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FREQUENCY DEPENDENCE IN TYRE-ROAD EMISSIONS USING THE CLOSE PROXIMITY METHOD

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Abstract

In the context of a Regional project about the characterization of existing road pavements and the study of new types of pavement mixtures, a study concerning the optimization of the acoustical features of the road surface has been performed. Several measurement techniques were used in order to describe the acoustical properties of the existing pavement surfaces, such as the Close Proximity Method. Data analysis shows that the correlation coefficients between equivalent sound level and vehicle speed are frequency dependent. They were calculated in the frequency range between 315 and 8000 Hz and they change in a considerable way, following the pavement roughness and porosity . In this work is proposed a method to characterize the pavement in a more complete way with respect to the formula given in the ISO/CD 11819-2 [1] which doesn't take in to account the frequency dependence in tire-road emission levels. Furthermore the variability of the noise levels depending on the length of the sampled segments of the road has been analysed.

1. INTRODUCTION

In the mechanism of noise generated by road infrastructures a great role is played by the road pavement. This must be crucial in the noise abatement planning, where the source emission must be considered. In fact, the use of noise mitigation solutions based on barriers (i.e. involving only the propagation path) can't be the only satisfactory solution . There are many cases where a barrier can't solve the problem at all (i.e. a road in the valley and houses in the hills).

During last years a great effort was made by some international research projects such as SILVIA (Silenda VIA "Sustainable Road Surfaces for Traffic Noise Control" - EU Fifth Framework Project), HARMONOISE ("Harmonised Accurate and Reliable Methods for the EU Directive on the Assessment and Management Of Environmental Noise", project funded by the EC under the Information Society and Technology Programme - Contract Number: IST-2000-28419) and IMAGINE ("Improved Methods for the Assessment of the Generic Impact of Noise in the Environment" - EU sixth Framework Project - Contract Number:

SSPI-CT-2003-503549-IMAGINE) to establish the correct relationships among sources for vehicles noise emissions. Particularly, it was clear the weight of tyre-road contact emissions and several techniques were studied to measure its strength. This emission is clearly bound to the pavement and to the tyre characteristics: using the same tyre system these components can be distinguished and the pure acoustical characteristics of the pavement may be obtained. The results of these projects pointed out the importance of the Close Proximity method (CPX, ISO/CD 11819-2 [1]) to measure the tyre-road emission levels and recently some different techniques were developed to simplify this kind of measurement.

In Tuscany a project co-funded by Italian Ministry of Transportation, Tuscany Region and the ten Tuscany Provinces, was planned in order to develop innovative noise mitigation techniques to be used in action plans for road noise sources, based on new type of pavement layers. Accordingly to this project, ten road sections, called "sites", all with regional road infrastructures, had to be characterised using several techniques (such as ISO 13472-1, 11819-1 SPB method and the CPX method). Besides, several municipal roads were characterised using the same techniques, in order to evaluate their acoustical properties and to prepare the relative action plans.

An analysis of the results obtained using the CPX technique and some considerations about the results in the frequency domain are shown here.

2. MEASURING SYSTEM

In order to perform the measurements of the CPX indexes, a device based on [3] was used. This measurement device is based on a regular passenger car (a Renault Xsara Picasso), with its factory tires Green Michelin Energy XH1 reference 185/65/R15. This vehicle is really used for acoustic measurements only. The tyres had a mileage of about 3000 km during the measurement campaigns here described. The microphones position was chosen as in figure 1 and it was based on the measurement system described in [3], near the back right wheel, in order to be as far as possible from the engine and exhaust system of the car. The two microphones were fixed to the car body and their relative positions respect to the tyre were chosen according to ISO 11819-2 [1] specifications, i.e. 0.2 m from the axis of the wheel and 0.1 m above the pavement surface. An encoder was mounted over the back left wheel, in order to measure the real car velocity.

Figure 1. Experimental microphones setup.

The data were acquired on a 4 channels system: two of them were dedicated to the acoustic signals, one to the tachometric data from the encoder and one for audio comments, when necessary. The encoder consists of a series of electric switches at equal angles (18°) and during the tyre rotation they produces a series of ten rectangular signals with a duty cycle proportional to the time between three consecutives switches. This leads to a subdivision of the tyre into ten angular sectors. From these data (i.e. time) the instantaneous velocity and position could be computed for each sector. The sound pressure levels are recorded together to the data from the encoder.

