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A NEW FRENCH METHOD FOR RAILWAY NOISE PREDICTION

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ABSTRACT

Regulations for railway noise are becoming more and more stringent and, along with a decrease of maximum acceptable sound levels, a more accurate environmental prediction is sought. This has brought about the need of sound level calculations at long ranges including meteorological effects. A new French prediction method for Railway Noise (NMPB-FER) has thus been developed on the basis of an already existing one for road traffic noise. This method specifies two calculation procedures: with meteorological conditions favourable to sound propagation and with atmospheric homogeneous conditions. The result is a long term equivalent A-weighted noise level obtained by the combination of the two calculations and taking into account the percentage of time when favourable conditions occur. The railway source is modelled as two independent sources, one being close to the rail/wheel contact plane (concerning highest frequencies) while the other is located at a height appropriate to a simple but correct representation taking into account aerodynamic sources (for lowest frequencies). This method implemented in the MITHRA ray tracing software offers some original specificities: barrier-carriage multi-reflections effects taken into account, calculation of the noise level vs time evolution, railway noise sources split up according to the total length of the convoy, composition of trains and determination of sound power level characteristics achieved by assembling the wanted rolling elements (locomotive and carriages, types and numbers). Input to the model can easily be obtained from multi-spectrum measurements close to the railway.

1 - INTRODUCTION

Regulations for railway noise are becoming more and more stringent and, along with a decrease of maximum acceptable sound levels, a more accurate environmental prediction is sought. This has brought about the need of sound level calculations at long ranges including meteorological effects. A new French prediction method for Railway Noise (NMPB-FER) has thus been developed on the basis of an already existing one for road traffic noise [1,2,3,4]. This method specifies two calculation procedures: with meteorological conditions favourable to sound propagation and with atmospheric homogeneous conditions. The result is a long term equivalent A-weighted noise level obtained by the combination of the two calculations and taking into account the percentage of time when favourable conditions occur. Specificities of railway noise are also taken in account, like source modelling and body-barrier interaction.

2 - PRINCIPLES OF THE NEW METHOD

2.1 - The long term equivalent noise level L_{LT}

The railway is represented as lines of point sources. Transmission path attenuation between a point source and the receiver is estimated by means of additive corrective terms for spherical divergence, air absorption, ground and diffraction effects, and reflection on vertical surfaces. All these attenuations are

calculated for two different meteorological conditions: favourable to propagation (giving level L_F) and homogeneous medium (giving level L_H).
The long term equivalent A-weighted noise level L_{LT} is then estimated by the relation:

$$L_{LT} = 10 \log \left(p \times 10^{\frac{L_F}{10}} + (1-p) \times 10^{\frac{L_H}{10}} \right) \tag{1}$$

where p is the time occurrence (value between 0 and 1) when favourable meteorological conditions statistically occur in the direction of propagation.
In this new method which is an octave band approach, L_H characterises the mean noise level without meteorological effects (no celerity gradient). The long term average equivalent noise level may thus never be lower than this minimum reference level.

2.2 - Determining the favourable conditions occurrence p

The percentage of time when meteorological conditions favourable to propagation occur (expressed in the method as occurrence p) may be evaluated using the simple qualitative Zouboff method [5]. It is based on a double entry *Ui-Ti grid* which requires simple meteorological data. *Ui* is the wind class (among 5) while *Ti* is the thermal class (3 classes at daytime and 2 at night). Values of occurrence p have been calculated for 40 different French meteorological stations for daytime (0600-2200) and night period (2200-0600), with a source-receiver direction varying by steps of 20°. The results correspond to the integration of at least 10 years of hourly meteorological data. When no data are available, fixed values of p may be chosen: p=1 at night (100% occurrence) and p=0.5 at daytime (50% occurrence).

3 - RAILWAY NOISE SPECIFICITIES

3.1 - Railway source modelling

The train is modelled as a set of equivalent point sources, each one being related to a bogie or a train element, and associated to a specific source type. Railway noise has mainly two different origins: the rolling noise due to the wheel-rail contact, and the aerodynamic noise due to the air flow along the carriage. This latest origin is significant for a TGV train travelling more than 250 km/h. The emission model used in the present method thus considers two different heights of the line of equivalent point sources:

- 80 cm above the rolling plane for lowest frequencies (125, 250 and 500 Hz),
- 5 cm above the rolling plane for highest frequencies (1, 2 and 4 kHz).

