{SI} : it is not necessary to require respectively more than 23, 27 or 30 dB because, beyond this performance, the transmitted energy becomes sufficiently negligible.

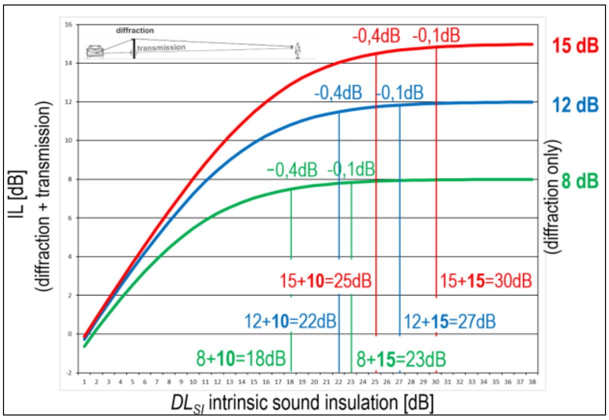

Figure 7. Effect of sound transmission on the *effective* IL, in function of the DL_{SI} performance [8].

Fig. 7 also shows also shows that the greater the theoretical IL, the higher DL_{SI} the must be.

However, traffic noise still remains a time-related phenomenon that occurs as each vehicle pass-by: even if the most common unit used to characterise traffic noise is the *equivalent sound level* $L_{Aeq,T}$, to specify relevant DL_{SI} values for noise barriers, it is necessary to consider the *instantaneous noise levels* $\Delta L_A(t)$ or even directly on ΔL_{Amax} instead of on $\Delta L_{Aeq,T}$.

In the same way as Fig. 1, one must consider the *pass-by noise levels*: Fig. 8, 9 and 10 show those levels when a 4 m high truck passes respectively in front of a [2 mH, DL_{SI} 20 dB] barrier, a [7 mH, DL_{SI} 20 dB] and a [7 mH, DL_{SI} 35 dB] one. With a [2 mH, DL_{SI} 20 dB] barrier, transmission slightly degrades the performance.

With a [7 mH, DL_{SI} 20 dB] barrier, transmission exceeds diffraction, what strongly degrades the performance: a DL_{SI} 35 dB is appropriate for such high noise barrier.

[2] by sound diffraction only

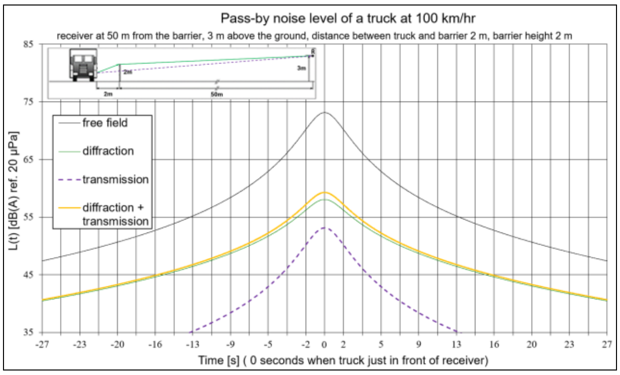

Figure 8. Sound transmission through a 2 mH noise barrier with a DL_{SI} performance of 20 dB [8].

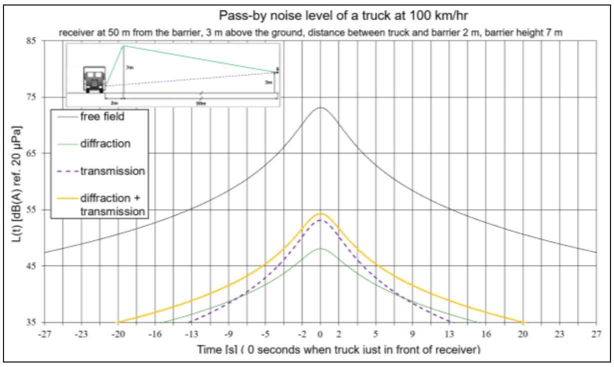

Figure 9. Sound transmission through a 7 mH noise barrier with a DL_{SI} performance of 20 dB [8].

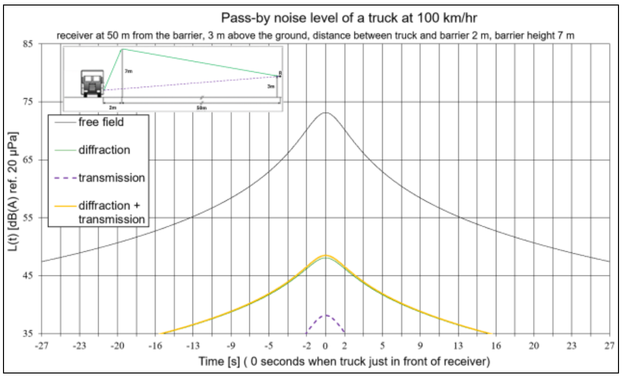

Figure 10. Sound transmission through a 7 mH noise barrier with a DL_{SI} performance of 35 dB [8].

2.2 Intrinsic characteristics

Intrinsic characteristics are those characterizing the acoustic performance of the *products* used: not only the sound absorption and (airborne sound) insulation, but also the sound diffraction effect that an added device[3] could have if placed on top of a noise barrier.

