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A model for the acoustical optimization of porous road surfaces

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Abstract

For the optimization of a porous road surface a model has been set up which enables the prediction of attenuation of SPL along the propagating path.
The propagation of a spherical shaped sound wave above a hard backed absorbing layer can be calculated using certain "numerical" and "analytical" models. However for the optimization a simple approximation of the model suitable for fast computation is required. Moreover as input data the real structure (e.g. distribution of grain size) should be used. Therefore the model of sphere packing has been employed.
In a study a set of models has been tested and the calculated results where compared with data of measurements. To obtain the results of measurements a pool of approximately 250 "Marshall-Specimen" and a few of real highway pavements were available.
Basing on the set up model a criterion for rating the pavements is proposed.

1. Introduction

Porous road pavement can attenuate the road traffic noise also by low traffic speed. This is in accordance with latest studies (e.g. [10]).
For the optimization of a porous road surface a model should be set up which enables the prediction of the effect of the attenuation along the propagating path. Outgoing from the so named technological parameters (e.g. distribution of grain size, form of grain) the calculation of the sound propagation above the pavement should be feasible.

2. The Theory

Basically the porous pavement is understood as a homogeneous porous material in the frequency range of interest.
The built up model consists of different stages. So on the interfaces the comparison with the results of certain measurements is enabled. During the examination a pool of 250 "Marshall-Specimen" of various compositions was available.
In the first stage the inhomogeneous structure of pavement has been assumed to be a composition of beads (sphere packing [1]). This allows the prediction of the properties of homogeneous absorbers (e.g. porosity, flow resistivity, tortuosity). In the next stage the prediction of the characteristic values of the absorber (complex characteristic impedance, the complex propagation constant) is implemented. From that the calculation of the "acoustic properties" (e.g. normal impedance) and the sound field above the surface is possible.
For this purpose different "absorber models" were examined. Thereby the suitability of the "Phenomenological Model" [2] by comparison of prediction data with measuring data of "Kundts-Tube" has been approved.
The dominating sound sources of tire/road noise are situated very close to the asphalt surface. That means spherical wave fronts can not be assumed as plane waves.
For the description of spherical wave fronts above an absorber the theory of "Weyl – von de Pol" is feasible e.g. [3]. However a "local reacting" absorber is a basic requirement for the validity of the derivation in [3]. One criterium for the existence of a local reacting absorber is a very large refraction index. That means the sound speed in the absorber has to be very small compared to the sound speed in air (c ≈340m/s). In Figure 1 the magnitude of sound speed in the porous asphalt pavement versus flow resistivity is diagrammed (f = 1000Hz, porosity σ= 0.24). Here for the prediction the "Phenomenological Model" was used. In consequence of the so calculated values the refraction index can not be assumed for all mixtures of asphalt as very large. Thus the absorber has to be understood as "extended reacting".

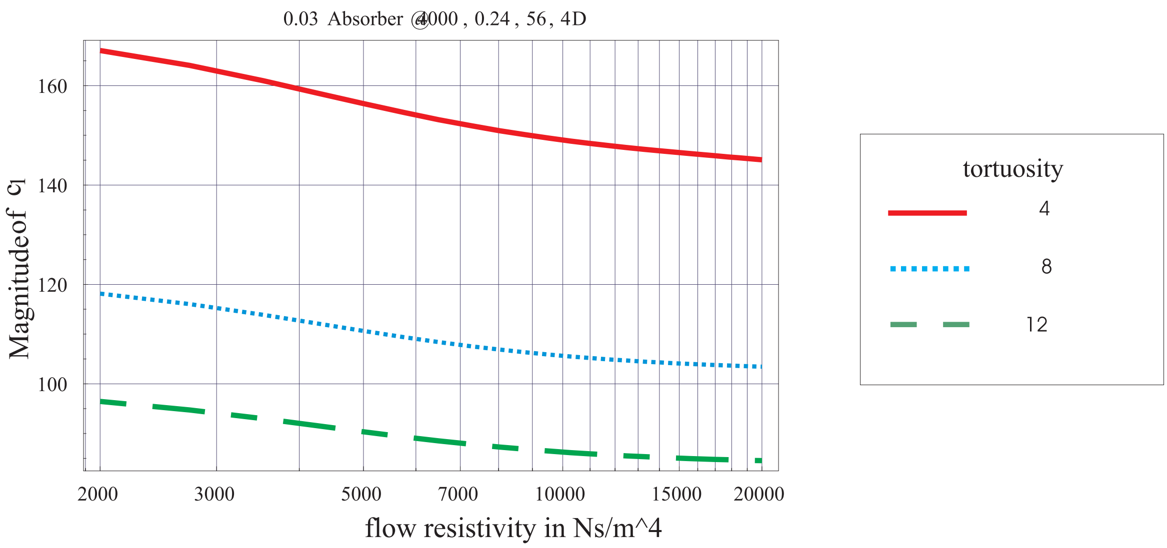


Figure 1: The complex sound speed in the absorber as function of the flow resistivity (porosity σ = 24%, f = 1000Hz).