A 3D directivity is also assigned to the point sources. In the horizontal plane, the directivity Dh expresses the sound emission due to the rolling elements − infrastructure system, and is written as:

$$Dh = \cos\theta \times 4/\pi \tag{2}$$

where θ represents the angle between the perpendicular to the line source and the horizontally projected source-receiver direction.
In the horizontal plane, the directivity Dv expresses the hiding of the sources by the body of the carriage and is given by the following analytical law:

$$Dv = 40/3 \times \left[2\sin\left(2\varphi\right)/3 - \sin\varphi\right] \times \log\left[\left(f + 600\right)/200\right] \tag{3}$$

where φ represents the angle between the horizontal and the vertically projected source-receiver direction.

3.2 - Body-barrier interaction

When an anti-noise barrier or a long vertical obstacle is laying along close the railway track, the acoustic rays from the railway source are reflecting many times between the carriage body and the barrier. This effect, called body-barrier interaction, is taken into account by means of image-source principle and by emitting the sound in a vertical plane tangent to the train body. This allows to take into account the acoustic absorption of the barrier. Its tilt is also taken into account. Moreover, for this model to converge, retro-diffraction phenomenon (that is when ray is reflecting close to the barrier edge, relatively to the wavelength) has to be considered. This is achieved by means of Babinet principle for a screen.

4 - CALCULATION OF THE ATTENUATIONS

Attenuations are calculated for each acoustic path. The equivalent sound level with conditions favourable to propagation and with homogeneous conditions are calculated by:

$$L_F = L_w - A_F \tag{4}$$

$$L_H = L_W - A_H \tag{5}$$

where the attenuations A_F and A_H are determined in octave band by:

$$A_F = A_{div} + A_{atm} + A_{grd,F} + A_{dif,F} \tag{6}$$

$$A_H = A_{div} + A_{atm} + A_{grd,H} + A_{dif,H} \tag{7}$$

In eqs (6) and (7), A_{atm} is the air absorption and A_{div} is the attenuation due to the spherical divergence, both calculated according to the ISO 9613-1 and −2 respectively [6]. $A_{grd,F}$ (resp. $A_{grd,H}$) is the attenuation due to ground effect and $A_{dif,F}$ (resp. $A_{dif,H}$) is the attenuation due to diffraction, for favourable conditions (resp. homogeneous conditions).

4.1 - Ground effect

The description of the ground characteristics is achieved through a factor G as in the ISO 9613-2 approach. G may take two values: G=0 for reflective surfaces (asphalt, concrete, ice) and G=1 for absorbing ground (any ground which supports growth). For a mixed surface, G equals to the portion of porous ground along the path. Source height z_S is referred to the wheels/rails contact plane while receiver height z_R is calculated with reference to a mean plane of the real terrain. The ballast is characterised by G=1.

Attenuation due to the ground in favourable conditions is calculated using ISO 9613-2 formulations. In homogeneous conditions, ground effect is determined by [1], [7,8]:

$$A_{grd,H} = -10\log\left[4\frac{k^2}{d_p^2}\left(z_S^2 - \sqrt{\frac{2C_f}{k}}z_S + \frac{C_f}{k}\right)\left(z_R^2 - \sqrt{\frac{2C_f}{k}}z_R + \frac{C_f}{k}\right)\right] \geq -3\left(1 - G_{path}\right) \tag{8}$$

where k is the wave number, dp the horizontal source-receiver distance, G_{path} the value of G along the path and (f is the frequency hereafter):

$$C_f = d_p \frac{1 + 3wd_p e^{-\sqrt{wd_p}}}{1 + wd_p} \tag{9}$$

$$w = \frac{0.0185 \times f^{2.5}G^{2.6}}{f^{1.5}G^{2.6} + 1.3 \times 10^3 f^{0.75}G^{1.3} + 1.16 \times 10^6} \tag{10}$$

4.2 - Diffraction effect

Principle of calculation of diffraction attenuation is given in Fig. 1.

