MODELING AND OPTIMIZATION OF TWO-LAYER POROUS ASPHALT ROADS

A. KUIJPERS, G. VAN BLOKLAND

M+P Noise & Vibration Consultants, Bruistensingel 232, NL-5231 AD's, Hertogenbosch, Netherlands

Tél.: +31 73 6408851 / Fax: +31 73 6408852 / Email: kuijpers@db.mp.nl

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ABSTRACT

During the last decade, experience has been gained with the application of two-layer porous asphalt roads in the Netherlands. The 'conventional' two-layer porous asphalt concrete construction has a top layer grading 4/8 and bottom layer grading 11/16. This type of road surface gives a noise reduction of 5 dB(A) compared to dense asphalt concrete with grading 0/16, mainly due to its absorptive behaviour. To further improve the acoustical characteristics of this road surface a finer top layer grading 2/4 was used to decrease the texture-induced vibrations, resulting in an additional noise reduction of 1-2 dB(A). Furthermore, the absorptive behaviour and sound propagation over the porous road surface was modelled. With this model a parameter study was performed to assess the influence of various road design and physical parameters on the acoustical performance of the two-layer porous asphalt road concept.

1-INTRODUCTION

Nowadays, road traffic noise is dominated by tyre/road noise. Therefore, successful noise mitigation measures should focus on that noise generation mechanism. In the Netherlands, the application of porous asphalt road surfaces proves to be very successful in decreasing the noise production of both passenger cars and trucks. Not only the tyre/road noise is decreased with these absorbing road surfaces. Driveline and aerodynamic noise is also suppressed by the sound absorption of the road.

The one-layer porous asphalt road concept (stone grading 6/16) is widely used in the Netherlands but it has a rather unfavourable texture from an acoustic point of view. The large stones induce tyre vibrations that are the main source of the generated tyre road noise. To overcome this problem, a finer grading can be used. But with a finer grading, clogging of the road becomes a more serious problem. To overcome that problem, a two layer porous asphalt concept is used with a fine-graded thin top layer having a low texture level to decrease the tyre vibrations. Furthermore, a coarse-graded bottom layer is used to ensure good drainage properties of the road. The top layer works like a sieve for the dirt. To predict and optimise the absorptive properties of the two-layer road concept, a theoretical model was developed with which the differences in sound transfer over different road surfaces can be determined. With this knowledge, the absorptive character of the road can be optimally matched with the characteristics of the tyre/road noise source.

2-MODELING TWO-LAYER POROUS ASPHALT

Absorption model. To model the absorptive behaviour of the porous asphalt road construction, the absorption model of Attenborough for granular materials is used [1,2]. In this microstructural model, the complex impedance Z and wavenumber k for an absorbing medium at a certain circular wavenumber ω are written as

$$Z(\omega) = \sqrt{\rho(\omega) K(\omega)}\ , \tag{1}$$

$$k(\omega) = \omega \sqrt{\rho(\omega) / K(\omega)}\ , \tag{2}$$

with

$$\rho(\omega) = \chi\rho_0 \big/ \sigma \left\{ 1 - \left[\lambda(\omega)\sqrt{-i}\right]^{-1} \tanh\left[\lambda(\omega)\sqrt{-i}\right] \right\}^{-1}, \tag{3}$$

$$K(\omega) = \rho_0 {c_0}^2 \big/ \sigma \left\{ 1 + (\gamma - 1)\left[\lambda(\omega)\sqrt{-N_{\mathrm{Pr}} i}\right]^{-1} \tanh\left[\lambda(\omega)\sqrt{-N_{\mathrm{Pr}} i}\right] \right\}^{-1}, \tag{4}$$

where

$$\lambda(\omega) = \sqrt{\frac{3\rho_0 \omega \chi}{\sigma\ \Xi}}\ , \tag{5}$$

$$\gamma = {c_0}^2 \frac{\rho_0}{p_0}\ , \tag{6}$$

with air density ρ_0 [kg/m^3], tortuosity χ [-], porosity σ [-], (adiabatic) speed of sound in air c_0 [m/s], Prandtl number N_{Pr} [-] and sp**e**cific flow resistance Ξ [Ns/m^4].

Transfer model. To model the sound transfer over the porous asphalt road, a simple plane wave description is used. This can be done since we are only interested in the differences between roads, and not in the absolute value of the transmitted sound. The mathematical description of the plane wave sound transfer over a two-layer absorptive surface is as follows.