The knowledge of the starting position of each measurement passage allows an almost perfect synchronization between different passages with a maximum error of $1/10^{th}$ of tyre turn length (about 20 cm with a tyre turn length of about 192 cm). This means an almost perfect correspondence between data collected during different passages in the same road position.

3. ANALISYS METHOD

According to the ISO CD 11819-2 [1], the CPX index must be calculated by means of multiple passages done at the reference velocities of 50, 80 and 110 km/h. In order to compute the various possible indexes (CPXL, CPXH, CPXI), shown by the ISO standard in the survey or investigatory methods for each reference velocity, the arithmetic mean L_{meas} of the measured A-weighted equivalent sound pressure levels (L_{Aeq}) given by the two microphones must be used. These L_{Aeq} values had to be energetically averaged along road sections 20 meters long.

In order to correct the unavoidable velocity fluctuations between the reference and the actual velocity inside each road section an empirical formula was given

$$L_{corr} = L_{meas} + B \cdot \log\left(\frac{v_{ref}}{v}\right) \tag{1}$$

Where v_{ref} is the reference velocity, v is the mean velocity inside the section, B is an experimental given value equal to 35, and L_{meas} is the L_{Aeq} mean value between the two microphones introduced above. Indeed, according to the ISO suggestions, the mean velocity along each section must deviate no more than 5% of the reference velocity.

In this paper a different approach is shown in order to obtain a more frequency accurate acoustical characterization of the pavement using the same data suitable for the CPX index calculation.

The general level description, for each third octave acoustical band, versus the vehicle velocity is expressed by:

$$L_{predict,i} = A_i + B_i \log\left(\frac{v}{v_{ref}}\right) \tag{2}$$

where the index i is the third octave band index, $L_{predict}$ is the predicted level as a function of vehicle speed v and v_{ref} is the reference speed set to 50 km/h (used, for example, as reference velocity in the source model developed in some international project, such as SILVIA, HARMONOISE). The couple of index A and B were evaluated by means of a linear fit using a set of consecutive passages on a single section at different speeds, with a chi-squared minimization algorithm (*multifit*). In figure 2 an example of the results obtained using this method for three cases (1000 and 2000 Hz frequency bands together with overall A weighted levels). The section used for the linear fit of Equivalent Sound Pressure Level versus velocity was about 20 meters long (actually 10 tyre turn lengths) as in the ISO norm formulation.

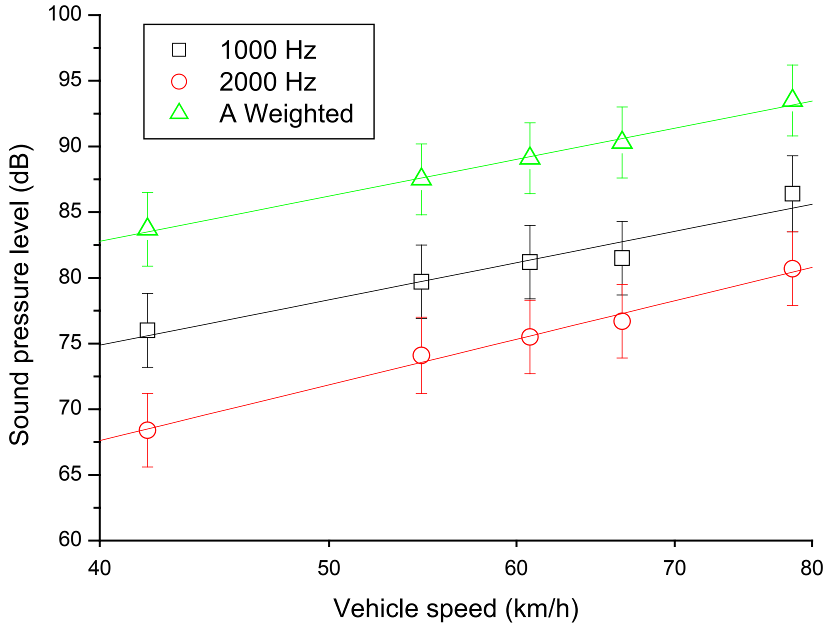

Figure 2. Sound pressure level plot versus vehicle speed.

It can be noted the different slope in the two trend lines relative to 1000 Hz and 2000 Hz bands for the specific pavement taken in to account.

