inter.noise 2000
The 29th International Congress and Exhibition on Noise Control Engineering
27-30 August 2000, Nice, FRANCE

I-INCE Classification: 3.1

ANTI-NOISE DEVICES EFFECTIVENESS: PHYSICS, MODELS, VALIDATION, HOW ARE WE ABLE TO CONCLUDE ON THESE?

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Keywords:
MODELS, ANTI-NOISE DEVICES, MEASUREMENTS, EFFECTIVENESS

ABSTRACT
During the last 30 years, numerous products have been developed in order to improve the effectiveness of anti-noise devices, including different shapes, materials, or added devices. Sometimes, these devices are presented as the best ever, claiming drastic improvements on existing "common designs". Some other times, one demonstrates the uselessness of such or such product. Who is right, and who is wrong? What can be the method to objectively quantify the "value" of such products? Using models can be the best or the worst thing, as one can forget, or even ignore some essential parts of the physics, what can modify the interpretation of some trends. Testing devices, either in laboratory or in situ is also a difficult matter, as the conclusions are always, and only, related to the test conditions. Understanding physics, we should be able to put the effectiveness in its right context.

1 - INTRODUCTION
Experience about anti-noise devices for ground transport becomes very important.
At the early stage of anti-noise devices, where the "classic" noise barriers, having a plane vertical design made from homogeneous materials, either reflective or absorptive. Already at that moment, came the dilemma whether absorptive materials where worthwhile or not. Yet, physics is already the reply: absorptive materials are worthwhile when, and only when, acoustic reflections are significant parts of the perceived sound level [1].
Original barrier shapes have also been investigated very soon [2], but seldom installed until "added devices" become recently used as a new tentative in order to increase the effectiveness of already installed devices [3]. Barrier shape and added devices constitute a controversial topic, as comparisons are very often made with "classic" noise barriers, claiming that such devices permit to reduce the height of the barrier: but how is it possible to conclude so roughly?
In addition, many situations require anti-noise devices, which strongly differ from "classic" noise barriers, as: absorptive treatment of existing reflective walls (sustaining walls, access to tunnels, "open ceiling" tunnels, tunnels), partial road covers, or even "false" tunnels. These applications require highly effective products (α, R), and appropriate modeling.
In facts, the effectiveness of the products always strongly depends on the situation, and nobody can claim any definitive value about this effectiveness without a relevant study. The main problem is that, either we have good and validated predicting tools for some of these devices, but one concludes on just a part of the truth, or we have not 100% validated predicting tools, but one still wants to conclude with incomplete modeling of physics. Unfortunately, in-situ measurements cannot give definitive help, as extending their results on wide scale conclusions can also be very dangerous.
If we could objectively fix the limits of validation of each of these tools (models, true characterization, in-situ measurements...), much more honest conclusions could be drawn on anti-noise devices. Globally, this paper concerns road as well as train traffic noise.

2 - PHYSICS
To be acoustically effective, anti-noise devices should reduce one or more of the three phenomena: sound transmission, sound reflection and sound diffraction. The key point is to quantify how effective the device

could be on each specific phenomenon, and how important is the phenomenon in the global process of sound propagation.
Propagation, transmission, reflection (on ground, as well as on any surface), and diffraction (of any kind) are perfectly known, as well as the atmospheric effects: they are all currently included in the models. However, one too often simplifies the sound emission, forgetting how road or rail traffic noise is generated. All the vehicles are effectively moving, each one including different sources of noise (having their own acoustic characteristics), and having their own body (with their own height, length and reflecting characteristics): it is just as simple as that. Then, neglecting nothing, physics always tell us the evidence. A better sound insulation is useful when transmission rule the global effectiveness, absorptive materials are useful when reflections occur in a significant manner, and added devices should always be effective in the zone where they have to, otherwise they could probably be useless.

