ODSURF: Optimized low noise urban road surfaces

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ABSTRACT

Based on results from the former project “Prediction and Propagation of Rolling Noise” developed in the framework of the German-French cooperation and during which an optimal low noise texture of dense road surface has been designed, ODSurf, financed by the French Environmental Agency and the German Federal Highway Research Institute is mainly devoted to the implementation of new technologies and materials particularly adapted for urban situations in terms of noise abatement to comply the European noise regulation. Different new solutions have been investigated. To achieve our objectives, we improved and/or developed new predicting models and experimental techniques. A particular attention has been paid on the consequences of texture, horn effect and air pumping modifications on tire-road noise emission. Theoretical approaches and new optimized road pavement designing have been carried out in parallel. Furthermore, the improvement of “conventional” wearing courses has been pursued in order to supply to end-users a complete set of low-noise solutions adapted to their own situations. First validation results are presented. Further, these new optimized pavements will be introduced in the common DEUFRABASE, previously implemented for suburban configurations, which will be completed and extended to urban situations.

Keywords: Traffic noise emission, Pavements I-INCE Classification of Subjects Number(s): 52.3

1. INTRODUCTION

In recent years, many documents were issued in Europe to establish a strategy for reducing transportation noise of at least 30% for the coming years. Cities across Europe are interested in setting up low-noise road surfaces to meet the requirements of the 2002 Environmental Noise Directive (1). Reducing noise at the source is still the best approach to decrease traffic noise harmful effects on road residents. Knowing that a significant part of the traffic noise emission is due to rolling noise (even in urban areas), two solutions can be investigated: directly acting on the tire or on the pavement. In this project we focus our efforts on the pavement characteristics.

In the past, porous coatings were tested in urban areas. Even if substantial effects, in terms of noise reduction, were observed just after the spreading, clogging phenomena significantly reduced noise attenuation after a few years of service. This problem was mainly attributed to the vehicle low speeds that could not ensure a self-cleaning of the porous layer. Thus, in urban configuration, it became urgent to work on dense low noise pavements. Some interesting projects have shown the feasibility of this type of surfaces. However, comparable noise performances with porous structures have not been actually achieved.

According to the results obtained in the previous DEUFRAKO-P2RN project "Prediction and Propagation of Rolling Noise" (2), it is theoretically possible to design a dense pavement structure producing a minimum noise emission comparable to a single-layer porous asphalt. However, the texture obtained being relatively different from conventional ones, it is not possible to build up this structure in a conventional manner with conventional materials.

The prefabrication aspect becomes very important if we wish to guarantee a constant quality of the wearing course independent of weather and traffic conditions. In addition, these solutions enable a better maintenance, particularly in terms of replacement during interventions. Solutions currently

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exist but need to be optimized. The study of these new pavement alternatives will be part of the project. Consequently, this project will be dealing with modeling, design and manufacturing and experimental validation after implementation.

Finally, one of the expected applications is to update and expand, for urban configurations, the current German-French database “DEUFRABASE” previously developed under the previous DEUFRAKO-P2RN project. To achieve these objectives, the project is structured in three main tasks: Production of noise-optimized dense pavements compared to more conventional low-noise pavements, improvement of tire-road noise emission models noise and upgrading of the DEUFRABASE.

2. PRODUCTION OF OPTIMAL LOW-NOISE DENSE SURFACES

According to the results obtained in the former project DEUFRAKO-P2RN (2) a road surface with an optimized dense texture can theoretically reach A-weighted pass-by maximum sound pressure levels in the same range of those obtained with a single-layer porous asphalt (cf. Table 1).

Table 1 – Sound emission for a light vehicle – Comparison with conventional pavements

Type of surface	L_{Amax} (90 km/h), dBA	Difference, dBA (re. French ref ; re. German ref)
Optimized theoretical dense surface	**73.8**	**(-3.0 ; -7.7)**
Single-layer PAC 0/6*	72.8	(-4.0 ; -8.7)
Single layer PAC 0/8**	74.4	(-2.4 ; -7.1)
DAC 0/10 (French reference)*	76.8	(0.0 ; -4.7)
German reference**	81.5	(+4.7 ; 0.0)

French pavements (*) ; German pavements (**)

At the end of P2RN project, techniques and conventional materials did not allow to implement this theoretical coating. One of the objectives of ODSurf project is to develop a new process to perform on-site this theoretical texture. New concepts in terms of materials and implementation are particularly investigated by German partners. A “ready-to-use” road pavement has to meet several criteria. Safety and durability are among them probably the most important. Even if this project is mainly dealing with the acoustical aspect, it does not forget the other ones. The results obtained with these optimized techniques will be compared with low-noise conventional road surfaces developed by partners, members of French road manufacturers.

