ACOUSTIC BARRIERS: PERFORMANCE AND EXPERIMENTAL MEASUREMENTS

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ABSTRACT

Aim of this work is propose an engineering method for calculating the attenuation of sound during propagation outdoor, taking into a particular attention the attenuation due to barriers. The paper outlines the main features and the acoustic performance of the barrier.

1 INTRODUCTION

The equivalent continuous downwind octave band sound pressure level at a receiver location shall be calculated taking into account the sound power level of the source, the directivity correction, and the octave bands correction that occurs during propagation from the point sound source to the receiver.

The most important attenuation terms are the geometrical attenuation, atmospheric absorption, ground attenuation effects and obviously the presence of barriers and other miscellaneous effects (as vegetation or trees). The forecasting proposed method takes into account those terms elaborating a complete procedure.

1.1 Barrier's Characteristics

We define an object as a screening obstacle (that means barrier), if it meets the following characteristics:
-Surface density is at last 10 kg/m^2
-The object has a close surface without cracks or gaps.
-The horizontal dimension of the object (barrier) normal to the source-receiver line is larger than the acoustic wavelength λ at the nominal midband frequency for the octave band of interest.
In particular, we will study that kind of object that fulfils these requirement and we will represent it as a vertical edge barrier, the top of which is a straight line that may be sloping.
Taking into account the attenuation due to a barrier we will even consider the reflection, transmission, absorption and obviously the diffraction terms.

2. OUTDOOR SOUND PROPAGATION

The reference used to determine the attenuation of sound during propagation outdoors is provided by norm ISO 9613 1-2 (1996). The basic equation utilized in this model is:

$$L_P(f) = L_W(f) + D_I(f) - A(f) \quad [1]$$

where:
Lp: the equivalent continuous downwind octave-band sound pressure level at a receiver location, calculated for each point source.

Lw : the octave-band sound power level, in decibels, produced by the point sound source relative to a reference sound power of one picowatt (1pW).

D_I :directivity index, in decibels, that describes the extent by which the equivalent continuous sound pressure level from the point sound source deviates in a specific direction from the level of an omnidirectional point sound source producing sound power level Lw.

A : the octave-band attenuation, in decibels, that occurs during propagation from the point sound source to the receiver.

The attenuation term in equation [1], is given by equation [2]:

$$A = A_{div} + A_{atm} + A_{gr} + A_{bar} + A_{misc} \quad [2]$$

where:
A_{div} : is the attenuation due to geometrical divergence
A_{atm} : is the attenuation due to atmospheric absorption
A_{gr} : is the attenuation due to ground effect
A_{bar} : is the attenuation due to a barrier
A_{misc} : is the attenuation due to miscellaneous other effects.

2.1 Attenuation due to geometrical divergence and ground effect.

The attenuation due to geometrical divergence from two distance points marked 'd' is calculated by this equation:

$$A^*_{div,gr} = 20\,log\left(\frac{d}{d_0}\right) + 8 \quad [3]$$

where:
d : is the distance from the source and the receiver in metres
d_0 : is the reference distance (d_0 = 1 metre)
The term + 8 takes into account the propagation for spherical spreading in the free field over reflecting soil from a point sound source (this approximation applies to a quarry of ornamental rocks). The ISO Standard, suggests the use of term + 11 because it indicates a point sound source in a free field, and introduces a method for calculating the ground effects separately.

2.2 Attenuation due to atmospheric absorption.

Sound energy is dissipated in the air by viscous losses and molecular relaxational process, it depends on air molecular composition, meteorogical conditions and sound frequency. The first of these phenomena is due to the friction between air molecules resulting in heat generation; it depends on temperature and frequency. The relaxational process depends on momentary energy absorption by air molecules that causes their vibration and rotation. It is the function of temperature, relative humidity and frequency.