3 - MODELS

Models too often consider that **moving vehicles** correspond to fixed point or line sources.
Roughly, cars can be assumed radiating sound as omni-directional point sources, though more accurate models exist [4], but once the sound is emitted, the body of the vehicle is there: it is a moving volume with its own sides, what **implies specific time-related reflections and diffractions**. The body and movement of the vehicles are of main importance for high-sided and long vehicles (lorries, trains) moving close to reflective surfaces. Modelling this phenomenon is rather complex, as the effect is time-related (vehicles are moving!) [5], [6].

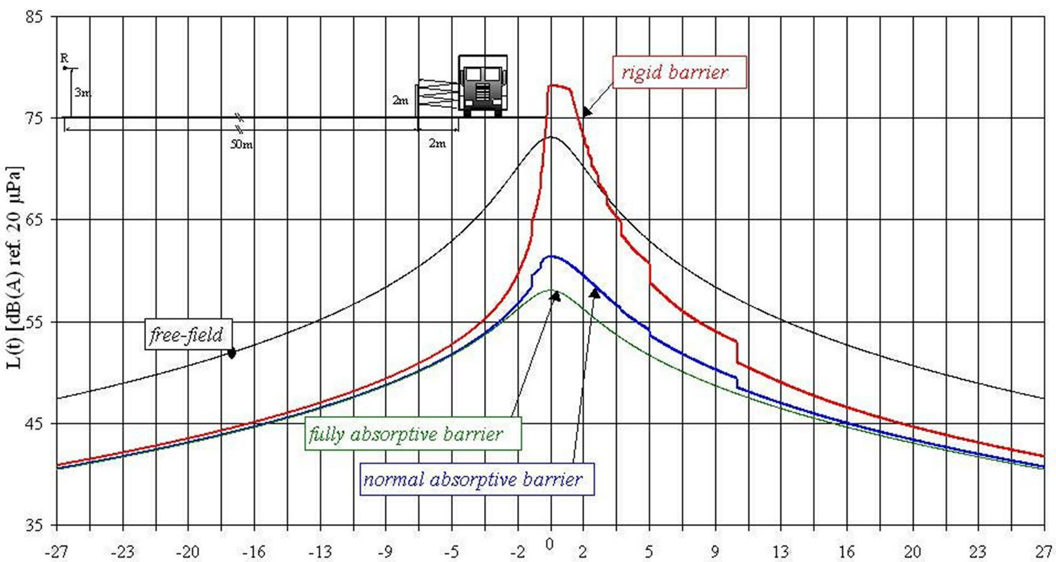

Figure 1: Pass-by levels of a lorry moving at 100 km/h, receiver 50 m behind the barrier.

The way models take this effect of multiple (close) reflections into account can drastically influence the interpretation about the usefulness of specific barrier shapes and materials.
The same remark applies to the problem of the coherence of traffic noise: the fact that **traffic noise sources are incoherent** is now widely accepted. However, many conclusions about the effectiveness of anti-noise devices have been drawn within previous studies still considering traffic made of coherent noise sources. These studies should be reviewed [5], [7].
Sound transmission is also very often neglected in models, while its effect could be important with poorly effective devices. Figure 2 shows the resulting effectiveness of a barrier while considering transmission through it in function of DL_R, as defined in [9]. As it is simple to model, transmission should always be included in models: that permits to calculate the true contribution of **transmission** in function of the relative location vehicles/ receivers, what **affects the pass-by noise** (highly effective devices, receivers in deep shadow zone...). This is the only way to specify the appropriate DL_R a device should have in order to ensure its global effectiveness.
Products are not as ideal as their models. Some methods, as BEM, can easily model the **heterogeneity of practical products**, but are still limited to specific configurations ("2.5D", close field...). On the other hand, "wide scale" models generally consider products as plane devices, acoustically homogeneous on their whole height. To demonstrate the effectiveness of devices of complex forms/heterogeneous