2.1 German contribution

To carry out this project, academic and industrial partners worked together in order to conceive and produce "prefabricated" industrial pavement structures based on non-conventional materials. To achieve this goal, a tender has been launched and its main objectives were to search innovative technologies in structuring the surface layer and to bring innovation in road construction.

Three projects have been selected. The first one, gathering the University of Kassel and Müller-BBM company is dealing with the development of a low-noise road surface layer using prefabricated structures based on a high performance cement concrete technique (UHPC). Its surface texture should be similar to that determined in the previous P2RN project (2) (cf. Figure 1). The second one gathering University of Kassel, the Technical University of Munich and Müller-BBM company concerns the development of a road surface layer made of low-noise cement concrete paving stones. Finally, the third and last one, supported by the University of Aachen, concerns the development of an innovative low-noise pavement based on synthetic materials.

On the three selected techniques, only the two first ones will be tested in-situ. Texture, noise, and skid resistance evaluations will be achieved on the whole products. The results will be first compared to theoretical predictions (3, 4) and then compared to "traditional" German as well as French innovative coatings. Final comparisons will be carried out before the end of the project in 2015.

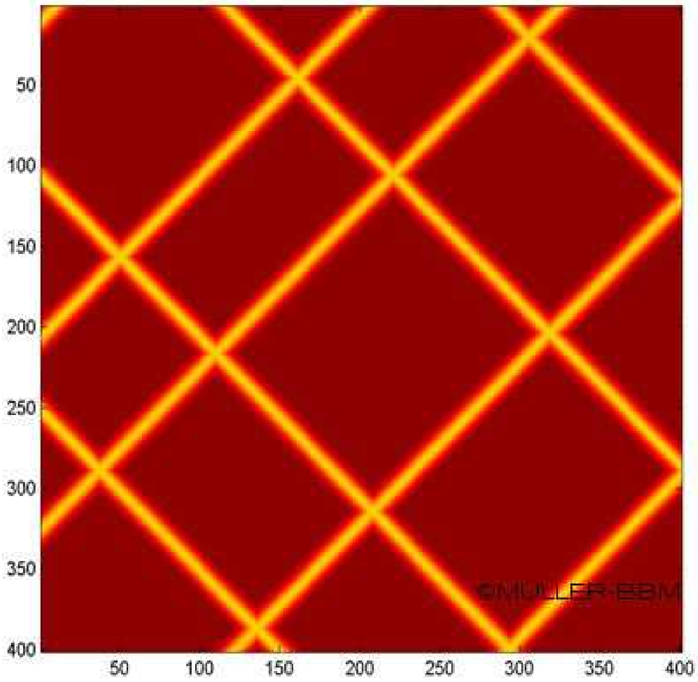

Figure 1 – Theoretical texture of UHPC

2.2 French contribution

The French contribution is mainly dealing with the improvement of the theoretical models predicting the main rolling noise mechanisms, the various experimental techniques necessary to identify the physical parameters to be introduced in the predicting models (road surface texture, distribution of the contact forces inside the contact area, acoustic absorption of the pavement structure) and finally, measurement campaigns to validate the different predictions. Based on these experimental results a comparison between conventional low-noise pavements for urban use and prefabricated optimal German pavements will be carried out. Additionally, an upgrade and an extension of the German-French database “DEUFRABASE” classifying a large set of road pavements for various realistic urban propagation configurations will be provided. This last point will be detailed in section 4.

2.2.1 Identification of physical parameters

Depending on the phenomenon to be modelled, the implemented techniques are based on various approaches. Hybrid (3, 4), statistical (5), physical (6) and numerical (7) models can be used. To implement those models, different input data corresponding to the main physical parameters have to be first identified. This identification is carried out through adapted experimental techniques. In the framework of this project, the main characteristics to be measured are the 3D surface texture spectrum and the absorption coefficient of the structure.

