PROCEEDINGS of the
23rd International Congress on Acoustics

9 to 13 September 2019 in Aachen, Germany

The determination of road surface corrections for CNOSSOS-EU model for the emission of road traffic noise

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ABSTRACT

In the CNOSSOS-EU noise emission model for road traffic noise, the calculation of sound power emission of vehicles introduces a road surface correction term, which can be calculated from a set of values provided for non-standard types of road surfaces. However, the data may be of limited use for the authorities in charge of strategic noise mapping if they do not match with the national or local types of surfaces or if newly developed types of surfaces are laid on their networks. A procedure for the acoustic characterization of road surface properties is currently discussed within the European standardization group CEN/TC227/WG5. This procedure, based on CPX tire-road noise measurements, could serve in two ways for the evaluation of road surface corrections as input parameters in CNOSSOS-EU. The first is a direct snapshot measurement on an existing network, providing a rapid and up to date evaluation of the road surface correction term, without considering the nature of the surface. The second is a reference measurement to collect reference data to serve for calculations at later stage. The paper presents the proposed method and its compatibility with the existing noise emission model.

Keywords: Rolling Noise, Road Surface, CNOSSOS-EU

1. INTRODUCTION

In the CNOSSOS-EU noise emission model for road traffic noise described in EU Directive 2015/996/EC [1], the calculation of sound power emission of vehicles introduces a road surface correction term, which can be calculated from a set of values provided for non-standard types of road surfaces. The data provided may be of limited use for the authorities in charge of strategic noise mapping if they do not match with the national or local types of surfaces or if newly developed types of surfaces are laid on their networks.

A procedure for the acoustic characterization of road surface properties is being currently discussed within the European standardization group CEN/TC227/WG5. This procedure was developed within the EU FP7 project "ROSANNE" [2]. The main objective is to set up a harmonized system for characterizing the acoustic properties of pavements, to which road authorities and road companies can refer in tenders for new pavements. However, this characterization procedure based on CPX tire-road noise measurements, could also be used to the benefit of strategic noise mapping, for the evaluation of road surface corrections. Obviously, this would enable road planners, road administrators, contractors, and manufacturers of pavements to assess in a consistent way the acoustic performance of road pavements.

More precisely, two ways of implementing the procedure for the purpose of noise mapping have been identified. The first approach consists in a direct measurement of the road surface corrections on an existing network (acoustic "snapshot"). The second approach consists in collecting reference data on specific types of road surfaces, to be used at later stage for the calculation of road surface corrections. The paper presents the overall approach.

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2. A PROCEDURE BASED ON CPX NOISE MEASUREMENTS

2.1 Rationale

The statistical pass-by (SPB) measurement of road surface effect on tire-road noise is a long standing and widely used method described in the international standard ISO 11819-1 [3]. In this method, tire-road noise levels are measured at the side of the road and integrate all sorts of vehicles (tires) in the traffic. This tends to suggest that the method is representative of the real exposure of people working or living close to the road. Over the last decades, large data base have been built of SPB noise on many road surfaces, and in several countries, national road surface characterization procedures make use of this measurement method. However, there are many disadvantages or limitations in this SPB method, the main one being that the measurement result only represents a short section of the road. Another drawback is the sensitivity to sound reflected from structures such as buildings or parked vehicles and to screening provided by guardrails or other objects affecting sound propagation from vehicles to the microphone position. This drastically limits the applicability of the method.

More recently, the close-proximity (CPX) measurement method was developed and published as an international standard ISO 11819-2 in 2017 [4]. In this method, the noise generated by specified reference tires is measured when running on the surface under test. Two test tires are specified in the technical specification ISO TS 11819-3 [5]: P_1 typical of passenger car tire emission and H_1 representing heavy vehicle noise emission. They are mounted on a vehicle, which may be self-powered or on a towed trailer. The main advantages of the CPX method are that the results characterize long sections of road and that it is less sensitive than the SPB method to influences from variation in the road environment. Among its disadvantages are that the measurement results are specific for the applied reference tire which may not necessarily represent the tire/road noise from various categories of vehicle. However, with this method, an entire network can be measured rapidly and efficiently, with no site restriction. These advantages made the CPX method much more used over the last few years than the SPB.