4. REPEATABILITY AND REPRODUCIBILITY OF THE MULTIFIT METHOD

ISO/CD 11912-2 [1] says that the sections used for the analysis must be 20 meters long. Here the trend of the acoustical characteristics of a road pavement segment will be studied using sections with a smaller length. So the robustness against repeatability of the *multifit* method previously described must be studied: this was obtained using the statistical χ^2 test to compare linear trends for each frequency band computed using more and more passages over the same portion (a section having a length of only one tyre turn length) of the pavement. It was observed that even with ten or more passages at different velocities these trends were not statistically stable at low frequencies (below 800 Hz). This is due to the fact that a longer time interval is needed to have a more stable mean value for low frequencies. This implies also a longer section length: in fact, using a section length of two or three tyre turn lengths the stable frequencies became respectively 500 and 315 Hz, using only five repeated passages at different velocity.

It must be pointed out that the uncertainty bound to the velocity (obtained as a mean over the section) should have not to be neglected for sections having length longer than 6 meters.

In figure 3 an example is shown for the 500 Hz frequency band. On the left side a 2 m long section is used for the fit, while on the right side a 6 m long section is considered (with the previous section in its central part).

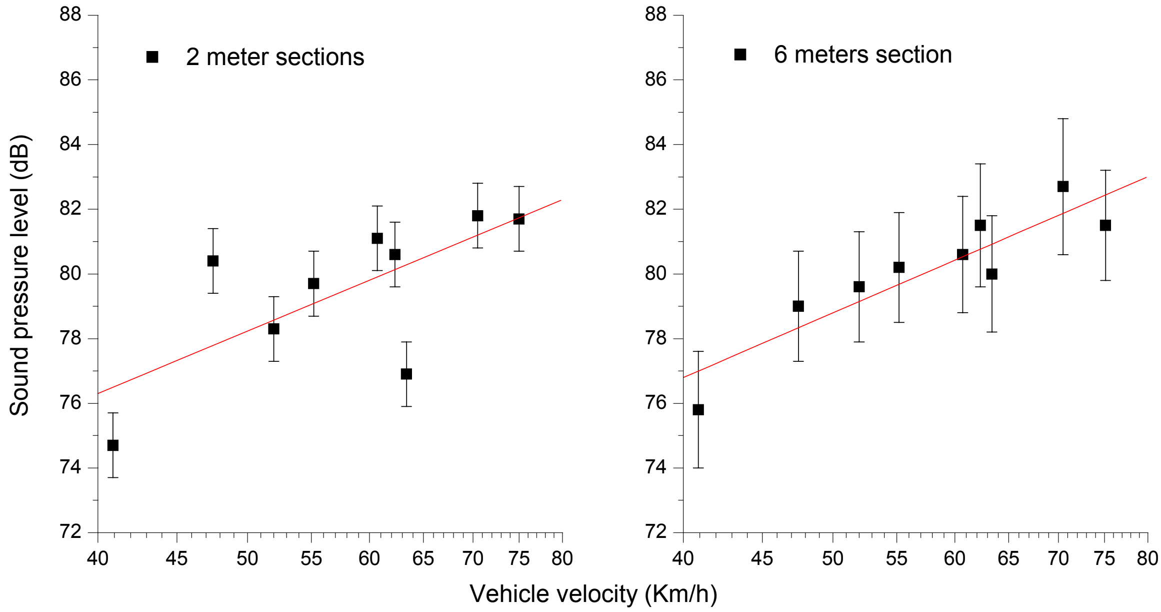

Figure 3. Increasing accuracy of linear fit with increasing of section length at 500 Hz

The computed χ^2 value for the left graph case was 3.4, while to accept the fit with a level of confidence equal to 95% the χ^2 should be less than 2.01. The right graph is instead acceptable with a χ^2 value is 0.59.

Then an estimation of the reproducibility of the method was carried out by comparing the different A and B coefficients obtained by the fit procedures applied to two independent set of passages, involving the same road segment. For each contiguous section in the segment the concordance of the two sets of coefficients is tested as a function of the section position: a set of plus and minus values (related to the sign of the difference between coefficients belonging to different sets) are statistically evaluated using the Wald-Wolfovitz test procedure (also known as run-test), besides of the usual comparison of the two different sets of coefficient using as weight their error estimation.