To measure the 3D surface texture spectrum, a specific equipment has been developed (cf. Figure 2). This system can perform, in a reasonable time, records of three-dimensional texture of a zone whose length (1.5 m) and width (0.35 m) are compatible with standard car tire dimension. The option that was chosen for this system is to use a contactless laser sensor (longitudinal and vertical sampling rates: 0.1 mm), able to provide altitude of points located on a segment of a given length (transducer 2D profiles). To reach the third dimension, a displacement system ensures the transverse scanning of the area to be measured. An acquisition system collects data from the sensor, regardless of the displacement system management.

Figure 2 – 3D Surface texture equipment
1: Chassis – 2: Motorized axle – 3: Brushless motor – 4: Control unit

In order to validate the equipment and the dedicated analyzing software, several reference textures (cf. Figure 3) implemented on the Ifsttar reference test track were measured and compared (cf. Figure 4) to previous measurements performed during the former P2RN project (2) using a 3D stereoscopic technique (German partner: BASt) and a classical 2D technique also based on a contactless laser sensor (French partner: Ifsttar). The following results have been found.

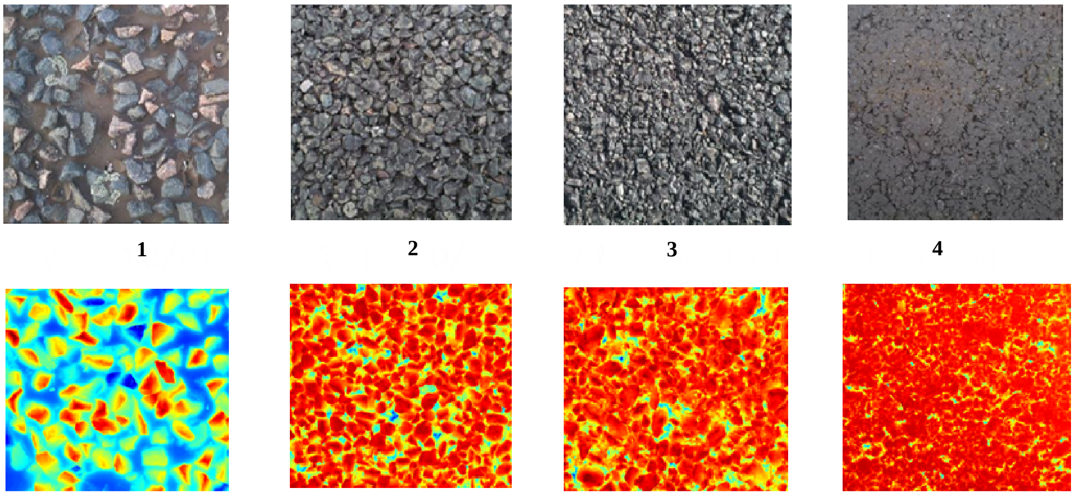

Figure 3 – A sample of 3D Surface texture: 1: Surface Dressing SD 8/10
2: Porous Asphalt Concrete PAC 0/6 – 3: Dense Asphalt Concrete DAC 0/10 – 4: ISO Surface

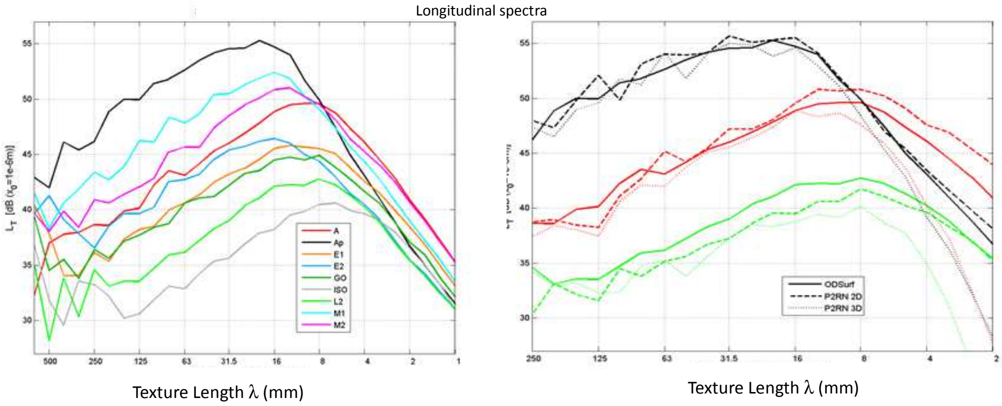

Figure 4 – 3D Surface texture spectra: Comparison between ODSurf and P2RN equipments

On the left figure above, Texture spectra are drafted for nine different pavements while on the right figure, the three measurement techniques have been only compared on three of them (black lines: SD 8/10, red lines: PAC 0/6 and light green lines: Sand Asphalt 0/4). Some differences are identified in the higher part of the spectrum particularly between the two 3D approaches. However, the new 3D texture spectrum is rather close to this measured with the classical 2D technique. That confirms the validity of the 3D technique presented in this paper which will be further used for measurements on the different experimental sites located respectively in France and Germany. Finally, these textures will be also used as input data for the multi-scale modeling of dynamic tire-pavement contact and for the modeling of the air pumping mechanisms (8, 9).