This mechanism is codified in ANSI Standard S1-26:1995 and ISO 9613-1; for a standard pressure of one atmosphere, the attenuation due to atmospheric absorption, in decibels, is calculated with this equation (par. 7.2 ISO 9613-2

$$A_{atm} = a \frac{d}{1000} \quad [4]$$

where:

d : is the propagation distance, in metres, from sound source and receivers

α : is the atmospheric attenuation coefficient, in decibel per metre, for each octave band at the midband frequency and one atmosphere. It is given by the following expression:

$$a = 8{,}689 \times f^2 \left\{ 1.84 \times 10^{-11} \left(\frac{T}{T_0} \right)^{1/2} + \left(\frac{T}{T_0} \right)^{-5/2} \left[\frac{0.01275 \times e^{-2239.1/T}}{F_{r,O} + f^2 / F_{r,O}} + \frac{0.1068 \times e^{-3352/T}}{F_{r,N} + f^2 / F_{r,N}} \right] \right\} \quad [5]$$

The function (5) is a function of two relaxation frequencies, $F_{r,O}$ and $F_{r,N}$, which are respectively the oxygen and nitrogen relaxation frequencies; their values in hertz shall be calculated from

$$F_{r,O} = 24 + 4.04 \times 10^4 h \frac{0.02 + h}{0.391 + h} \quad \text{and} \quad F_{r,N} = \left(\frac{T}{T_0} \right)^{-1/2} \left\{ 9 + 280 h \times e^{\left[-4.17 \left(T / T_0 \right)^{-1/3} - 1 \right]} \right\} \quad [6]$$

T : ambient atmospheric temperature, in Kelvin

T_0 : reference air temperature: T_0 = 293,15 K

h : molar concentration of water vapour (%).

2.3 Reflection

Reflections are considered in terms of image source. These reflections are from outdoor ceilings and vertical surfaces, such as rock walls which can increase the sound pressure level at the receiver. Once the geometry of the site is known, we identify the image sound source and its characteristics (sound power levels and directivity), thus applying the algorithm without considering the ground effect one obtains:

$$L_P(f) = L_W(f) + D_I(f) - A(f) \quad [7]$$

2.4 The Huygens-Fresnel Principle

The attenuation due the barrier will be studied using the classical approach to the diffraction problem.

According to the Huygens construction every point of a wave-front may be considered as a centre of a secondary disturbance which gives rise to a spherical wavelets, and the wave-front at any later instant may be regarded as the envelope of these wavelets. Let S be the instantaneous position of a spherical monochromatic wave-front of radius r_0 which proceeds from a point source P_0 and let P be a point at which the disturbance is to be determined. It is possible to obtain for the elementary contribution dU(p) due to the element dS at Q the expression:

$$dU(P) = K(c) \frac{Ae^{ikr_0}}{r_0} \frac{e^{iks}}{s} dS \quad [8]$$

where s=QP and K(χ) is an inclination factor which describes the variation with direction of the amplitude of the secondary waves. Hence the total disturbance at P is given by

$$U(P) = \frac{Ae^{ikr_0}}{r_0} \iint_S \frac{e^{iks}}{s} K(c) dS \quad [9]$$

The basic idea of the Huygens-Fresnel theory was put in a mathematical basis by Kirchhoff who considered first a strictly monochromatic scalar wave:

$$V(x,y,z) = U(x,y,z)e^{-iwt}$$

in vacuum the space dependent part then satisfies the time-independent wave equation (Helmotz Equation):

$$\left(\nabla^2 + k^2\right)\cdot U = 0$$

where k is the wave number k=ω/c.

Let now V be a volume bounded by a closed surface S, and let P be any point within it; we assume that U possesses continuous first and second order partial derivatives within and on the surface. If U' is any other function that satisfies the same continuity requirements as U, we have the Green's theorem:

$$\iiint_V (U\nabla^2 U' - U'\nabla^2 U)dv = -\iint_S \left(U\frac{\partial U'}{\partial n} - U'\frac{\partial U}{\partial n}\right)dS \qquad [10]$$

where $\frac{\partial}{\partial n}$ denotes differentiation along the inward normal to S.

After some approximation and applying the theory to a straight edge barrier, we obtain:

$$[Att.]_{\frac{1}{2}} = -10\log_{10}\frac{1}{2}\left[\left\{\frac{1}{2} - C_{(n)}\right\}^2 + \left\{\frac{1}{2} - S_{(n)}\right\}^2\right] \qquad [11]$$

where $n = H_e \cdot \sqrt{\frac{2}{l}\left(\frac{1}{a} + \frac{1}{b}\right)}$, is proportional to the Fresnel number

Solving with numerical method the Fresnel's integrals one can obtain the attenuation due to a semifinite barrier. The Fresnel integrals are calculated using the Newton integral method that is a simple numerical solution.