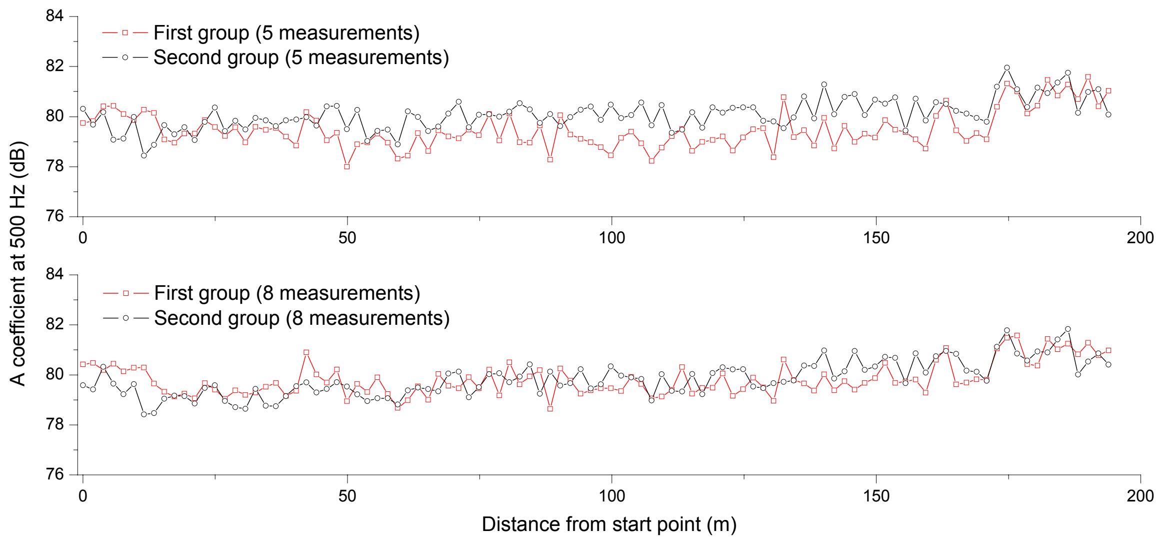

Figure 4. Test of measurement reproducibility by the Wald-Wolfovitz test procedure

In order to have statistical comparable results for each frequency band with both methods (run test and direct comparison) for the two independent set of coefficients, they must be obtained using at least 8 passages at different velocity on the same road segment.

This is shown in figure 4 for A coefficients (i.e. the L_{Aeq} generated at 50 km/h), where two cases are plotted, one with 5 passages (upper graph) and the other one with 8 passages (lower graph). In the former case, the run test marks the measurement as a not reproducible one (it can be especially seen in the zone between 100 and 150 m from the starting point). In the latter case the test gives positive results.

5. RESULTS

By using this procedure with 8 different passages on a city road in Pisa having two different pavement types, the following results should be observed. In figure 5 the A coefficients values are plotted versus distance, as a function of frequency bands (for clearness, only six bands and A-Weighted levels are shown). Four regions can be identified in the plot separated by dashed lines: the first three of them related to the same type of pavement (corresponding to three different pavement status: one with presence of superficial impurity, one normal, and one with many potholes), the last corresponding to the second type of pavement present in the segment analyzed.