To find a remedy the solutions of for example [4] or [5] could be used. Here the absorber is considered as "extended reacting".
Various solutions were compared in [4]. It turns out that in consideration of certain conditions the different solutions are consistent.

In [6] the calculation of a sound field of spherical waves above an “extended reacting” absorber by introducing a so called “effective impedance” is suggested. The calculated numerical results of this model are in agreement with the results of measurement data of Nicolas et. al. [7] and [6]. This solution is also suitable for a fast computation.

3. Measurement

For the validation of the prediction of the sound field above a real porous street an “in-situ” measurement technique for the “acoustic properties” has been developed [8]. Moreover transfer functions (microphone to sound source) above different porous road surfaces for very flat angles of incidence were determined. To account for the effect of attenuation this transfer functions where related to the propagation above an “acoustical hard surface” (e.g. dense pavement).

In Figure 2 a maximum of attenuation can be observed at the frequency around 700 Hz. Furthermore a maximum of the function absorption coefficient versus frequency can be detected at the same frequency range (see Figure 3). For small heights of the source compared to the wave lengths say for small “Helmholtz”-Numbers *H* the transfer functions for different heights of source are nearly consistent (see Figure 2). Because of interferences for $H \geq 1$ deviations of the transfer functions for different heights are occurring.

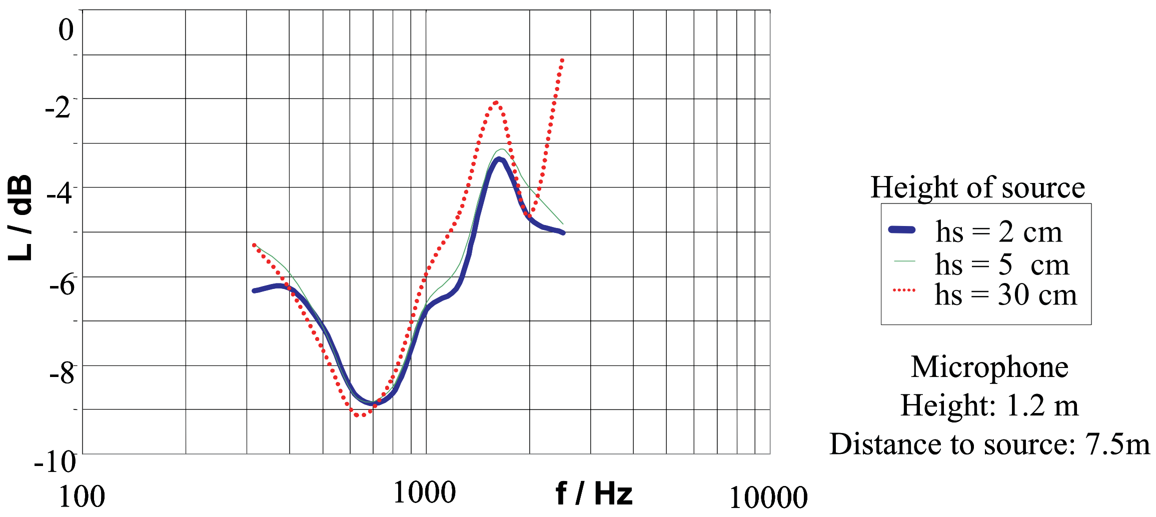


Figure 2: Attenuation of SPL by use of porous road pavement A1 (one-third-octave frequency). The transfer function (microphone to sound source) is related to that above an “acoustical hard” road pavement (omnidirectional sound source: tube coupled on a driver of a horn loudspeaker).

The results of calculations suggested by Li [6] and measurement data presented in one-third-octaves are in a contenting agreement (see Figure 4).

Critical should be mentioned that for certain asphaltmixtures deviations between predictions and measurements both in the “Kundts-Tube” and “in situ” can be observed. So an objective of further investigations is a systematical examination of these deviations.