According to Maekawa's theory[5] it is possible to add together more attenuation (i.e. ground attenuation), paying attention that we are now looking for an expression for the attenuation due to diffraction trough a window whereas Maekawa spoke about diffraction over a semi-infinite barrier. According even to the Babinet's[4] principle, we obtain the total attenuation like a sum of contributions due to the four attenuation terms of each window edge.

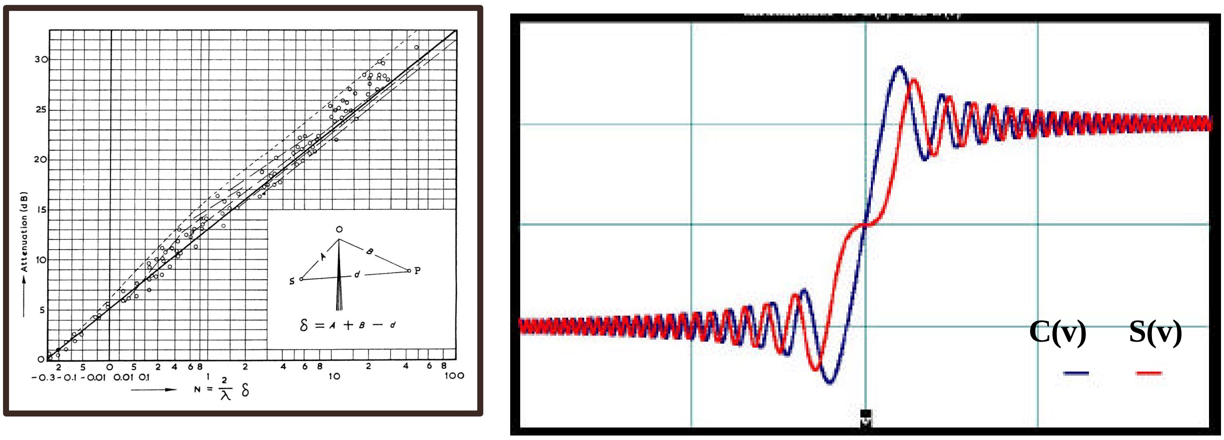

Figure 1. Maekawa attenuation graphic method (left) and Fresnel's integrals C(v) and S(v) (right)

Figure 1 shows the well-known Maekawa graphic which allows calculating the attenuation term due to a barrier only using the Fresnel number that is a simple function of the wavelength.

By applying the Kirchhoff diffraction theory which embodies the basic idea of the Huyghens theory to a semi-infinite barrier the sound attenuation by screens, after some approximation is given by a formula that depends on the Fresnel's integrals and the v parameter, function of the He number often called effective height.

The figure below (figure 2) shows the values assumed by the attenuation term depending on the point of observation lies in an illuminated region (v<0) or in the geometrical shadow zone (v>0).

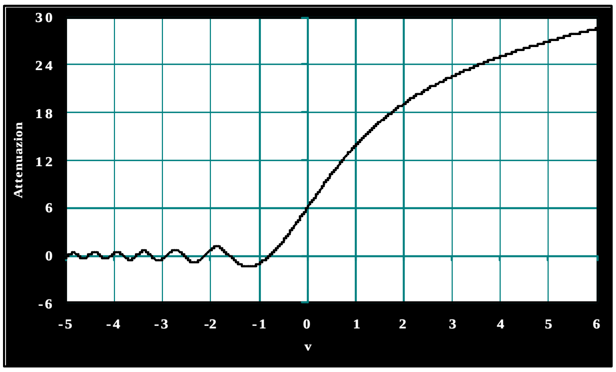

Figure 2. Attenuation in function of the v parameter

3. MEASUREMENTS AN EXPERIMENTS

We made two sets of measurements; at the begin we used a continuous signal. The source is a known sound reproduced by a digital compact disc with a pink noise, and the figure 3 shows the spectral characterization. The sound level meter used is a Larson & Davis 824.

