The effect of road absorption on tyre-road horn effect

Fabienne Anfosso-Lédée

Laboratoire Central des Ponts et Chaussées, Centre de Nantes, F-44341 Bouguenais, France,
Email: fabienne.anfosso@lcpc.fr

Introduction

Horn effect is an amplification phenomenon of the tyre-road noise generated at the contact patch, caused by multiple reflections between the tyre belt and the road surface. This effect can reach more than 10 dB, but may be drastically reduced when the pavement is sound absorbing, which is the case for porous pavements. A 2D BEM model was used to predict this effect in which a non local absorption condition was introduced to take into account the effect of porous road surfaces. A theoretical validation was made previously for purely reflecting boundary conditions. This paper presents an experimental validation made on porous and non-porous real pavements, using the principle of reciprocity.

The 2D-BEM model approach

Purely reflecting boundary conditions

The tyre is approximated by an infinite rigid cylinder, with the same diameter as a tyre (0.60 m), laying on an infinite rigid plane. This cylinder is assumed to be rigid, not distorted by the contact with the plane surface, and with perfectly reflecting boundary conditions. The road pavement represented by the plane surface – roughness is neglected - has purely reflecting boundary conditions in a first approach. In this 2-dimension problem, only a section is considered, and the contact between the tyre and the road is reduced to a point.

The acoustic source can be a velocity distribution on the contour Γ_t, but in this paper, an equivalent point monopole source S located near the contact patch is used. It can represent the "air-pumping" source due to successive compressions and dilatations of air trapped in road and tyre cavities. The resulting sound can be calculated at one or many receiver points (R) located in the air-filled horn.

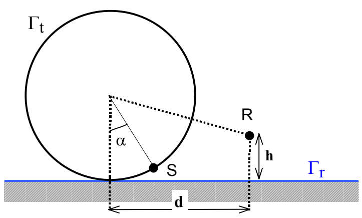

Figure 1: 2D geometrical description.

The sound pressure at the receiver point $p(R)$ is expressed by the integral formulation :

$$p(R) = p_i(R) + \int_\Gamma \left[\frac{\partial G(R,M)}{\partial n} p(M) - G(R,M) \frac{\partial p(M)}{\partial n} \right] d\Gamma(M) \quad (1)$$

where $p_i(R)$ is the incident sound pressure, G the free-field Green function, the total boundary $\Gamma = \Gamma_t \cup \Gamma_r$.

This integral equation is expressed as a boundary equation, and solved by numerical procedures using boundary elements. In case the road surface is assumed perfectly reflecting, the use of semi-free-field Green function reduces drastically the calculation, and a set of linear equations of unknown the nodal pressure vector $\{p\}$ is derived :

$$[H]\,\{p\} = \{p_i\} \quad (2)$$

The model has been successfully compared with the analytical model developed by Kropp, and with other BEM models [1], [2].

Porous layer absorption boundary condition

In the case of porous road surface, the boundary condition is not straightforwardly introduced in the BEM model, because the assumption of local reaction can not be made : the surface impedance depends on the angle of incidence, i.e. for a given source location, the surface impedance varies along the interface. The error committed when considering a local reaction is even more important than the incidence is grazing. In the present case, the sound source is close to the contact patch, and consequently, the incidence of acoustic wave propagating in the horn is typically grazing.

A coupling between two boundary equations was then developed : one in the air medium (equation (1)), the other describing the sound propagation inside the porous medium. The coupling of the two equations is achieved by the continuity of sound pressure and particle velocity at the interface between air and porous material. The numerical solving of this system gives a system of linear equations of unknown the nodal pressures $\{p\}$ and nodal pressure gradients $\{\partial p/\partial n\}$ on the boundary :

$$\begin{cases} [H_0]\,\{p\} - [G_0]\,\{\partial p/\partial n\} = \{p_i\} \\ [H_p]\,\{p\} - [G_p]\,\{\partial p/\partial n\} = \{0\} \end{cases} \quad (3)$$

The subscripts “0” (respectively “p”) stands for air (respectively porous) medium quantities. The Green function and its normal gradient inside the porous medium are derived by using the phenomenological model developed by Hamet [3]. This model requires 4 parameters : porosity, specific flow resistance, tortuosity, and layer thickness. Typical predictions of horn effect on porous road surface can be found in [1] and [2].

Experimental validation

Description of the experiment

The 2D tyre was simulated by a 3 m long concrete tube, diameter 0.60 m, rigid and acoustically reflecting. It was placed first on a reflecting road surface (BBSG), and later, on a porous road surface (BBDr). The principle of reciprocity was used by placing a sound source *S* in the horn in front of the tube, and a microphone *R* flush on the surface of the tube, near the contact with the road surface. Different positions of the microphone were tested, for angle α with the vertical ranging from 5° to 45°. The centre of the source was located at *h* = 0.3 m above the road surface, and *d* = 1 m from the centre of the tube (Figure 1 where *S* and *R* are inverted). A M.L.S. signal was driven through the loudspeaker, and the impulse response was measured at the microphone. The transfer function was derived by Fourier analysis. The amplification horn effect was evaluated with reference to semi-free field condition above the road surface, i.e. as the ratio of transfer functions with and without the tube at the same microphone position. The edge influence of the finite tube is removed by the time windowing.

