Application of SPERON® to the development of low noise road surfaces "EuroRegio2016"

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Abstract
Developing a new low noise road surface can be a very time-consuming and costly process. Thus, the use of SPERoN®, has clear advantages. The scope of this paper is to show how SPERoN® can assist on the development of an improved low noise surface. From the initial definition of the input physical parameters to the discussion on how the output quantities can be used in the design of the new road surface. The results of coast-by measurements will validate the SPERoN® outcomes and show the advantages of this approach. Finally, other applications of SPERoN® are presented such as, acoustic monitoring of roads, conformity of production of a new road surface, among others.

Keywords: low noise road surfaces, acoustic optimisation tool.

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1 Low Noise Road Surfaces

As proposed by [1], a "low noise road surface" is a road surface that, when interacting with rolling tyres, under mixed traffic conditions, can achieve an initial noise reduction of at least 3 dB(A) when compared to common pavements. Although there is no standard definition for a common road surface, as this might differ from country to country, it is assumed that a dense asphalt concrete (DAC) with maximum chipping between 11 and 16 mm, can be used as a reference. In Germany for example, a non-structured mastic-asphalt (gussasphalt) is defined in the RLS-90 – the regulation for traffic noise calculations.
There are a number of road surface properties that affects the acoustic performance of roads [2]:

1. Road texture;
2. Porosity: is the percentage of voids which are open to the air in a given volume of total pavement mix. Accordingly, the surfaces can be classified in terms of porosity as: dense layers (air-void of 4-9%), semi-dense (air-void of 9-14%), semi-open (air-void of 14-19%) and open/porous layers (air-void is over 19%).
   - 2.1. Thickness of the porous layer: influences where the maximum absorption occurs in the frequency spectrum;
   - 2.2. Air flow resistance: is important in leading the air flow in the pores of the surface;
   - 2.3. Tortuosity: is a measure if the curved nature of the air path through the surface layer (shape of interconnecting voids).
3. Stiffness/Elasticity.

The parameters given above interact with each other. This means that a porous road surface normally also has a rougher texture than a dense surface. Many attempts in the past to create mathematical relationships between the parameters of a road surface given above and the pass-by level of a car on such a road surface have failed. The reason for this is that the fundamental physical principles for rolling noise generation are to a high degree non-linear as shown e. g. in [3]. To be able to calculate the rolling noise on a road surface it is therefore necessary to have a simulation tool. One such tool which will be described in the following chapter and potential applications are shown in the second part of this paper.

2 SPERoN® Tool

SPERoN® is a noise prediction modelling framework that is used to predict the influence of road properties on tire/road noise. As a hybrid modelling framework the SPERoN® model consists of a physical and a statistical part that simulates the different components of tire/road noise. The physical part predicts the tire/road contact forces and the statistical part consists in a series of multivariate linear regression models to predict the noise spectrum resulting from tire vibrations, airflow related mechanisms, tire cavity noise and aerodynamic vehicle noise. Therefore the name SPERoN® is an acronym for Statistical Physical Explanation of Rolling Noise.
The model is available to a wide public through a GUI (Graphical User Interface) software application, the SPERoN® - Acoustic Optimization Tool (AOT). The user can investigate the effect of changes at the physical characteristics of a road, such as the texture (i.e. roughness), the acoustic absorption and the flow resistance or the dynamic stiffness. The results are presented as an estimated noise spectra and levels.

2.1 The SPERoN® model

The SPERoN® model calculates the coast-by noise of a vehicle by adding up 4 incoherent sound sources components: tire-vibration p^2_{vibr}, the aerodynamic sound sources p^2_{air}, the tire cavity modes p^2_{cav}, and the residual sound sources p^2_{resid}, describing mainly the aerodynamic noise around the car body [4]:

$$p^2{}_{coast-by} = p^2{}_{vib} + p^2{}_{air} + p^2{}_{cav} + p^2{}_{res}[dB(A)] \qquad (1)$$

Thus, in the SPERoN® - Acoustic Optimization Tool (AOT), the input characteristics of road surface necessary to obtain results on the coast-by noise of a vehicle are [5]:

- Road texture: that is a measure for the roughness of the road surface. This property directly influences the generation of vibrations and consequently the sound emission of tires. This is a direct input parameter for the model.
- Acoustical impedance: is a measure for the sound reflection and absorption properties of a road surface. A derived quantity of the acoustic impedance is the absorption coefficient, which is the ratio of the sound energy absorbed in the road surface and the sound energy incident on the surface. This value varies between 0% (surface totally reflecting) and 100% (totally absorbing).
- (Air)Flow resistance: is the resistance that is experienced by the air that is expelled from the contact area between tire and road during the rolling process. When the resistance is high the

air is effectively compressed in the contact area and might produce sound. This is also a direct input parameter for the model.