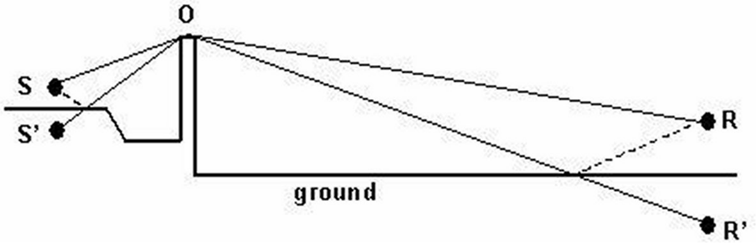

Figure 1: Principle of calculation of attenuation due to diffraction.

The attenuation due to diffraction in favourable and homogeneous conditions, respectively, is calculated through the following expressions:

$$A_{dif,F} = \Delta_{dif,F}\left(S,R\right) + \Delta_{grd,F}\left(S,O\right) + \Delta_{grd,F}\left(O,R\right) \tag{11}$$

$$A_{dif,H} = \Delta_{dif,H}\left(S,R\right) + \Delta_{grd,H}\left(S,O\right) + \Delta_{grd,H}\left(O,R\right) \tag{12}$$

where $\Delta_{dif,F}\,(S,R)$ and $\Delta_{dif,H}\,(S,R)$ are the attenuations due to diffraction for path S-O-R in favourable and homogeneous conditions, respectively, and where $\Delta_{grd,F}\,(M,N)$ and $\Delta_{grd,H}\,(M,N)$ are the attenuations due to the ground between points M and N in favourable and homogeneous conditions, respectively.
The term Δ_{dif} represents a pure diffraction by a barrier and is calculated by:

$$\Delta_{dif} = 10\log\left[3 + (40/\lambda)\,C''\delta\right] \leq 25 \quad \text{for} \quad (\,40/\lambda)\,C''\delta \geq -2 \tag{13}$$

where λ is the wavelength, δ is the path difference of the diffracted ray and C” a corrective term taking into account multiple diffraction like in ISO 9613-2. When $(40/\lambda)\,C''\delta \geq -2$, Δ_{dif}=0. The evaluation of δ is achieved in homogeneous conditions (straight rays for $\Delta_{dif,H}$) as well as favourable ones (curved rays [1], [8] for $\Delta_{dif,F}$).
The terms Δ_{grd} are written as

$$\Delta_{grd}\,(S,O) = -20\log\left[1 + \left(10^{A_{grd}(S,O)/20} - 1\right) \times 10^{\left(\Delta_{dif}(S',R) - \Delta_{dif}(S,R)\right)/20}\right] \tag{14}$$

$$\Delta_{grd}\,(O,R) = -20\log\left[1 + \left(10^{A_{grd}(O,R)/20} - 1\right) \times 10^{\left(\Delta_{dif}(S,R') - \Delta_{dif}(S,R)\right)/20}\right] \tag{15}$$

In eqs 14 and 15, A_{grd} and Δ_{dif} are calculated from eqs 8 and 13, respectively. The ground effect before the diffraction point $A_{grd}(S,O)$ and after the diffraction point $A_{grd}(O,R)$ are weighted respectively by the difference between attenuation by diffraction for the image-source and the source, and for the receiver and the image receiver in the ground.
The principle is applied to both meteorological conditions favourable to propagation and homogeneous medium. It allows the calculation of the transmission path attenuation either for barriers or terrain like embankments and wedges.
It is of importance to remember that when there is a diffraction, $A_{grd,F}$ and $A_{grd,H}$ are set to 0 in eqs 6 and 7, since ground effect is taken in account directly in the $A_{dif,F}$ and $A_{dif,H}$ terms.

5 - COMPARISON WITH MEASUREMENTS

The experimental determination of a long term average equivalent continuous A weighted sound pressure level particularly at a long range requires to have the most representative features to limit the discrepancies linked to the main parameters (equivalent acoustic source position, meteorological conditions, railway traffic, ground absorption characterisation,...).
If for several ones, there will be nearly no problem of determination, others will require further investigations like sources position and meteorological conditions characterisation. As a project, the NMPB railway version has taken into account the conclusions of recent works, particularly on rolling noise and aeroacoustic sources generation mechanisms.

5.1 - Railway source position

The choice of the position of railway system equivalent acoustic sources (0.8 m above rail for lower frequencies, nearly rail level for higher frequencies) has been done in accordance with the results outlined through the last research projects:

- importance of the aerodynamic noise at lower frequencies (TGV train) [9],
- predominance of the rolling noise (wheel/track acoustic emission) in high frequencies from low speed to 300 km/h [10].