Finally, a quantification of the pros and cons of both methods was carried following a list of criteria. The CPX method turned to be the more promising one for the acoustic characterization of pavements: higher practicability, wider applicability (no site restriction) and coverage (network), flexibility for speed range, representativeness for long sections, homogeneity checks, lower time consumption and lower cost, resistance to change in vehicle fleet, etc.

2.2 The relation between CPX and SPB

Although CNOSSOS-EU is not a measurement method, the noise calculation model is supplied with input parameters derived from measurements. The road surface correction coefficients are defined as the difference in tire-road sound power emission on the surface and on a virtual reference surface. This virtual reference road surface corresponds to an average between Dense Asphalt 0/11 and Stone Mastic Asphalt 0/11 road surfaces, all between 2 and 7 years old and in a representative maintenance condition. The octave band coefficients provided for the reference tire-road sound power are originated from the averaging of a large set of measured SPB noise levels during the EU FP6 project IMAGINE. The road surface correction coefficients provided are also originated from SPB measurements in the Netherlands.

The consistency of an approach purely based on CPX measurements for deriving input parameters in CNOSSOS-EU was investigated in the EU FP7 project ROSANNE [6].

In a first theoretical approach assuming a simple point source and propagation model, the relation between the sound pressure levels measured by CPX on two different surfaces (ΔL_{CPX}) and the road surface correction coefficient in CNOSSOS-EU ($[\Delta L_{WR}]_{\text{CNOSSOS-EU}}$) was derived:

$$\Delta L_{CPX} = [\Delta L_{WR}]_{\text{CNOSSOS-EU}} + \Delta A_{CPX} - \Delta A_{SPB} \quad (1)$$

Where ΔA_{CPX} and ΔA_{SPB} are the differences between the two surfaces of the ground attenuation between the point source and the microphone measuring respectively CPX and SPB noise levels.

For reflecting road surfaces (dense surfaces), ΔA_{CPX} and ΔA_{SPB} are both equal to zero and therefore ΔL_{CPX} and $[\Delta L_{WR}]_{\text{CNOSSOS-EU}}$ are fully equivalent.

For road surfaces with porosity, there is a difference due to the difference in ground effect between the two measurement configurations. The simulations in the case of a typical porous pavement using a method described in [7] showed that the discrepancy between the two sound attenuation differences can be between 2 and 3 dB in the mid-frequency range (around the peak of sound absorption of the porous pavement). It is illustrated in figure 1 as the difference between the two curves. It means that according to the simulations, a CPX noise level difference between a porous and a dense surface can be a few dB higher than the sound power level difference (road surface correction in CNOSSOS-EU) between the same road surfaces. But it is clear that, by assuming point sources, the simulations are probably overestimating the phenomena, in particular the interferential effect. In reality, the tire noise radiation is no point source when heard from a 0.20 m distance and a vehicle passing-by at 7.5 m distance is no stationary point source.

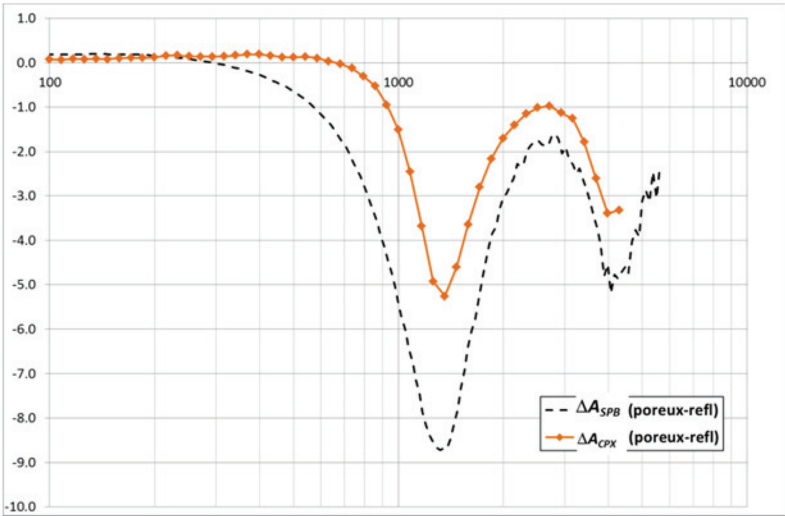

Figure 1 – Sound attenuation difference over a porous road surface with respect to a reflecting surface for SPB and CPX positions (from [6] and [7])