- Mechanical impedance: is defined as the ratio of the input force and vibration velocity measured at a certain point of the structure. The mechanical impedance used in the SPERoN® model is the driving point impedance which is the ratio of input force (F) and vibration velocity (v) at the excitation point: $Z_m = F / v$.

In order to build a road surface model, the input parameters can be measured, retrieved from literature or “designed”, depending on the purpose of the study.
The SPERoN® structure is as follows:

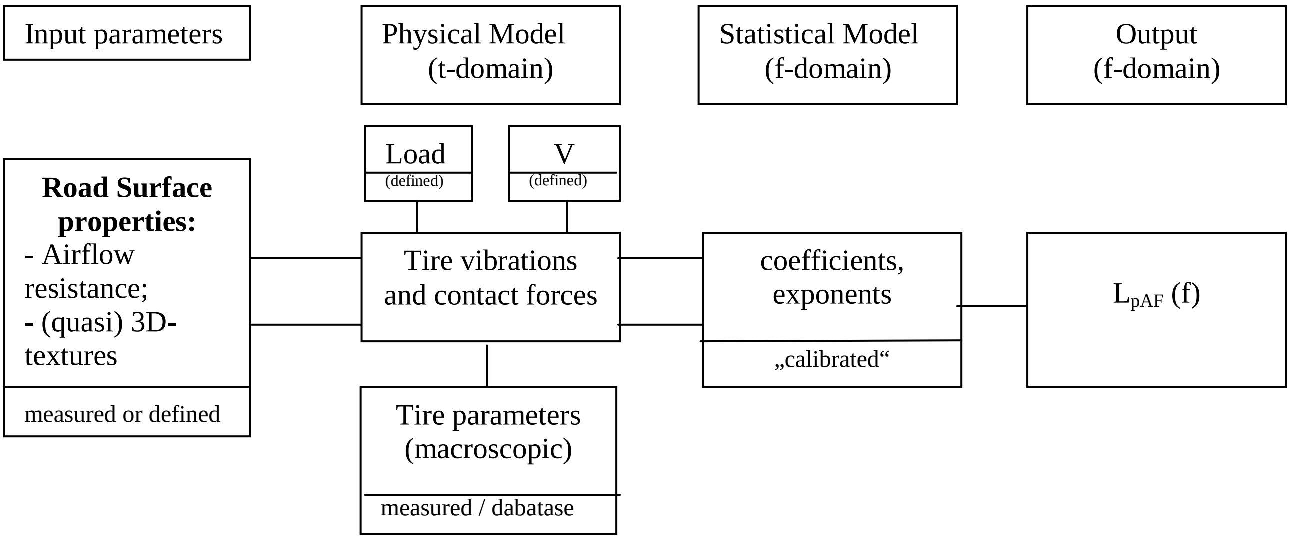

Figure 1 – SPERoN® structure (adapted from [6])

2.2 Model Accuracy

The validation of this model was perfomed by the comparison of eight coast-by measurement results with the results of SPERoN® calculations [7].
The SPERoN® input parameters were set to adjust to the conditions of the measurements. The considered rolling speed was of 90 km/h, the tire used (both for measurements and simulations) was Michelin Energy E3A 195/65 R15 with a tire load of 393 kg. The overall coast-by levels giving in (Figure 1) are the sum of 3rd octave band levels from 315 Hz to 2000 Hz both for the measured and the calculated values. The calculations were done for temperature conditions of 20 °C, therefore the measured 1/3octave band levels were corrected for this temperature.

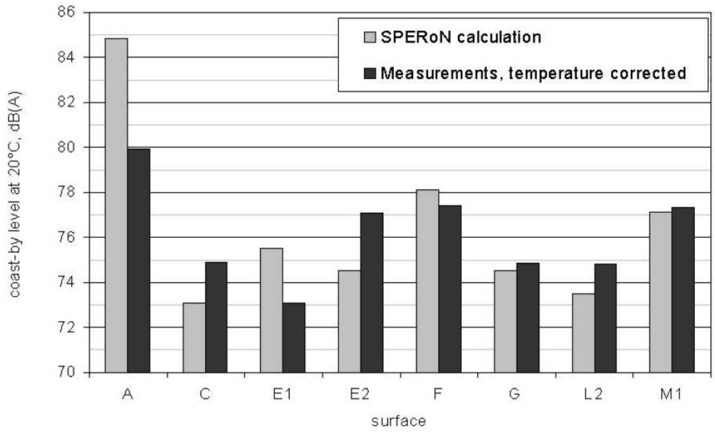

Figure 2 – Comparison of measurement and SPERoN calculation results depending on the surface for a velocity of 90 km/h.