Preliminary validation results have been performed with an acoustic array in order to check the coherence of the source position choice.
The acoustic array developed by SNCF to deal with mono- or bi-dimensional localisations has been used in a vertical configuration, defined to cover the 1/3 octave bands with midband frequencies from 315 to 4000 Hz.
Results obtained with this tool are given in Figs 2 and 3. In these figures, the full vertical scale (ordinate) corresponds to the total height of the train.
Even if the accuracy of that tool is less important in the lower frequencies (under 315 Hz, accuracy ($> 2\lambda$) is not sufficient to conclude), main sources are located higher than the rail.
The repartition of the energy is interesting to be considered in the higher frequency where the aerodynamic and rolling noise contributions are clearly pointed out. It has to be noticed that the levels of the aeroacoustic sources are at least 5 dB less than those linked to the rolling noise.
Again, the low frequency sources are upper than those in higher frequency ranges, located near the rail.

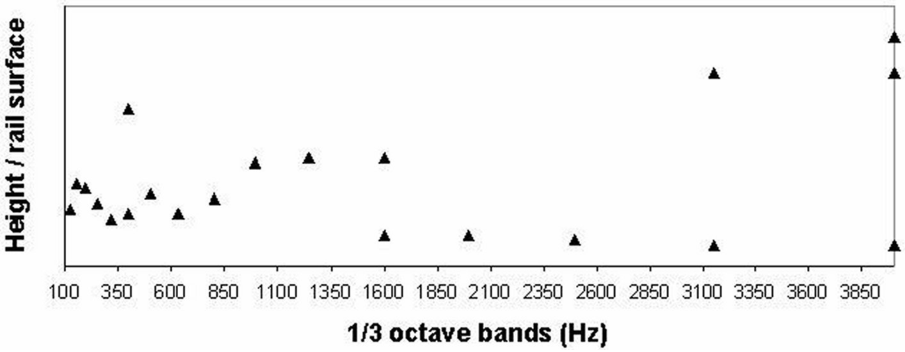

Figure 2: Acoustic sources vertical localisation on a TGV running at 288 km/h.

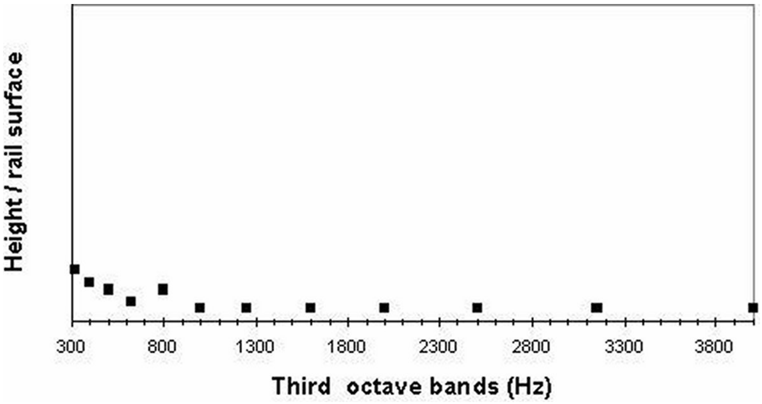

Figure 3: Acoustic sources vertical localisation on a Fret train running at 90 km/h.

So, these preliminary results have confirmed the coherence of the source position choice adopted in a first approach for the prediction model. But, it is not sufficient in a validation process and it is clear that an experimental validation is still required.

5.2 - Long term meteorological indicators

The LA_{eq} discrepancies linked to meteorological variations (favourable to propagation or homogeneous) can reach up to 10 dB with MITHRAFER calculations. Thus, it seems essential to be in the position to separate the measurements values according to the nature of the meteorological conditions during the tests. The difficulty will come from the assessment of a long term indicators from short or mid-term measurements.

6 - CONCLUDING REMARKS

A new method for railway noise calculations has been established in order to predict a long term equivalent noise level. This approach is original by several aspects: meteorology taken into account through p, L_F and L_H terms, railway source modelled as two frequency dependent sources and body-barrier interaction taken into account with retro-diffraction phenomenon. Moreover, the decomposition into equivalent point sources allows the calculation of sound signature (*ie.* level vs time) of any passing train.
A validation process is nevertheless required to be in the position to define and perform environmental noise assessment procedure to answer noise regulations requirements.

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