The second characteristic to identify is the absorption coefficient. The ISO 13472-1 technique (10) is implemented (cf. Figure 5).

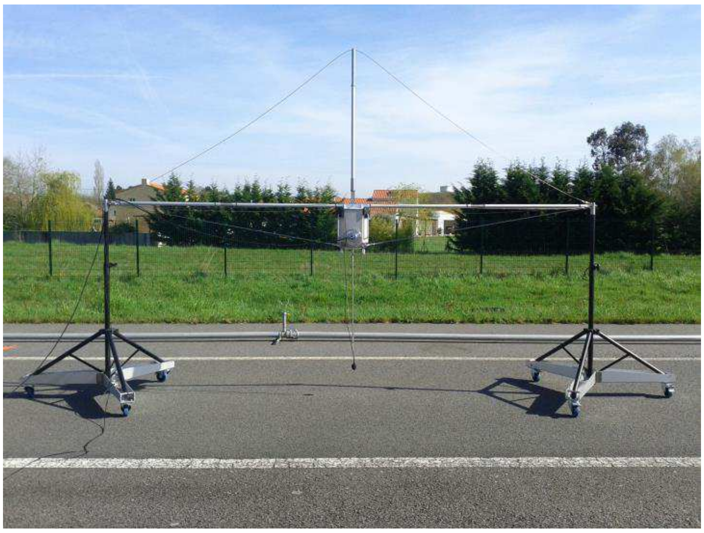

Figure 5 – Absorption coefficient measurement according to ISO 13472-1 Standard. Experimental device installed on the Ifsttar reference test track

Only the porous pavements of the Ifsttar reference test track were measured. For each pavement, five various positions are selected and then averaged to obtain a mean absorption spectrum for each of them. Figures 6 and 7 show the frequency absorption evolution for a Porous Asphalt Concrete 0/6 (Figure 6) and a Very Thin Asphalt Concrete 0/6 (Figure 7). Variations between the two pavements are mainly due to their respective thickness and connecting porosity.