Each porous layer *i*, is described by its specific acoustic impedance Z_i, complex wavenumber k_i and thickness d_i. Z_i and k_i can be determined with equations (1) and (2).

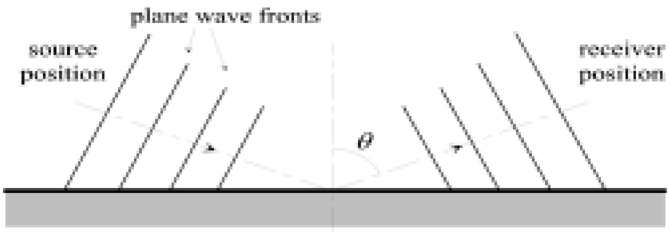

Fig. 1: Reflected-sound path for plane wave sound transfer.

For the absorption computations, the air layer above the road surface is also considered as one of the road layers. The layers are subsequently numbered with a counter *i*: from $i = 0$ for the air layer, $i = 1$ for the top absorbing layer, to $i = n$ for the bottom absorbing layer. So, for the two-layer porous asphalt concrete $n = 2$. Firstly, the reflection coefficient of the total layer is computed for a plane wave, incident on the road surface with angle θ as the angle between the propagation direction of the incident wavefronts and the road surface normal (see Fig. 1). This reflection coefficient $r \equiv r_1$ is determined with the recurrence relationship from $i = n$ to $i = 1$,

$$\cos^2\theta_i = 1 - \left(\tfrac{k_0}{k_i}\right)^2 \sin^2\theta\,, \tag{7}$$

$$F_i = \frac{Z_i \cos\theta_{i-1}}{Z_{i-1}\cos\theta_i}\,, \tag{8}$$

$$G_i = r_{i+1} e^{2\mathrm{i}\, k_i d_i \cos\theta_i}\,, \tag{9}$$

$$r_i = \frac{F_i(1+G_i) - (1-G_i)}{F_i(1+G_i) + (1-G_i)}\,, \tag{10}$$

with $k_0 = \omega / c_0$ and with end conditions,

$$F_n = -\frac{Z_n \cos\theta_{n-1}}{Z_{n-1}\cos\theta_n} / \tan(k_n d_n \cos\theta_n) \tag{11}$$

$$G_n = 0\,. \tag{12}$$

The absorption coefficient α for plane waves incident with an angle θ is then determined with

$$\alpha = 1 - \left|r^2\right| = 1 - \left|r_1{}^2\right|\,. \tag{13}$$

Notice that the attenuation due to transfer path length (differences) is not described with this model: the sound pressure at a point is independent of the transfer path length. However, this is not a relevant limitation of the model, since we are only interested in differences between roads and these differences are also independent of the transfer path length. Furthermore, when needed, it is quite trivial to extend the current model with a more sophisticated transfer model, e.g. a point source model with direct and indirect (reflected) transfer paths.

3-PARAMETER STUDY

To assess the differences in absorptive behaviour of different road concepts, some parameter studies with two different porous road constructions were performed. The two-layer porous surfaces were chosen to represent actual two-layer concepts currently used for urban silent-road solutions in the Netherlands. The material properties of these surfaces are given in Tab. 1. In the parameter studies we assessed the influence of the angle of incidence; the bottom layer thickness; the top layer porosity; and the difference between the fine and coarse top layer.

surface	name	layer	layer thickness [mm]	porosity σ [-]	tortuosity χ [-]	flow resistance Ξ [Ns/m^4]
2L-PA 4/8 + 11/16	2L-coarse	top	25	20%	3.5	6000
		bottom	45	25%	4.0	1500
2L-PA 2/4 +11/16	2L-fine	top	15	20%	2.5	24000
		bottom	55	25%	4.0	1500

Table. 1. Material properties for the porous surfaces in the parameter study

Angle of incidence. In the first parameter study, the angle of incidence θ of the plane waves was varied for road 2L-coarse. The resulting absorption coefficient α as a function of frequency and angle of incidence is depicted in Fig. 2.

Increasing the angle of incidence slightly increases the frequency of the first and subsequent absorption maximums. It also broadens the absorption peaks. Above θ=75°, the first absorption maximum decreases rather quickly. The second and subsequent absorption maximums are less affected.