Complete sets of twelve EN standards have been published to characterize road and train noise reducing devices. As noise barriers are never placed in *reverberant* sound field conditions but rather in *open spaces*, they must be characterized by relevant tests under *direct sound field conditions*, *as* described in EN 1793-5 and 1793-6 [10,11] for roads, and EN 16272-5 and 16272-6 [13,14] for trains.

These tests are based on transient signal analysis within the so-called "Adrienne time window" as shown in Fig. 11 for sound reflection tests: all unwanted components (e.g.: reflection on the ground or on any close object, or diffraction on the edges) should be kept outside [10].

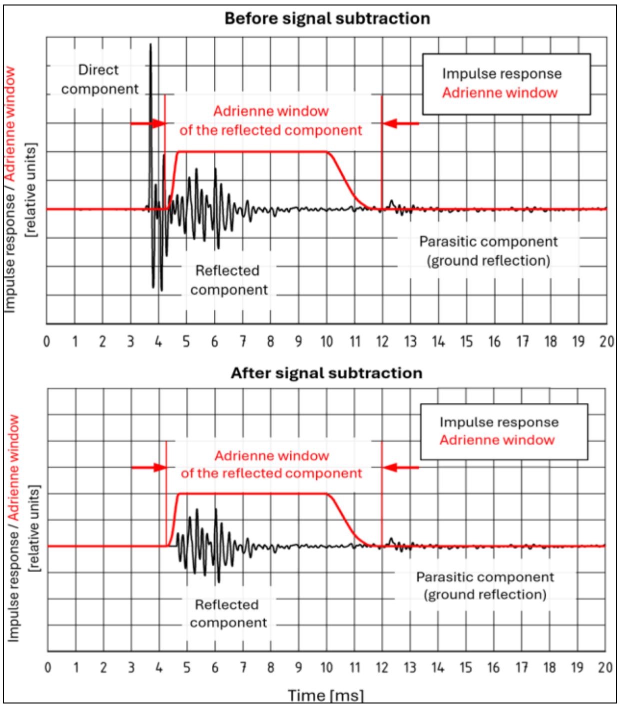

Figure 11. Example of an impulse response measured in front of a vertical, non-flat sound absorbing noise barrier [10].

[3] added device: additional component that influences the acoustic performance of the original noise reducing device.

For certification purposes, test samples must have the *minimum* dimensions[4] of 4 mH by 4 mL for sound absorption tests (Fig. 12 left), and 4 mH by (4 + 2) mL when characterizing sound insulation of noise barrier elements as well as at posts (Fig. 12 left and right).

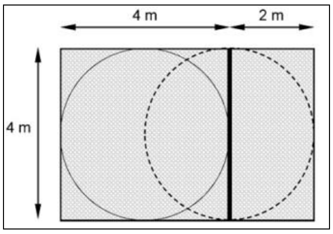

Figure 12. *minimum* dimensions of test samples for certification purposes [11].

For those dimensions, two Adrienne window lengths are used[5]: $T_{W,ADR}$ = 7.9 ms to give a *normative* value in the 1/3rd octave band centred at 200 Hz and *informative* values at 100, 125 and 160 Hz, while $T_{W,ADR}$ = 6.0 ms delivers *normative* values in the 1/3rd octave > 200 Hz [10].

Frequently claims are about the fact that intrinsic characteristics "are not determined below 200 Hz" while building acoustics considers frequencies down to 100, 80 or 50 Hz: such claims highlight some confusion about the relevant frequency range for noise barriers (see Fig.1 and *2.1.4 Sound diffraction*): this range can vary a lot. In addition, standards cannot be written for an infinite number of products that are themselves used under an infinite number of conditions: they are written to be fair under the conditions stated under their scope and hypothesis. To get values outside of these conditions, two alternatives can be considered. The first one is to enlarge $T_{W,ADR}$ to consider lower frequencies, but keeping the standardized minimum dimensions, with the risk of integrating unwanted components within the window: it will virtually increase either the reflected energy (absorption), or the energy arriving behind the barrier (insulation), what *underestimates* the intrinsic performance but could still give interesting values. The second alternative is to enlarge enlarge *both* $T_{W,ADR}$ and the test sample dimensions to push the unwanted components out of the window: depending on the targeted low frequency, test samples can need important dimensions. However, this alternative is relevant when using higher noise barriers for which, of course, intrinsic performances at lower frequencies become more and more relevant.

[4] Outside certification purposes, tests can still be performed.

[5] Two for reflection, but only one (7.9 ms) for insulation tests.

3. CONCLUSION

Since the early 70's, huge progress has been done to improve the use of road and railway noise barriers. However, several characteristics are not yet fully considered by numerous users or sound propagation models. It is impossible to present all those characteristics in a single paper like this one. This paper emphasized some specific points as: the relevance of road and railway traffic noise spectra and their corresponding wavelengths, the importance to consider the actual movement of the vehicles when designing noise barriers, e.g.: for all the time-related effects as interactions between barriers and close vehicles or when specifying sound absorbing performance and / or the sound insulation performance, how the noise barrier dimensions can be effective in very low frequencies, or not.
EN standards allow to fairly characterize the intrinsic acoustic performances of noise barriers within relevant frequency range… As of today, the most challenging point stays to model vehicles as they are (complex reflective bodies) and as they move on the roads / railways, considering their actual movement in a 4D dimension (x,y,z and t), including the relevance of possible interferences, when they exist…

4. REFERENCES

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