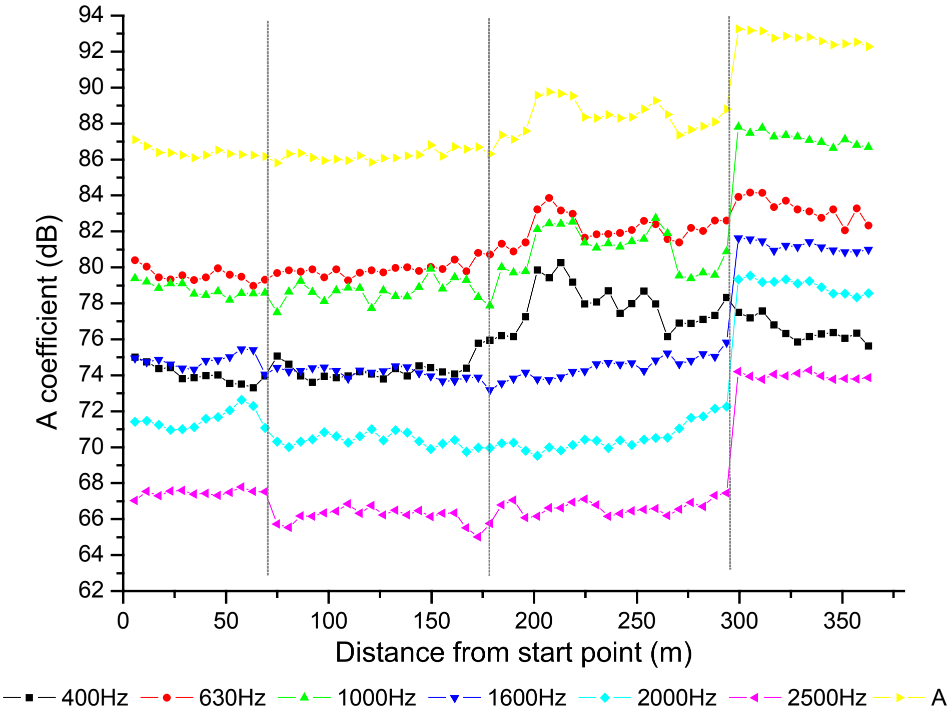

Figure 5. Section history of a road made by two different kind of asphalt.

Clearly it represents a real urban road and it cannot be compared with an homogeneous test track as the one mentioned in the ISO 10844 [2]. However the four regions are well identifiable in the frequency band analysis.

In figure 6 the mean results for the four regions previously described obtained for the A and B coefficients are shown, as a function of the frequency third octave bands.

It can be seen as the coefficients vary as a function of the frequency and as a function of the pavement characteristics and this variation can not be modeled as a simple equal translation for all levels.

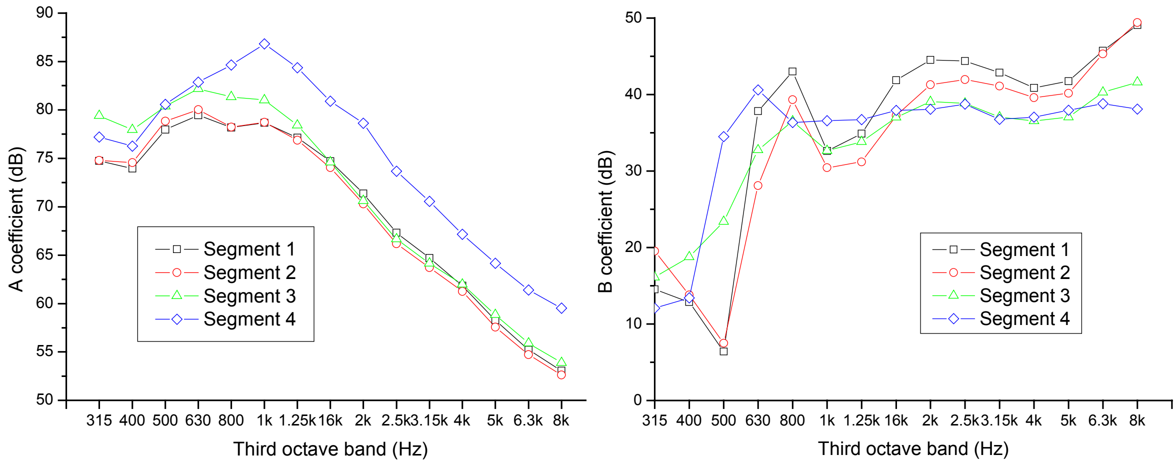

Figure 6. Plots of A and B coefficients for four different asphalt types

6. CONCLUSIONS

A punctual analysis method for road pavements characterization has been defined using a linear fit of third octave bands sound pressure levels versus natural logarithm of vehicle velocity that permits to identify the frequency dependence in tyre – road nearfield sound emissions.

This method has been validated using adequate statistical criteria in order to define the minimum number of measurements to carry on to obtain reliable results in the frequency range from 315 Hz to 8000 Hz. The minimum road section length has been identified where the mentioned analysis was performed with a statistical consistence .

A specific software which automatically provides the results previously described has been developed. It uses the wave files acquired by the multi-channel recording system from two microphones and an encoder.

Intrinsic peculiarities of pavements can be so put in evidence while they cannot be deducted by analysis of the single overall A-weighted levels or using the CPX technique as described by the ISO/CD 11819-2 [1]. For example, it is possible the localization of the change between different segments of asphalt with different conditions occurred during hot rolling.

This method is moreover useful in order to test road segments located in complex urban contexts, where the presence of holes and irregularities of various kind would make impossible to discern the peculiarities of asphalt itself.

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