The relation between CPX and SPB noise levels was further investigated on a statistical perspective [8]. Measured data were collected from different EU countries (Austria, Denmark, Germany, Belgium, UK, France) of CPX noise levels and SPB noise levels measured on the same road sections and pavements at approximately the same time. The analysis concluded that an average 1:1 relationship between CPX noise levels measured with reference tire P_1 (Uniroyal SRTT Tigerpaw tire) and SPB noise levels from passenger cars (vehicle category *m*=1 in CNOSSOS-EU) can reasonably be derived, as long as both types of noise levels are measured at the same reference speed, yielding a 20.5 dB average difference between the two measured quantities and with almost 90 % of all data being within ±1 dB around this trend line (figure 2). Considering truck tire noise at 80 km/h, the average SPB noise levels from multi-axle trucks on dense pavements is 9.5 dB lower than the CPX noise levels measured with H_1 tire (Avon AV4). For two-axle trucks, the corresponding difference is 12.0 dB.

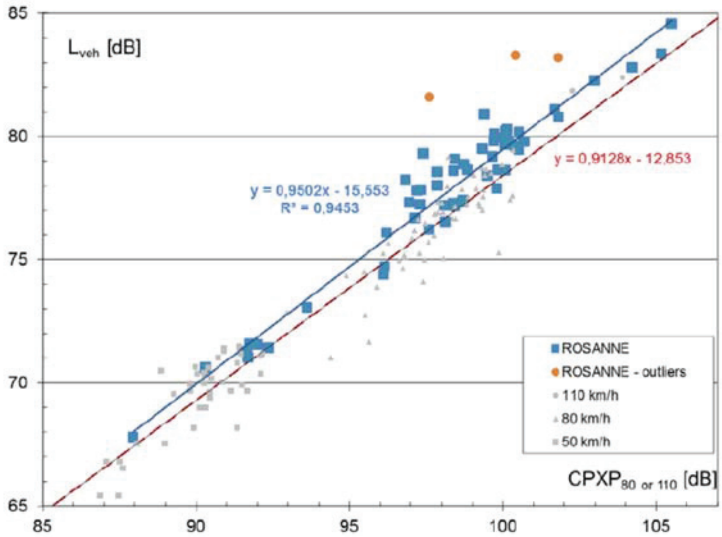

Figure 2 – Relationship between CPXP80 (tire P_1 at 80 km/h) and light vehicle pass-by L_{veh} at the same

reference speed. Grey data points are from measurements at different speed; the dashed red line is the trend line for these data (from [8])

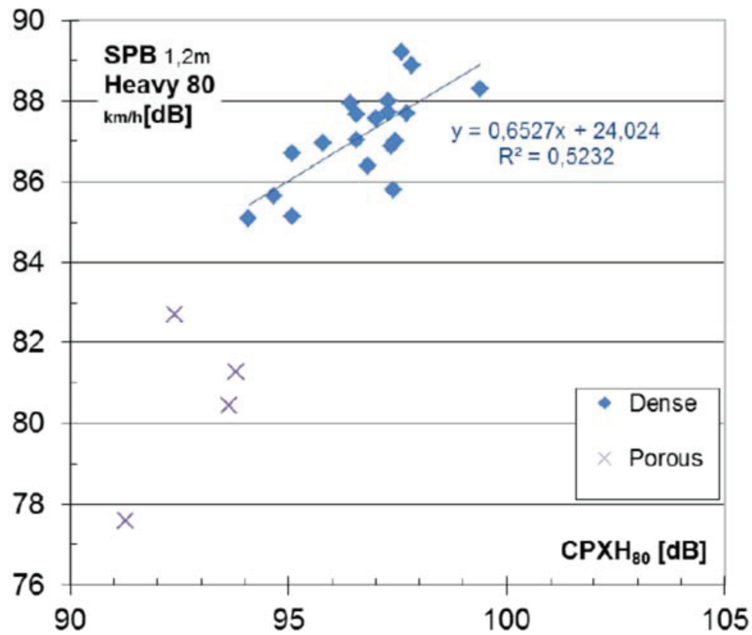

Figure 3 – Relation between CPXH80 noise levels and SPB noise levels for multi-axle heavy vehicles at 80 km/h (from [8])