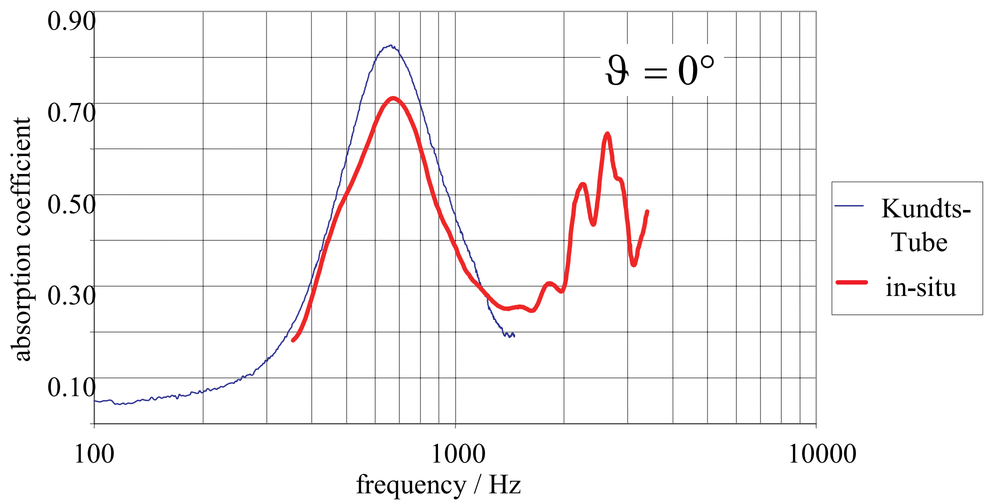


Figure 3: The absorption coefficient of a real porous road surface A1. Comparison of measurements above the road surface “in-situ” and measurements in “Kundts-Tube” on an extracted core of this pavement.

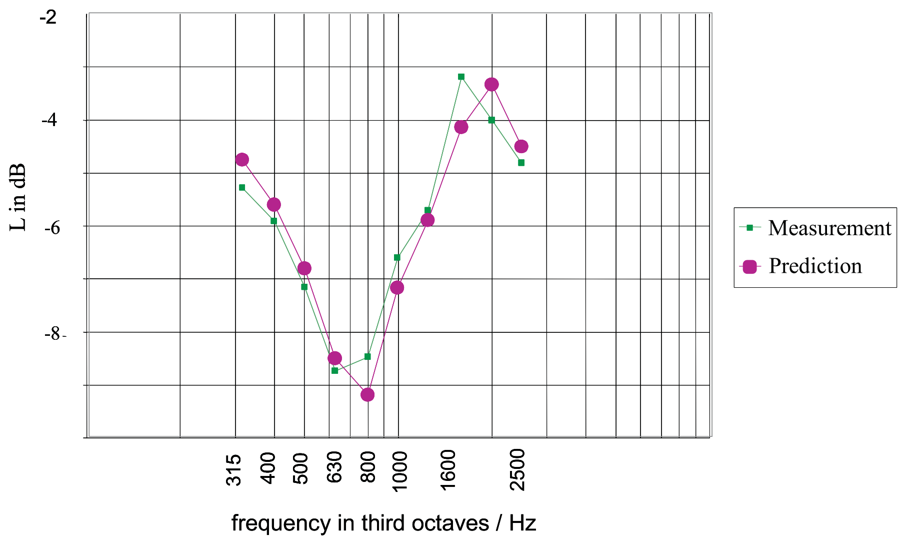


Figure 4: Attenuation of SPL by use of porous road pavement (height of source = 0.02m, distance source to microphone 7.5m, height of microphone 1.2m, absorber: flow resistivity = 4000 Ns/m^4, porosity = 0.24, tortuosity = 4, thickness of layer = 40mm).

4. A criterion for the assessment of the attenuation

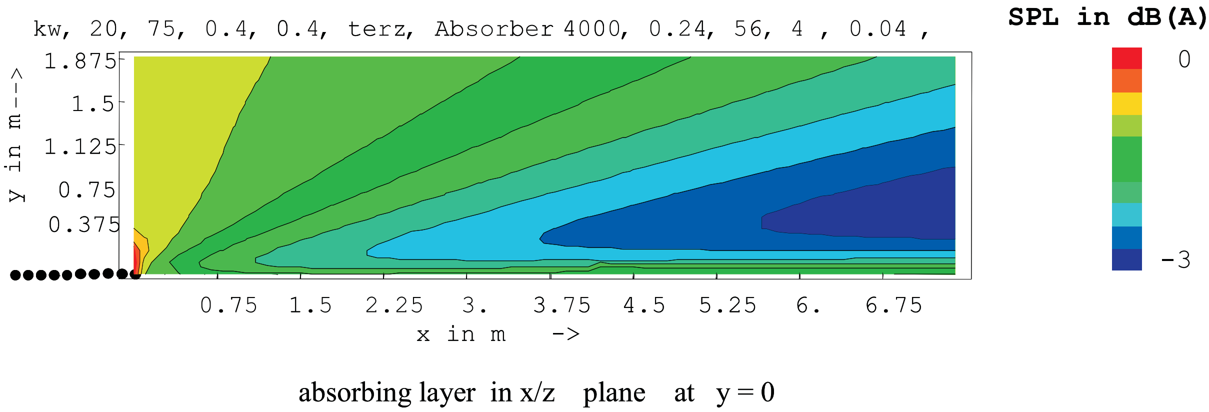
For the optimization of porous pavement a criterion has been introduced. This is based on the model proposed by Li [6].