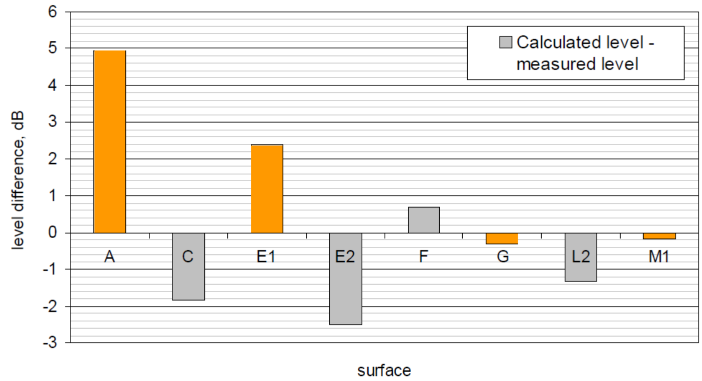

Figure 3 – Total level differences at 90 km/h.

The results show that the total sound levels for all road surfaces have a mean precision of 1,5 dB for all investigated road surfaces. Road surface A reveled to be a non-realistic road surface that in real-life would not comply with most of the requirements for road surfaces; more information on the road surfaces can be found in [8]. This means that for realistic and practical road surfaces the total sound levels have a mean precision of 1,0 dB.

3 Practical Application of the SPERoN model

A practical application of the SPERoN model to the development of a new road surface made of concrete block surfaces is presented in this section. These road surfaces present extra challenges as they are made of small elements that have discontinuities for the rolling noise. This means that such a surface has not only a macrotexture (which is the texture of a surface in the wavelength region from 0,5 mm to 50 mm) [9] being relevant for the noise generation but also joints between the single paving blocks.

In a research project both of these properties (macrotexure and joints) have been investigated to create a low noise dense concrete block pavement.
For the macrotexture of the paving blocks the results from former research projects such as ITARI [10] have been further developed and adapted for the production of paving blocks. Using SPERoN® it is possible to define a road surface (or paving block) texture as a 3 dimensional matrix and calculating the pass-by level as a function of speed for a set of tires being practically used.
This resulted finally in a paving block surface as shown in the following figure.

Figure 4 – Paving stone with an acoustically optimized macrotexture.

The macrotexture is a relevant parameter regarding the tire/road-noise generation, but especially for paving stone road surfaces it is essential also to optimize the joints in between the single stones. From an acoustic point of view these joints should be as small as possible, but for constructional reasons it is not possible just to minimize them without losing constructional durability in the long term. In fact there are a number of different joint parameters such as:

- the joint width
- the joint orientation
- the joint filling
- the chamfer of the stones
- the density of joints (or the size of the stones)

and these parameters are interacting each other when a road surface has to be built. This means that a road surface with a larger stone size needs also somewhat larger joint-widths to ensure constructional durability. For the tire/road-noise generation however, both the density of joints (which is a function of the stone size) and the joint width are relevant and tire/road-noise will increase with both of these parameters.
This means that there is a target conflict between constructional and acoustic needs that can be optimized by performing SPERoN®calculations.
Figure 5 shows a 3 dimensional texture dataset including joints in one configuration.

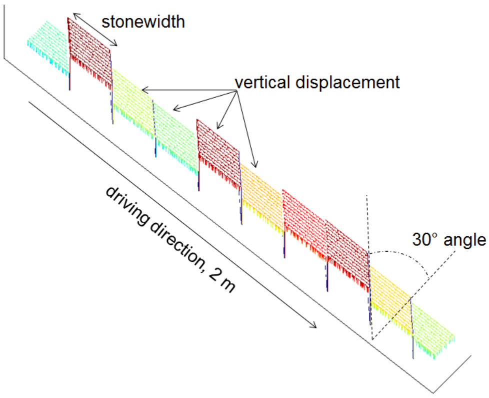

Figure 5 – Texture dataset with one joint configuration and some vertical displacement from stone to stone.

Such datasets were made for different joint geometries. The tire/road-noise levels were than calculated and compared for different configurations.
In the following figure the results are shown for different joint widths and stone sizes.

Joint width →

Stone width ↓

dB(A)	1 mm	3 mm	5 mm	7 mm	9 mm
10 cm	61,1	61,6	61,8	62,0	62,2
20 cm	59,3	59,7	60,1	60,2	60,4
30 cm	59,3	59,6	59,9	60,1	60,2
40 cm	58,6	58,9	59,1	59,2	59,1

Figure 6 – SPERoN results for different joint widths and stone sizes.