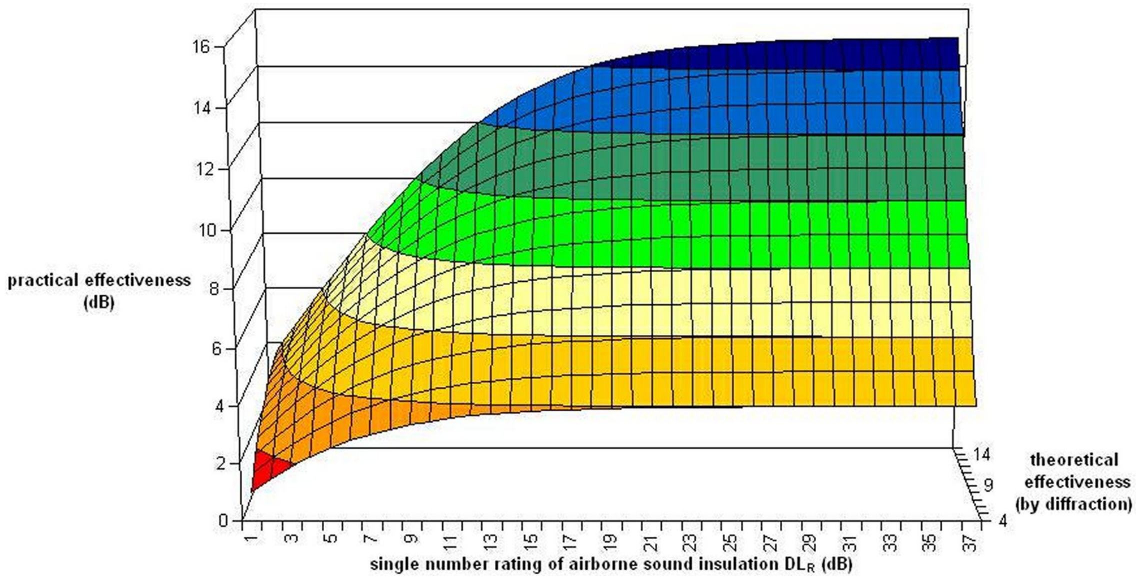

Figure 2: Effect of sound transmission through the device.

acoustic characteristics in actual situations, one should be able to model these, otherwise no improvement, nor uselessness, for such products could be claimed.

Finally, characterizing the heterogeneity of the devices is also necessary for complex solutions, as partial road covering, or even "false tunnels". One not only needs to model the **characteristics** (α, R) of each different part of the device, but also to characterize these with values **corresponding to their intended use** (under specific incidences, or diffuse field).

4 - MEASUREMENTS

Intrinsic characteristics are sound **absorption**, airborne sound **insulation** and sound **diffraction**.

The last characteristic is quite unusual but becomes relevant as some new complete devices, or added devices, specifically acts on diffraction: if these products claim performances different from the usual ones we get with "classic" devices, they should objectively proof it. It becomes thus important to think about a "intrinsic diffraction index": this topic is under development within CEN/TC226/WG6, and any suggestion is welcome!

About absorption and insulation, important remarks have to be done on the representativeness of the values obtained with different test methods: existing methods, as described in [8] or [9], are using diffuse sound incidences, while the intended use (under traffic noise) does much better correspond to specific incidences. The "ADRIENNE" method [10] has been developed for testing under specific incidences and is now in a phase of a wider scale validation, before being ready as new standard [11].

Logically, [11] **should be appropriate for "open field" applications**, while [8] and [9] **should be relevant of applications as tunnels, road covers or deep "open ceiling" tunnels**. Unfortunately, only [8] and [9] are available today, what leads to mistakes while comparing, for instance, flat absorptive products with strongly non-flat products claiming strong absorptive performances. This remark is valid not only for characterizing products in a fair way, but also to put relevant data in models.

Extrinsic characteristics constitute the final effectiveness of the devices, i.e. the **insertion loss**. Measuring these characteristics can be done either with scale models or in-situ. This kind of measurements is interesting while looking at performances of devices that are difficult to model.