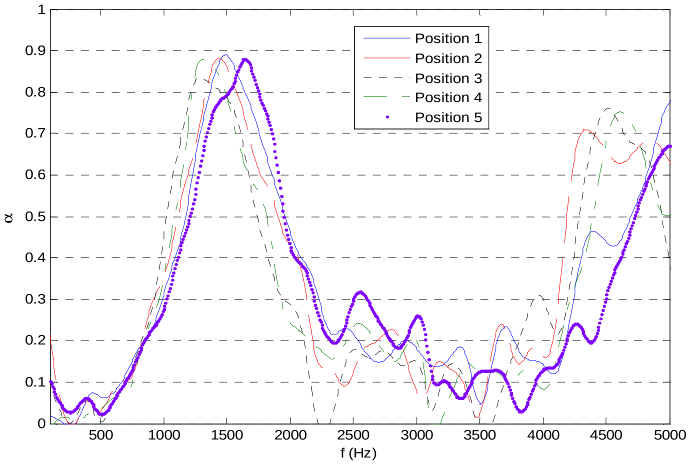

Figure 6 – Absorption coefficient spectrum of a PAC 0/6

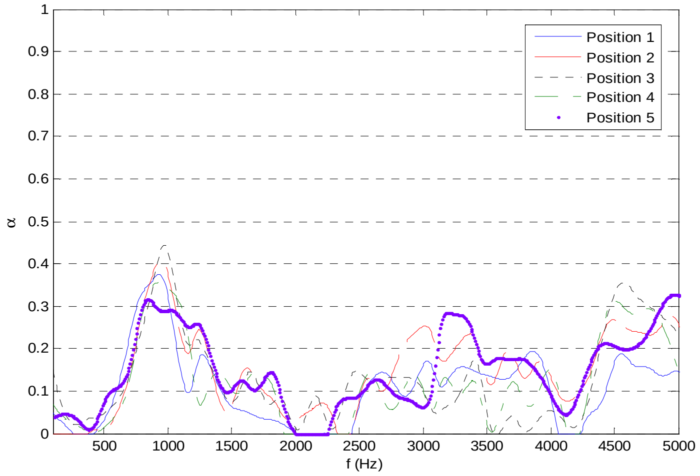

Figure 7 – Absorption coefficient spectrum of a VTAC 0/6

The acoustic absorption will be further use for pass-by sound pressure level prediction from the HyRoNE model (3, 4) and also to quantify the horn effect on porous pavements. This last point will be particularly investigated by French ENPC partner as shortly detailed in the section 3.

2.2.2 Conventional low-noise pavement for urban use

After having validated the various approaches on different pavements of the Ifsttar test track and in order to rank the different German and French pavements, including the optimized pavements designed during this project (cf. §2.1), it has been decided to compare, in a first time, all those pavements to the French conventional techniques producing one of the lowest tire-road noise.

Two formulations produced by the two French road companies (Colas and Eurovia), partners in the project, were selected: a Very Thin Asphalt Concrete (VTAC) 0/4 and a VTAC 0/6. The first one has already been built in Mouvaux in Northern France and the second one will be built in Villeneuve-sur-Lot in South-Western France.

Concerning the first one (VTAC 0/4), built in 2009, different measurements have been performed in March 2013 and more recently in July 2014: texture analysis, Coast-by noise (CB) (11), Close-proximity noise (CPX) (12) and absorption (10). In the next tables and figures, some preliminary results (CPX and absorption) of the July 2014 campaign are presented in addition to a first comparison with some other pavements. For the considered speeds, tire-road noise is predominant with respect to engine noise and aerodynamic noise. It can be expressed by the following regression equation:

$$LAeq_{CPX}(Speed) = LAeq_{CPX}(Speed_{\mathrm{Re}\,f}) + a_{CPX} \cdot \log_{10}\left(\frac{Speed}{Speed_{\mathrm{Re}\,f}}\right) \tag{1}$$

In Table 2, the A-weighted equivalent sound pressure levels are obtained after recombining the energy between the 1/3 octaves 400 Hz and 4 kHz at 70 km/h after a regression analysis between 65 and 110 km/h for the various pavements on the reference test track and, between 65 and 90 km/h for the VTAC 0/4. This difference in the maximum speed can maybe explain the rather high value of the regression slope. 70 km/h has been chosen because it corresponds to the regular speed on the urban boulevard where the VTAC 0/4 was implemented. We note that at this speed, the VTAC 0/4 can be considered as one of the quietest surface coating, quite similar to PAC /6 and VTAC 0/6. This can be also verified on the spectral comparison displayed on Figure 8.

Table 2 – CPX values: Comparison between different types of surface at 70 km/h

Type of surface	$LrAeq_{CPX}$(70 km/h), dBA	Regression slope (a_{CPX})
Surface dressing (SD 8/10)	99.0	36.9
Porous Asphalt Concrete (PAC 0/6)	93.9	19.3
Dense Asphalt Concrete (DAC 0/10)	95.7	33.9
Soft Asphalt Concrete (SAC 0/10)	94.2	29.4
ISO 10844 Reference track	95.3	33.0
Sand Asphalt (SA 0/4)	94.0	30.2
Very Thin Asphalt Concrete (VTAC 0/4)	**93.8**	**38.0**
Very Thin Asphalt Concrete (VTAC 0/6)	93.5	22.8
Very Thin Asphalt Concrete (VTAC 0/10)	95.7	31.0