From this analysis - based on overall noise levels - it was concluded that the CPX measurement method can reasonably provide road surface correction coefficients consistent with those provided with SPB measurements, provided that the test tire is adapted to the vehicle category (P_1 for category m=1 and H_1 for m=2 and 3) and with a reference speed that should be as close as possible to the average speed of the traffic for the category of vehicles. Additional experiments would be necessary to further validate and generalize this assumption for wider speed range and frequency range.

2.3 Reference conditions

2.3.1 Reference road surface

In the harmonized calculation method, the road surface correction coefficient is defined with regard to a virtual reference surface. This reference corresponds to an average noise emission on a mix of Dense Asphalt Concrete (DAC) 0/11 and Stone Mastic Asphalt (SMA) 0/11 surfaces, all between 2 and 7 years old and in a representative maintenance condition.

Such surfaces have been measured with the CPX method with the two test tires P_1 and H_1 [9]. The measured data from several EU countries (Belgium, Denmark, Poland and Sweden) were collected and averaged. Data for DAC are for surface aged from 2 to 7 year old with an average of 4 years. They were measured on 9 sections with tire P_1 and 3 sections with tire H_1. Data for SMA surfaces are aged from 2 months to 8 years with an average of 3.4 years. They were measured on 42 sections with tire P_1 and 5 sections with tire H_1.

The resulting average noise levels at 80 km/h and expressed in octave bands are shown in figure 4 for tire P_1 and figure 5 for tire H_1. The corresponding average values are and listed in Table 1.

Table 1 — Reference CPX octave band levels for test tires P1 and H1 at 80 km/h (in dB)

Octave bands	**63 Hz**	**125 Hz**	**250 Hz**	**500 Hz**	**1000 Hz**	**2000 Hz**	**4000 Hz**	**8000 Hz**
$L_{CPXPref,80}$ (dB)	--	--	77.4	87.8	97.6	92.7	83.5	--
$L_{CPXHref,80}$ (dB)	--	--	76.7	89.4	96.9	90.3	81.1	--

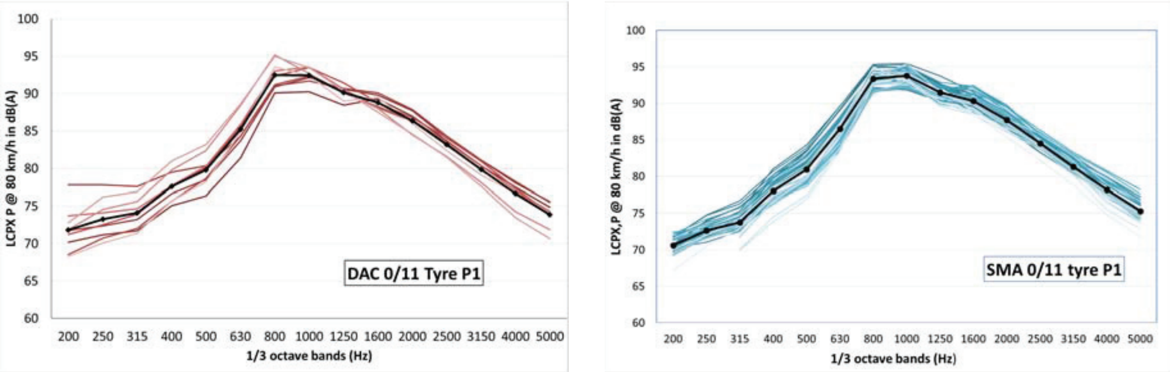

Figure 4 – CPX spectra measured at 80 km/h with tire P_1 on DAC 0/11 (left) and SMA 0/11 (right). Calculated average (thick black curve) (from [6])