As input a 2-dimensional incoherent array of point sources is used [9]. The calculated values are revered to the values determined for a reference pavement. In the easiest case the reference pavement shall be assumed as ideal “acoustical hard”.

Further the input sound power spectra suggested in DIN EN 1793-3 is employed. This spectrum is A-weighted and matches the statistical distribution of the sound power level of tire/road noise.

The attenuation of SPL due to absorption along the propagation path is shown in Figure 5. Here the SPL of the sound fields of each source were calculated in one-third-octaves and added in each one-third-octave energetically (incoherence of sources). Then the difference between the A-weighted SPL for the sound field above the absorber and the sound field above the reference surface has been determined.
In Figure 5 a wedge shaped range of a significant attenuation is visible. As expected this wedge is situated above the absorbing layer. In Figure 5.II the influence of interferences due to larger Helmholtz-Numbers (concerning the source height) can be seen.
The amount of attenuation on a certain point in the sound field depends mainly on the vertical dimension of the array. For higher source locations the SPL in the "wedge of attenuation" is lower (Figure 5.I and 5.II).

I)



II)

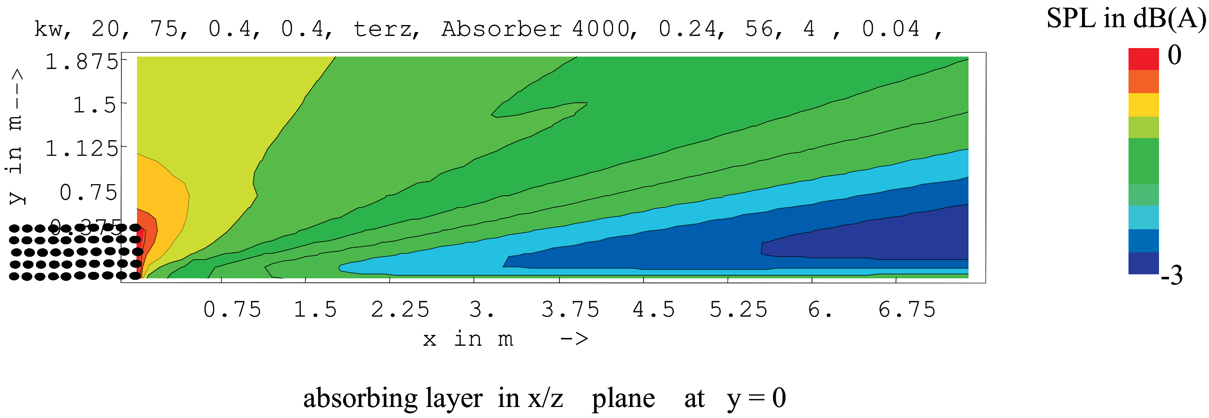


Figure 5: Distribution of attenuation of SPL by use of porous road pavement
I: line source array (10x1)
II: source array: 10x5
(absorber: flow resistivity = 4000 Ns/m^4, porosity = 0.24, tortuosity = 4, thickness of layer = 40mm)

5. Proposal for a suitability test

Today the accuracy of the result of an "in-situ" measurement depends strongly on the experience of the operator and on the prevalent environment conditions. Therefore alternatively the examination of extracted cores of the pavement in a special prepared

"Kundts-Tube" is imaginable. By the way the extraction of cores is a usual procedure for suitable tests (tightness) in Germany.

In a special prepared "Kundts-Tube" the characteristic values of the absorber could be determined. Using these values the sound field above the street is predictable. Thus the comparison with a certain target value of attenuation is possible.

Of course, it has to be taken into account a change of acoustical properties due to the extraction of the core (e. g. flushing of the pores of the asphalt).

Conclusion

The set up model enables the optimization of porous pavement in regard to the attenuation of tire/road noise. For the effective optimization of the asphalt the input data (porosity, flow resistivity …) should be decimate. Therefore the relation tortuosity versus porosity and the dependents of the flow resistivity on the porosity of the material has to be examined.

However effects in the near field of the tire (e.g. air pumping) are not considered yet.

Moreover there is a need to examine the deviations of measured and predicted data of certain mixtures of "Marshall-Specimen".

6. Acknowledgements

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