With a microphone position at 7.5 m from the axis of the road at 1.2 m height, the angle of incidence is about 80°. This means that the recorded sound pressure is very sensitive to the exact microphone height because the absorption is so sensitive to the angle of incidence. When the microphone is positioned at 5 m above the road surface, the incidence angle is about 60°. Therefore this position is more suited to examine the absorptive behaviour of the road.

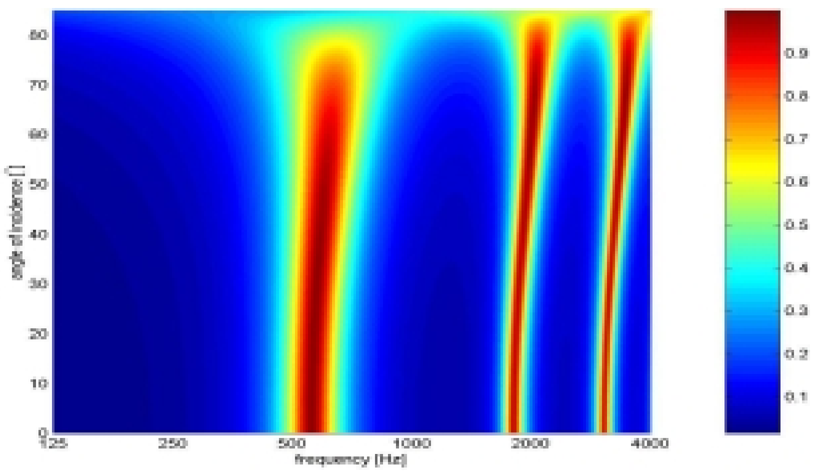

Fig. 2: Absorption spectrum as a function of the angle of incidence for road 2L-coarse.

Thickness of the bottom layer. In the second study the bottom layer thickness of the 2L-coarse road surface was varied. The effect of this variation is illustrated in Fig. 3. A decreased layer thickness results in an increased frequency of the absorption maximums. This effect is well-known and similar to the effect of changing the total thickness of a one-layer surface. In practice the thickness of the two-layer surface can decrease when dirt is deposited at the bottom layer due to insufficient drainage or cleaning.

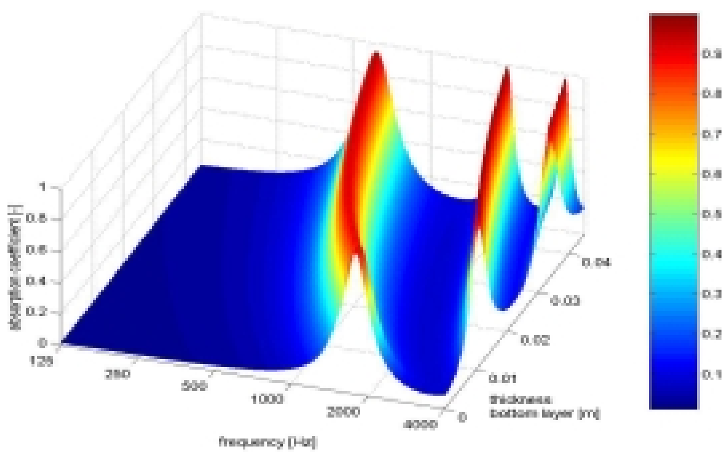

Fig. 3: Absorption spectrum as a function of the bottom layer thickness for road 2L-coarse.

Porosity of the top layer. Another important parameter for the absorption of the two-layer surface is the porosity, especially of the top layer, since this layer can be clogged by dirt. When this happens the porosity will decrease and the frequency of the first absorption maximum will decrease (see Fig. 4). Furthermore, the value of the second, third and subsequent absorption maxima will decrease.

In practice it is possible that the thickness effect of the previous study and the porosity effect of this study will occur simultaneously. This means that the frequency of the first absorption maximum will be about the same even though both the top and bottom layer are clogged. Therefore the (change) of the frequency of the first absorption maximum might not be a good indicator for the degree of clogging of the porous surface.