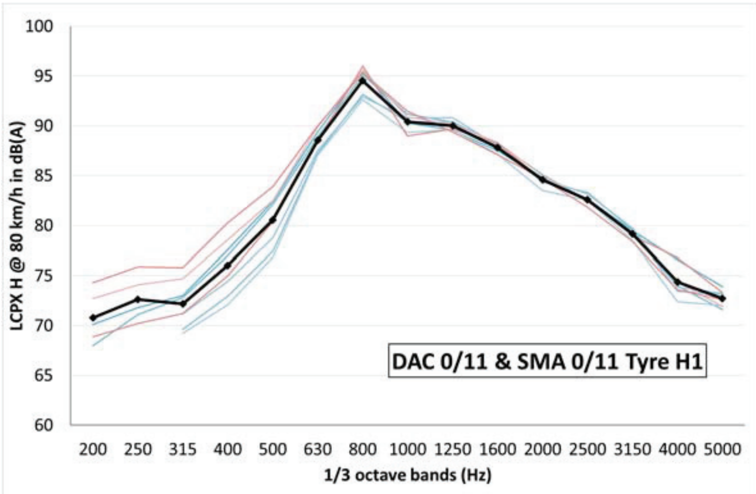

Figure 5 – CPX spectra measured at 80 km/h with tire H_1 on DAC 0/11 and SMA 0/11. Calculated average (thick black curve) (from [6])

2.3.2 Frequency range

In the current ISO 11819-2 standard, the CPX measurements are provided for one-third octave bands between 315 Hz and 4 kHz, thus covering octave bands from 500 Hz to 4 kHz. This frequency range is preservative with regard to possible contamination of the measurements by aerodynamic noise and by near field effects (car body and tire vibration). However many measurement systems are more immune to this contamination (due to cover) and can perform at lower and higher frequencies. Furthermore, in the lowest and highest frequency bands, the effect of the road surface is very low, as the noise emission is dominated by propulsion noise for which road surface characteristics are not significant. Therefore, even for the most exposed measuring devices, the reference noise levels in the octave band i = 250 Hz can be approximated as if the sound pressure levels measured in the third-octave band 315 Hz is constant in the three 1/3 octave band:

$$L_{CPXPref,80}\ (i{=}250\ \text{Hz}) = L_{CPXP;315,80} + 10\log_{10}(3) \quad (2)$$

$$L_{CPXHref,80}\ (i{=}250\ \text{Hz}) = L_{CPXH;315,80} + 10\log_{10}(3) \quad (3)$$

For the other extreme octave bands (i = 63 Hz, 125 Hz and 8 kHz) the road surface correction coefficients will be approximated to zero. The validation of such approximations still needs further investigation.

2.3.3 Reference speed

Regarding the reference speed, the measurements shall be made as close as possible to the reference speed v_m (in km/h) corresponding to the average speed of the flow of vehicles of category m, as considered for the calculations. Usually, if local measurement data is unavailable, v_m is taken as the maximum legal speed for the vehicle category. Different reference speed may apply for light motor vehicles and heavy vehicles, consequently for measurements with P_1 and H_1 test tires.

When the measurements are performed at a different speed than the reference speed for the calculations, the noise levels must be corrected using a $\beta \log_{10}(v/v_{ref})$ law, where β is the speed correction coefficient. Usually, this coefficients ranges between 25 and 35. The statistical analysis of the French database of SPB measurements showed that there is no correlation between the speed coefficient and the surface age, the reference speed, the traffic intensity, etc. The following average slopes were found [8]:

- For light vehicles: β = 28 on porous and semi-porous (211 data), 30 on dense pavement (258 data).
- For heavy trucks: β = 28 for porous (71 data), 30 for semi-porous (37 data) and 27 for dense pavement (156 data).

By taking a coefficient of 30 is a reasonable approximation when the nature of the road surface is unknown. The effect of the coefficient on the calculation of the road surface correction coefficient is illustrated in figure 6. The highest predicted error by taking a speed coefficient of 30 instead of 25 (or 35) is estimated at 1.5 dB at 40 km/h.