Major problems of **scale models** come with 2 difficulties: the first is that scaling absorptive materials is still difficult in a simple pass process, secondly, scale models take rarely the movement and the body of the vehicles into account. Doing that, scale models quite often overestimates the performance of absorptive devices.

In-situ measurement is another topic: few 100 % objective methods exist to measure the true in-situ insertion loss. ISO 10847 specifies that the best way to measure the in-situ insertion loss in preferably done with **uncontrolled traffic**, and could also be done with **controlled traffic** under specific conditions, while **controlled artificial noise sources** are said not suitable. All these assumptions have to be understood carefully. Uncontrolled traffic constitute for sure the closest conditions to the actual ones, but give no value of the specific pass-by levels of each vehicle, while this information could be of

great importance for understanding the effectiveness of the device (particularly the most unusual ones). Controlled traffic, as well as artificial noise sources could suffer problems of background noise, what enlarge the time and cost of already expansive measurements surveys. Powerful artificial noise sources could be a way to improve S/N ratio, but the way to simulate the true passage of a vehicle with an artificial noise source, keeping in mind that the movement and bodies of the vehicle are relevant, is not an easy task. Furthermore, all the in-situ measurements are conditioned by atmospheric conditions.
At present, CEN/TC226/WG6 is looking at in-situ measurement of insertion loss, but faces much more problems than finds solutions to.
Finally, in-situ measurements are always specific to the test conditions, and conclusions based on these are only valid for strictly identical conditions, what is too often forgotten in advertisement of product manufacturers.

5 - PRODUCTS AND THEIR INTENDED USE

There is no limit to the imagination of product manufacturers (see fig. 3)!
We, as scientist, have no way to foresee any new anti-noise device for road or rail noise. However, we have the responsibility of the conclusions we provide about such or such products: we must avoid to let manufacturers use our knowledge to let them claim worldwide that their products are the best, and the others are useless. Every product should be qualified for their **intended use** and nothing else than that: unfortunately, for some commercial reasons, many products are claimed to be used everywhere and anyway.
Absorptive materials are always useful when sound reflections are important and useless otherwise. However, considering absorptive materials, one should not forget that they may be only parts of the device, what means that absorption may be not effective on the whole height. Barriers build on concrete safety barriers are of this kind: do the models model this reflective part of the barrier? In the same way, how modeling an absorptive barrier placed higher than the traffic, at the top of an embankment, and so on?
Specific shapes and materials are important as far as they can give relevant improvement in the insertion loss, as specific form for reflective barriers on viaducts [13], or railway noise barriers (fig. 3). However, great care must be taken using these, because the improvement of a specific device at some locations could also lead to degradation at some other locations.
Similarly, **added devices at the top of barriers** are also a bit controversial. Their use has to be strictly limited to situations where improvements are, and avoided everywhere else. For instance, these devices are more useful on viaducts, where houses are low enough. Stating that an added device could replace a higher classic barrier is nonsense if not specifying the context where this is true: lowering the shadow line give never improvements for receivers which are close or higher to this limit to the viaducts. However, great care must be given when stating that an added device could replace a higher classic noise barrier, as lowering the shadow zone give no improvement for receiver which are closer to its limits.

Figure 3: Who knows how complex the next design should be?

6 - CONCLUSIONS

This paper just recalls evidences, but these are too often forgotten. Qualifying the effectiveness of anti-noise devices is a difficult task.
Great care has to be done before concluding on a specific product. One should:

- conclude only with relevant characteristics (α, R, diffraction index),

- measured only with test methods relevant with the intended use (diffuse/direct incidences);
- if the effectiveness is variable: specify the relevant noises maps of the true insertion loss;
- avoid to roughly compare two different designs, which can be each effective in different situations;
- model every important characteristic of the whole propagation process, taking the complexity, shape and heterogeneity into account, as well as considering multiple reflections, the scattering effect and movement of the vehicles, ...
- avoid to enlarge conclusions of effectively measured products to situations which are different from those corresponding surveys;
- when it doubt, go back to physics.

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