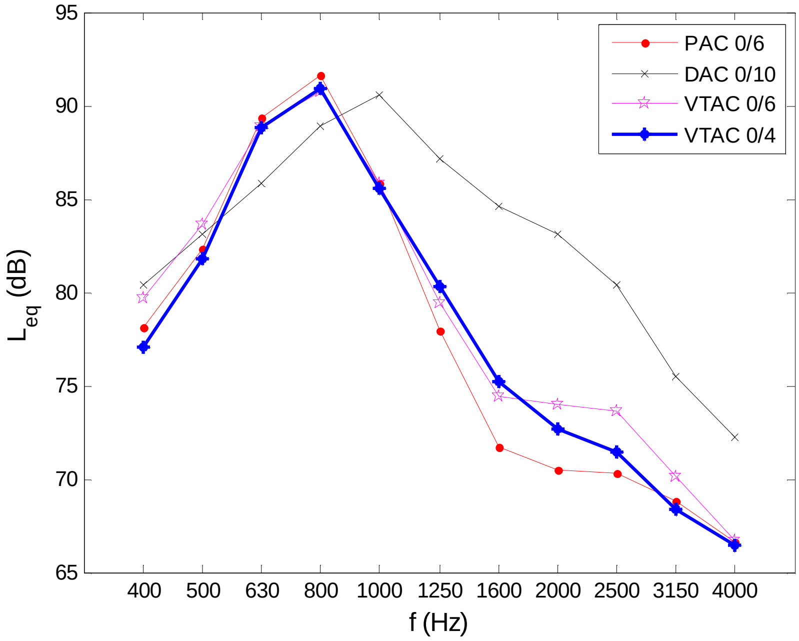

Figure 8 – CPX spectra: Comparison between low-noise pavements and DAC 0/10 at 70 km/h

Another important issue concerns the maintenance of the pavement characteristics over time. To answer this question, two different measurements have been carried out at one year interval. For this comparison, a lower urban speed (50 km/h) is selected. The results are presented in Table 3. If we integrate the uncertainties around the mean values, we can consider that there is no evolution over this period.

Table 3 – VTAC 0/4 CPX values: Comparison over one year interval at 50 km/h

Date	$LrAeq_{CPX}$(50 km/h), dBA	Regression slope (a_{CPX})
March 2013	87.8	29.0
July 2014	87.7	41.5

Even if this VTAC 0/4 cannot be considered as a porous pavement like a PAC 0/6, it shows interesting absorption characteristics as presented on Figure 9. Although the absorption maximum is less than that of a PAC, it is still high enough to produce a substantial reduction of sound energy in the frequency range where the road traffic noise energy is maximum. This explains its good positioning in the ranking of low-noise pavements.

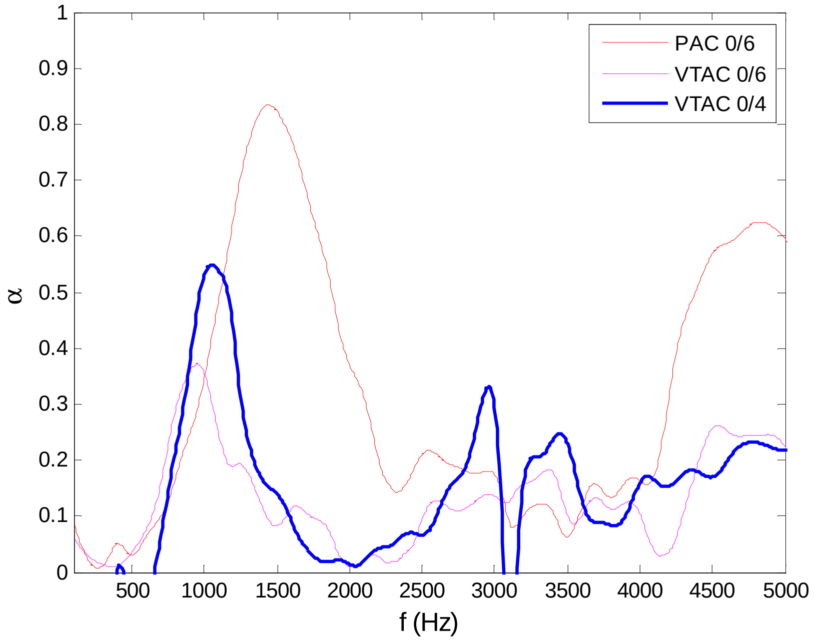

Figure 9 – Absorption coefficient spectra: Comparison between PAC 0/6, VTAC 0/6 and VTAC 0/4

3. IMPROVEMENT OF THEORETICAL APPROACHES FOR TIRE-ROAD NOISE PREDICTION

To predict the global tire-road noise emission, various mechanisms are to be modelled. That can be carried out differently depending on the technique used. Even if hybrid models based on a physical approach, in which the values of the main characteristics are obtained after a statistical analysis on experimental data, provide interesting predictions to be directly compared to pass-by measurement results, it is always interesting to analyze more in depth the various mechanisms involved in the tire-road noise process. In the project, the main improvements concern the modelling of the air-pumping phenomenon, the multi-scale approach of the dynamic contact and the impact of the pavement texture on the horn-effect. Preliminary results have been drafted in the project mid-term report (13) and already presented in the last Internoise 2013 conference (9). The final validation of each characteristic modelling will be further carried out with a specific facility whose construction is currently underway.