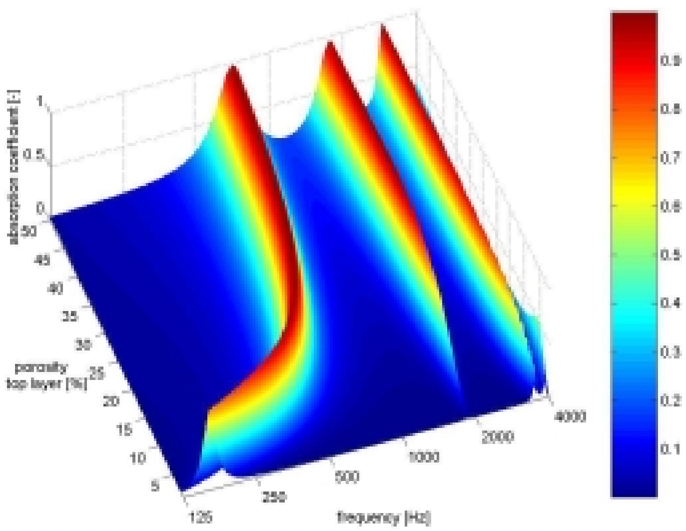

Fig. 4: Absorption spectrum as a function of the top layer porosity for road 2L-coarse.

Improvement of the top layer texture. To assess the effect of the finer top-layer texture, the modelling of the absorption is insufficient. To investigate this effect SPB-measurements have been done on two double layer porous surfaces, both with the same total thickness, but with different top layer gradings: 2/4 vs. 4/8. The results obtained with absorption models for both surfaces (not given here) showed that the absorptive behaviour of both surfaces is similar. Therefore, the differences in the measured sound spectra are directly related to the change of the texture-induced vibrations of the tyres. The spectral difference between the fine and coarse top layer is given in Fig. 5. There, we see that the texture optimisation is most effective in the frequency range between 500 and 1000 Hz. However, we also see an increase of the sound above 1250 Hz. The total texture effect is a decrease of the A-weighted sound level of about 2 dB. The thinner top layer also permits a smaller total thickness of the layer. This can improve the acoustic performance of the road since a thinner layer increases the frequencies of the absorption peaks so they are better matched with the source spectrum of tyre/road noise (which generally has a maximum at 1000 Hz). A thinner layer is also preferable because it requires less asphalt to be used.

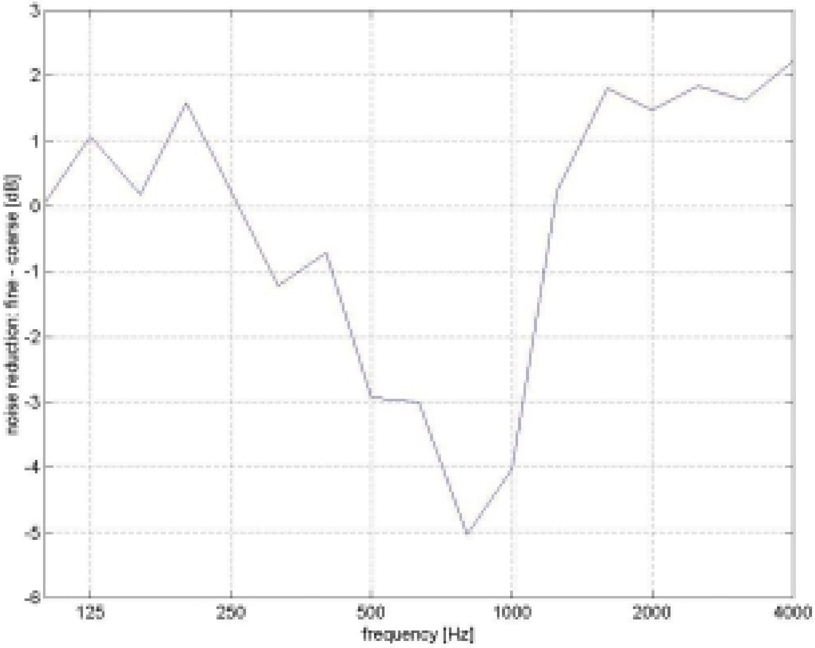

Fig. 5: Measured effect of finer texture of the two-layer porous asphalt on the tyre/road noise.

4- CONCLUSIONS

The absorptive behaviour of two-layer porous asphalt concrete was modelled with a theoretical model and plane wave transfer. With this model, the influence of the angle of incidence, layer thicknesses, and layer porosity on the absorption spectrum was investigated. From the analysis on the angle of incidence it was concluded that the standard SPB microphone position is not wel suited to assess the absorptive properties of a road surface. Furthermore, clogging of the porous road cannot be diagnosed accurately with the change of frequency of the first absorption maximum, because clogging of the top layer decreases this frequency while clogging of the bottom layer increases it. To accurately assess the absorptive characteristics of a road, it is important to measrue at high microphone positions and it is also important to look at the second and higher absorption maximums.

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