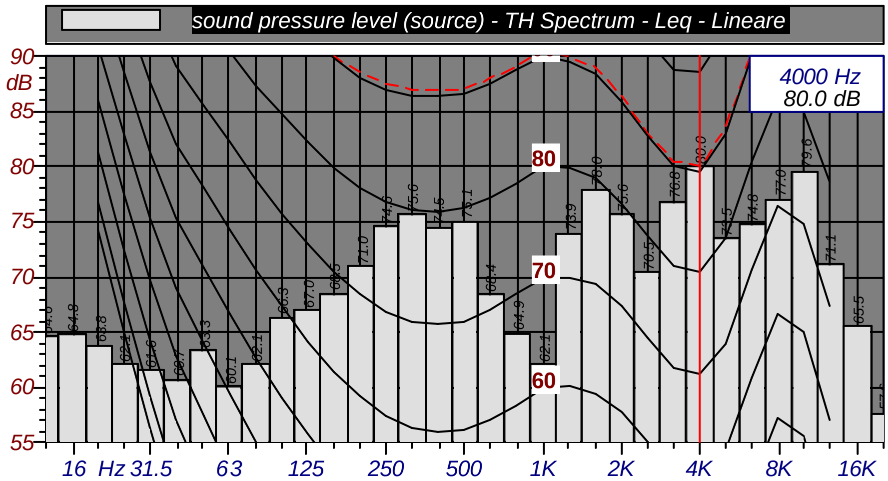

Figure 3: Source characterization

In figure 4 it is shown how the forecasting method works. Going fom left to right you can see the acoustics field for the frequency of 31,5 hz, 250 hz, 4000 hz and 16000 hz.