4. UPGRADING OF THE DEUFRABASE

The present work is related to the extension of the current database named DEUFRABASE to urban configurations. This database previously developed in the framework of the former P2RN project (2), posted on the BASt website (14), is mainly concerning geometrical configurations corresponding to non-urban situations with or without noise barrier and/or with or without embankments and cuttings. To implement the future version including urban configurations, calculations under Python® environment corresponding to several typical urban geometries will be performed. These new data will be further used to complement the database.

From a technical point of view, several 2D street typologies (vertical cut corresponding to linear sources) will be investigated in order to build a new database integrating spectral attenuation data for various receivers inside the streets and in front of the building façades (cf. Figure 10). To take into account the urban façade diversity, different reflection and absorption conditions will be considered. At this stage, atmospheric conditions will not be integrated in the model. Consequently, only homogeneous propagation conditions will be considered.

Depending on the acoustic field characteristics in the medium, calculations will be carried out using different codes. One is based on an energetic approach more relevant for prediction in diffuse fields (15). The other one is based on an undulatory approach more adapted to prediction in presence of surfaces characterized by a complex acoustic impedance (16).

In a first time, the objective is to compute acoustic attenuations for several source-receiver configurations, en presence of buildings characterized by an acoustic absorption and an acoustic diffusion.

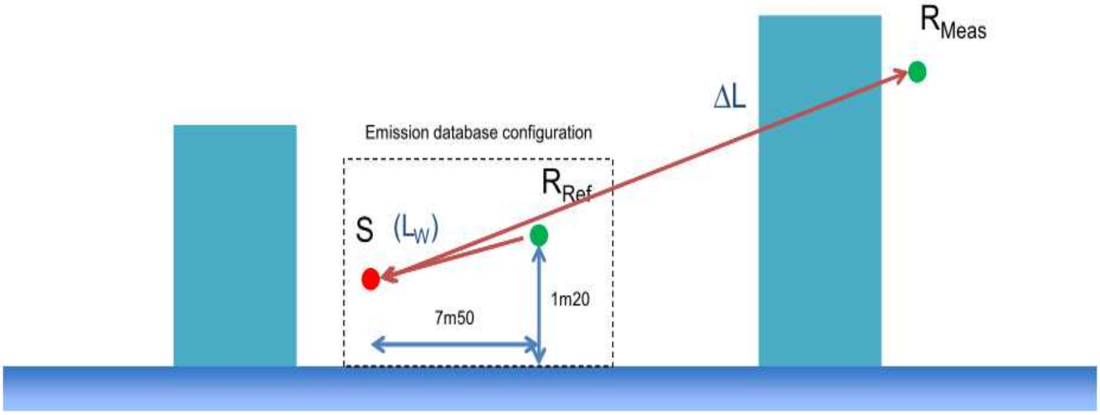

Figure 10: Principle of the method implemented for urban configurations.

In a second time, the database will be upgraded. After having extracted data currently used in the present DEUFRABASE, new data (sound attenuations and Reverberation Time) relative to urban configurations will be integrated. The whole data will be formatted through SQL tables that can be accessed through a new interface which is still to be done, using the Ifsttar I-Simpa software (17), on an Ifsttar server on which it will be possible to be connected from the outside. This work, currently in progress, will be over in the following months and presented during the next Internoise 2015 Conference.

5. CONCLUSION AND OUTLOOK

To reduce traffic noise in urban area, different possibilities can be envisaged. The most effective solutions concern the reduction of the noise emission from de source. The other being more related to propagation conditions and to the traffic management. Among the solutions used to mitigate the source emission, the use of low-noise pavement surfaces can be interesting because tire-road noise is also at urban speeds an important part of traffic noise emission. In the present project, several optimized dense surfaces have been designed and developed in Germany according to the previous results found during the former DEUFRAKO P2RN project (2). In a short future, they will be tested and compared in terms of sound pressure levels to conventional urban pavements currently developed in France.