The sound pressure levels given in figure 6 represent the vibrational component (which is most relevant at low driving speeds) at a driving speed of 50 km/h. Each given sound pressure level thus represents the mean value of 144 calculations (3 joint depths, 3 edge forms, 4 vertical displacements, 4 joint orientations). The lowest mean value is given for a maximum stone-width and a minimum joint-width and vice versa. Another interesting result is that the level difference for different stone widths is much bigger than for different joint-widths: From small to big joint-widths the level differences are about 1 dB, while for different stone widths the spread is about 3 dB [4]. Another important result is that the joint orientation can be optimized, so that the joints are not in a rectangular angle to the driving direction. This reduces the impact of the leading edge of the tire on the joint and thus the tire/ road-noise.

Near-field measurements according to ISO 11819-2 [9] have shown the differences (see Fig. 7).

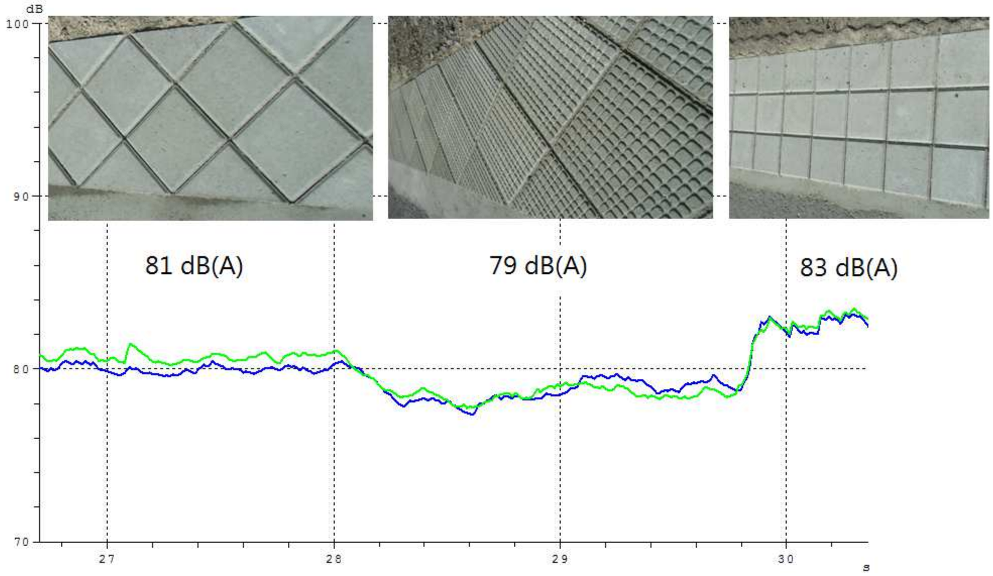

Figure 7 – Sound-pressure level of the tire/road-noise on different test tracks.

The figure shows that just another orientation of the joints reduces the tire/road-noise by approximately 2 dB from 83 dB (A) to 81 dB (A) for a driving speed of 30 km/h in the near field. Applying the macrotexture described above reduces these values by another 2 dB, so that a near field level of 79 dB (A) can be achieved.

4 Future applications

Research projects [11] have shown that there is a high demand on effective and innovative measures to reduce road traffic noise and – especially – tire/road-noise. Standard procedures being used in the road surface construction do not allow for much further improvement of the acoustic properties [12]. To handle upcoming noise issues it may be necessary to improve road surface concepts generally and - probably – to work with multi-modal applications. This could for example mean to combine aesthetics and acoustics together, as can be seen in the next figure:

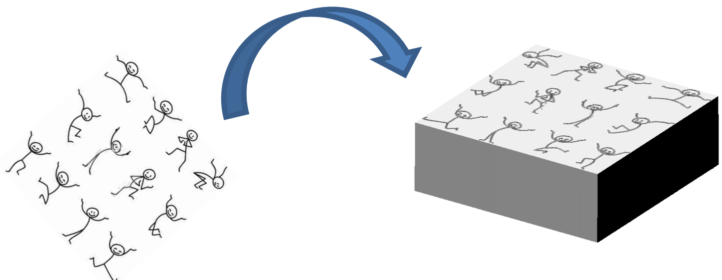

Figure 8 – Pattern stamping in concrete block pavements.

There is a great potential to apply these surfaces in urban environments where the sound levels are a major concern, especially in residential areas. SPERoN® model can be very helpful in supporting the research of such road surfaces.

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