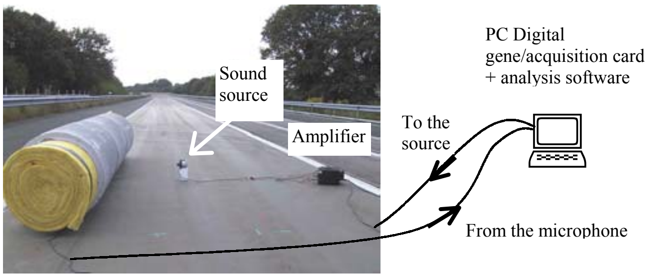

Figure 2: experimental set-up : concrete tube filled with glasswool to avoid mode propagation inside the tube

Estimation of the road acoustic impedance

In parallel, the amplification was calculated with the BEM model. For the porous road surface, the 4 physical parameters introduced in the boundary conditions were deduced from in situ measurements of sound absorption coefficient at normal incidence. The measuring method is described in [4]. The best fit between the measured and the predicted coefficient of absorption with the phenomenological model [3], gave the parameters : porosity Ω = 0.17 ; specific flow resistance R_s : 37000 MKS Rayls ; tortuosity factor K = 2.5 ; Porous layer thickness e = 0.04 m.

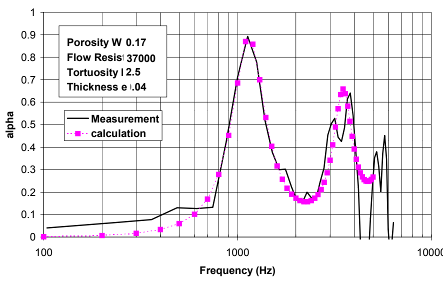

Figure 3: Absorption coefficient of the tested porous road surface – comparison between measurement and predictions.

Comparison between model and experiment

Experimental results and model predictions of horn effect amplification brought by the tube are shown in Figure 4 for the purely reflecting road surface, and in Figure 5 for the porous one. The results at 2 microphone positions are presented : the nearest to the contact patch (α = 5°, green curves) and an intermediate one (α = 30°, black curves). The overall comparison is fairly good, the curve shapes are similar, the orders of magnitude of amplification are comparable. The agreement is lower when getting closer to the contact patch (α = 5°). This can be explained by the difficulty to position accurately the microphone at the exact location (1mm above the surface). This inaccuracy explains the interference deep displacement in Figure 5 for instance. At higher source position, the positioning is more accurate, and a better agreement is obtained.

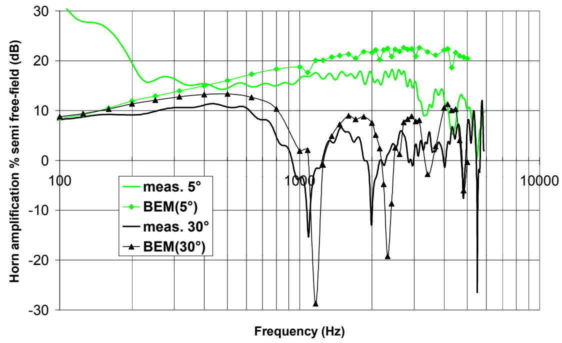

Figure 4: horn amplification by the tube on REFLECTING road surface – comparison measurement / calculation for source at 5° and 30°

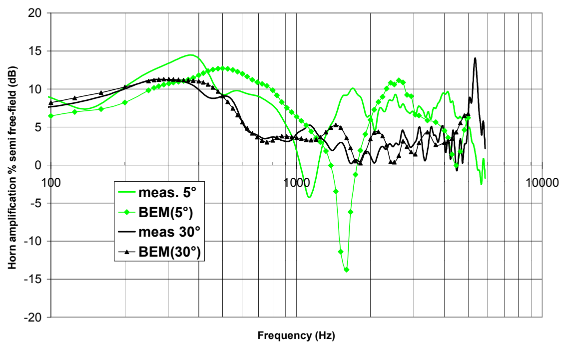

Figure 5: idem figure 4 on POROUS road surface

Conclusion

A 2D BEM model was used to predict the horn effect amplification, both for reflecting and sound absorbing properties of the road surface. This model can contribute to the optimisation of road properties for tyre-road noise reduction. An experiment on real road surface was made for the model validation, and a good agreement was found both for reflecting and porous road surfaces. It is confirmed that the amplification effect relative to semi-free field condition is significantly reduced when the road surface is porous.

References

[1] F. Anfosso-Lédée et al., Tyre/road noise horn effect, 7th ICSV, Garmisch-Partenkirchen (2000)

[2] F. Anfosso-Lédée et al., Comparison of 2D and 3D models for horn effect, InterNoise, Nice (2000)

[3] J.F. Hamet et al., Acoustical characteristics of porous pavements, InterNoise, Louvain (1993)

[4] ISO/DIS 13472-1 : "Acoustics - Procedure for measuring sound absorption properties of road surfaces in situ – part1 : extended surface method" (1999).