During the first months of the project, in parallel to the German works, French partners worked on the new updated models in order to better understand the main physical mechanisms occurring in the tire-road contact zone and, on adapted experimental techniques for further validation. Concerning the measurements techniques, they have been applied in a first time on various selected pavement textures before being used for the optimized low-noise surfaces developed in the project.

A first French site with a VTAC 0/4 has already been experimented and compared to the other pavements. A second site with a VTAC 0/6 will be measured by the end of 2014. In the same period of time, the German optimized low-noise dense pavements will be set on German open sites and experimented with the same methods, in terms of texture and noise emission. Considering the results obtained during those French and German experimental campaigns we will be able to rank the different pavements with respect to their specific use and to introduce them in the new updated DEUFRABASE which will allow end-users adapting the right solution in terms of pavement for the right situation.

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REFERENCES

1. Environmental Noise Directive 2002/49/CE; 2002.
2. Droste B., Auerbach M., Bérengier M., Gauvreau B. Anfosso-Lédée F., Cesbron J., Hamet JF., Klein P., Lelong J. Duhamel D., Yin H., Kogevnikov I., Meunier Y., Franchomme O., Beckenbauer T., Männel M., Altreuther B., P2RN : Prediction and Propagation of Rolling Noise - Final Report, February 2009,Convention ADEME N°: 05 66 C0069.
3. Beckenbauer T, Klein P, Hamet J-F, Kropp W. Tyre/road noise prediction: A comparison between the SPERoN and HyRoNE models - Part 1, Proc Acoustics 08, 29 June-04 July 2008, Paris, France.
4. Beckenbauer T, Klein P, Hamet J-F, Kropp W. Tyre/road noise prediction: A comparison between the SPERoN and HyRoNE models - Part 2, Proc Acoustics 08, 29 June-04 July 2008, Paris, France.
5. Dubois G, Cesbron J, Yin H.P, Anfosso-Lédée F, Duhamel D. Statistical estimation of low-frequency tyre/road noise from numerical contact forces. Applied Acoustics, 2013; 74(9): 1085-1093.
6. Dubois G, Cesbron J, Yin HP, Anfosso-Lédée F. A multi-asperity tyre/road contact model for rolling noise prediction. In: Proc. Forum Acusticum, 27 June-01 July 2011, Aalborg, Denmark.
7. Meftah R, Duhamel D, Cesbron J, Yin H. A fast method for computing convolutions with structural Green's functions: application to tyre dynamic contact problems. European journal of Computational Mechanics, 2013; 22(5-6): 284-303.
8. Conte F, Klein P, Bérengier M. Investigating lateral porosity effect on air pumping noise from connected road cavities with CFD simulations. Proc INTER-NOISE 2014; 16-19 November 2014; Melbourne, Australia.
9. Conte F, Klein P. 3D CFD modelling of air pumping noise from road cavities with constant volume. Proc INTER-NOISE 2013; 15-18 September 2013; Innsbruck, Austria.
10. ISO 13472-1. Acoustics: Measurement of sound absorption properties of road surfaces in situ - part 1: Extended surface method, 2002.
11. NFS31119-2: Acoustique – Caractérisation in situ des qualités acoustiques des recêtements de chaussé – mesurages acoustiques au passage, 2000.
12. ISO CD 11819-2. Acoustics: Measurement of the influence of road surfaces on road traffic noise - part 2: the close-proximity method, 2000.
13. Bérengier M, Cesbron J, Conte F, Klein P, Lelong J, Picaut J, Tian B, Duhamel D, Yin H, Coquelle E, Gautier JL, Pouteau B. ODSurf : Modélisation et réalisation d'une couche de roulement de chaussée optimisée, dense et peu bruyante, Mid-term Report, ADEME Convention Number : 11 17 C0038, May 2013.
14. http://deufrako.bast.de/
15. Picaut J, Fortin N. SPPS, a Particle-Tracing Numerical Code for Indoor and Outdoor Sound Propagation Prediction. Proc Acoustics 2012, 23-27 April 2012; Nantes, France.
16. Guillaume G, Picaut J, Dutilleux G, Gauvreau B. Time-domain impedance formulation for transmission line matrix modelling of outdoor sound propagation. Journal of Sound and Vibration, 2011; 330 (26): 6467‑6481.
17. Picaut J, Fortin N. I-Simpa, a Graphical User Interface Devoted to Host 3D Sound Propagation Numerical Codes. Proc Acoustics 2012, 23-27 April 2012; Nantes, France.