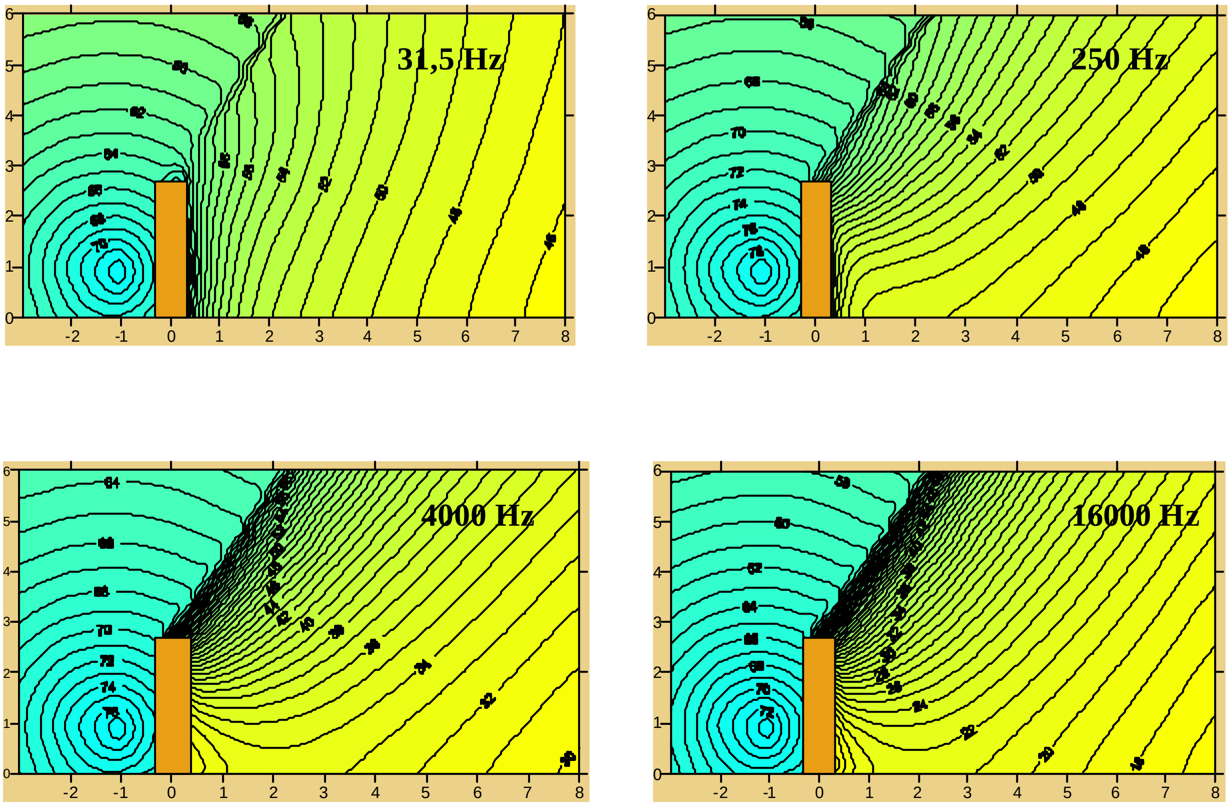

Figure 4: Diffraction of sound around the barrier

3.1 A First conclusion

The comparison between the forecasts and the measurements shows good results at the medium frequencies. Low frequencies suffer from the heavy presence of the noise floor, in particular we may say that:

-31 hz: the noise floor causes mistakes mainly because the low frequency sounds propagation is not obstructed by the barrier and by atmospheric attenuation.

-250hz: good results, the measured and the forecast values are quite close.

-16000hz: results are good till values about 27 dB. Going lower noise floor (ambient noise) becomes the main cause of noise.

In order to erase these mistakes we introduced new measurements using impulsive signals and two different analyzers: the first (L&D 824) is situated near the sound source, the second describes a reticular grid (40 measurements) over the barrier (L&D 2900).

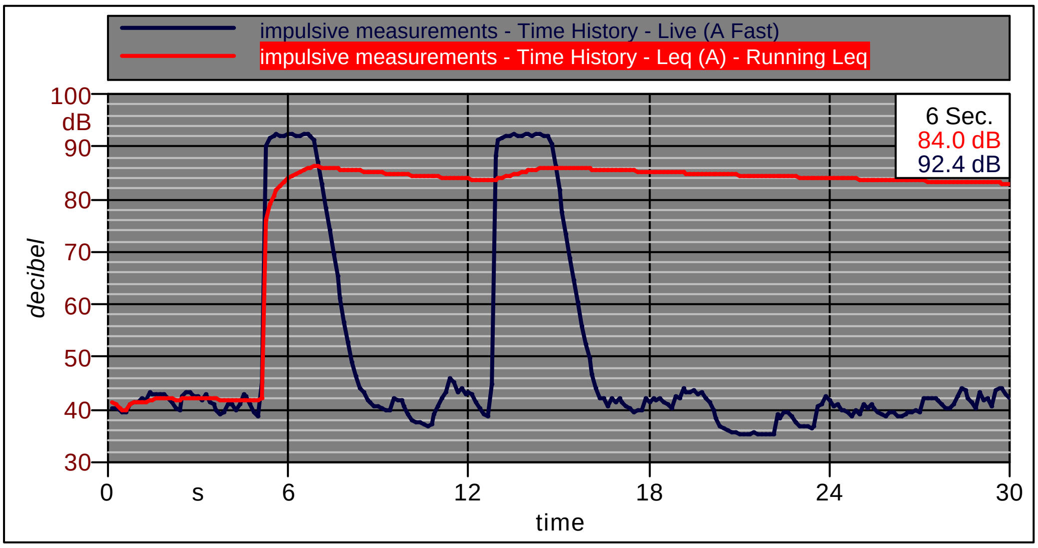

Figure 5. The impulsive signal used in the second measurement.

Repeating the calculus and, above all, introducing a new fictitious source given by the noise floor as measured before the impulsive signal, we obtain new values quite closer to the measurements then the previous ones. That because the noise floor is quite preponderant, as said before, at the low bands.

CONCLUSION

In the present paper an easy method in forecasting the sound barrier characteristics was presented. Good results were found for the middle-high bands frequency even without considering the noise floor. Anyway we could foresees that behaviour, being the Kirchhoff's theory good for high frequency. Nevertheless good results was found even at low frequency when we added a fictitious noise source that takes into account the noise floor. Comparison between forecast and measurements in this second set of experiments shows a difference not higher then 2 dB(A).

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