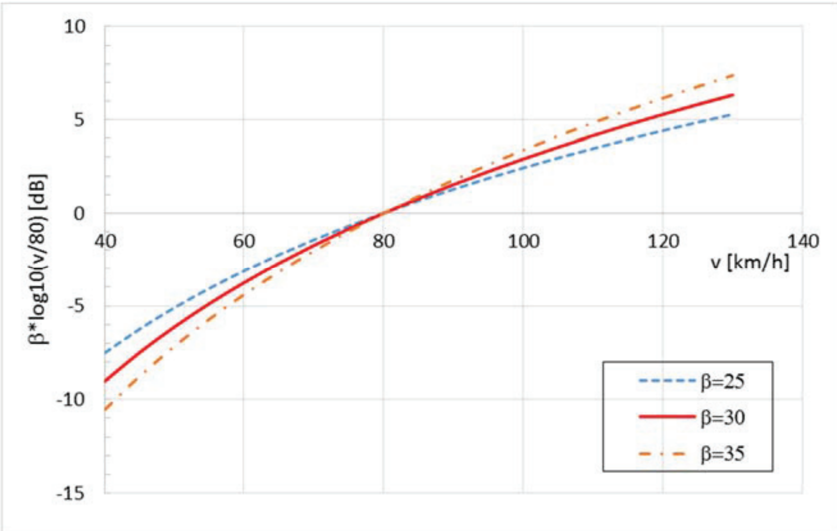

Figure 6 – Effect of the speed coefficient on the correction as a function of speed

Alternatively, speed coefficients provided in CNOSSOS-EU (β_m) can be used when the nature of the road surface is known.

3. A TWO WAY APPROACH FOR NOISE MAPPING

Two ways of implementing the acoustic characterization procedure for the purpose of noise mapping have been identified. The first approach is a direct measurement of the road surface corrections on an existing network. The second approach is a measurement of spectral coefficients on specific types of road surfaces to be stored and used as later stage for the calculation of road traffic noise emission. They are described in the following sections.

3.1 Direct determination of the road surface corrections on a road network

3.1.1 Proposed measuring procedure

The first approach consists in a direct measurement of the road surface corrections on an existing network (acoustic "snapshot"). It provides a rapid and up to date evaluation of the road surface correction term on a specific network, without considering the nature of the surface. The use of CPX method instead of pass-by method makes it possible to perform the evaluation of an entire network in a reasonable time frame

The measuring procedure is typical of a "monitoring" routine for the acoustic performance of road surfaces, aiming at understanding how a surface degrades acoustically over its working lifetime and informing surface maintenance/replacement strategies. In this procedure, a single measurement run may be satisfying the needs of the network provider as well as stated accuracy requirements. The specificity in the present case of measuring road surface correction coefficients is the imperative need for octave band noise levels.

The road surface corrections can be measured directly on site, on segments or sections of an existing network compatible with the road sections used for the calculation of source line emission in CNOSSOS-EU, and without any consideration of the nature of the surface.

Measurements with test tire P_1 will be used for evaluating the road surface correction for light motor vehicles (category m=1 in CNOSSOS-EU). Measurements with test tire H_1 will be used for evaluating the road surface correction for medium heavy vehicles (category m=2 in CNOSSOS-EU) and heavy vehicles (m=3 in CNOSSOS-EU).

CPX noise levels are expressed at the reference speed v_m in octave bands, preferably from 63 Hz to 8 kHz, in any case at least from 500 Hz to 4 kHz.

3.1.2 Processing of measurement results

For each road segments, the output of the measurements is a set of $L_{CPXP;i;v1}$ and $L_{CPXH;i;v2}$, where:
i is the index of octave bands,
$v_1=v_m$ for m=1 and $v_2=v_m$ for m=2 or 3.
$L_{CPXP;i;v1}$ is the CPX noise level in octave band i, measured with tyre P at the speed v_1 (in km/h),
$L_{CPXH;i;v2}$ is the CPX noise level in octave band i, measured with tyre H at the speed v_2 (in km/h).

For each octave bands i, the road surface correction can be expressed by:

$$\Delta L_{WR,road,i,1} = L_{CPXP;i;v1} - L_{CPXPref;80} - 30 \log_{10}(v_1/80) \quad \text{for } m=1 \tag{4}$$

$$\Delta L_{WR,road,i,2} = \Delta L_{WR,road,i,3} = L_{CPXH;i;v2} - L_{CPXHref;80} - 30 \log_{10}(v_2/80) \quad \text{for } m=2 \text{ and } m=3 \tag{5}$$

where $L_{CPXPref;i;80}$ and $L_{CPXHref;i;80}$ are the reference levels specified in Table 1.

In these formulas, a speed coefficient (i.e. the slope of the variation of noise level relative to the logarithm of the speed) of 30 is assumed (see section 2.3.3).

In the case where CPX levels can't be measured for the octave bands i = 63 Hz, 125 Hz and 8 kHz, the road surface correction can be approximated to zero:

$$\Delta L_{WR,road,i,1} = 0 \qquad \text{for } m=1, 2 \text{ or } 3 \tag{6}$$

3.2 The collection of reference input data

3.2.1 Proposed measuring procedure

The second approach consists in collecting reference data on specific types of road surfaces, to be stored in a database and used at later stage for the calculation of strategic noise maps. In the Directive 2015/996/EC [1], the road surface correction coefficients $\Delta L_{WR,road}$ can be calculated from input data $\alpha_{i,m}$ and β_m representing respectively the spectral corrections in octave bands and the overall speed effect, for a vehicle category m:

$$\Delta L_{WR,road,i,m} = \alpha_{i,m} + \beta_m \times \log_{10}\left(\frac{v_m}{v_{ref}}\right) \tag{7}$$

It is possible to supplement or update the available data base by using the procedure for characterizing the acoustic properties of a road surface type (procedure for acoustic labelling of road surfaces), with some specificities mentioned hereafter.

Because the measurements aims at evaluating a specific pavement type, a minimum number of five test sections shall be selected and tested to determine the acoustic parameters representative of the whole type. The test sections should be representative of the lifetime of the road surface type, assuming proper maintenance. Some of the sections may present some discontinuities due to ageing. The selected sections will only show discontinuities related to the pavement condition, with the exclusion of exceptional or specific discontinuities such as repairs, paintings, bumps, manholes, etc. The length of each test section shall be a minimum of 200 m without interruption of the road surface; ideally the length shall be 500 m or longer.

The CPX measurements shall be performed at least three times (meaning one measurement and two repetitions) on each test section for each reference tire and for each applicable reference speed.

Measurements with test tire P_1 will be used for evaluating the input data for light motor vehicles (category m=1) and measurements with test tire H_1 will be used for medium heavy vehicles (category m=2) and heavy vehicles (m=3).

In order to enable the determination of speed coefficients, measurements shall be performed at different reference speeds – at least two - at which the surface is expected to be used, and with a total range of at least 30 km/h. One of the measurement speeds shall be the reference speed of the Directive 2015/996/EC [1]: $v_{refCNOSSOS\text{-}EU}$ = 70 km/h.

For each section, CPX noise levels for each tire configuration are expressed at the reference speed $v_{refCNOSSOS\text{-}EU}$ in octave bands, from 63 Hz to 8 kHz, or in any case at least from 500 Hz to 4 kHz.

Finally, for each road segments, the output of the measurements is a set of CPX noise levels $L_{(CPXP;i;vrefCNOSSOS\text{-}EU}$ and $L_{CPXH;i;vrefCNOSSOS\text{-}EU}$, measured with tire P_1 (respectively H_1) in octave band i, at the speed $v_{refCNOSSOS\text{-}EU}$ = 70 km/h.

3.2.6 Determination of coefficients $\alpha_{i,m}$ and β_m

For each octave bands i, the spectral coefficients $\alpha_{i,m}$ are expressed by:

$$\alpha_{i,1} = L_{CPXP;i;vrefCNOSSOS\text{-}EU} - L_{CPXPref;80} - 30\log_{10}(70/80) \qquad \text{for } m=1 \qquad (8)$$

$$\alpha_{i,m} = L_{CPXH;i;vrefCNOSSOS\text{-}EU} - L_{CPXHref;80} - 30\log_{10}(70/80) \qquad \text{for } m=2 \text{ and } m=3 \qquad (9)$$

$L_{CPXPref;i;80}$ and $L_{CPXHref;i;80}$ are the reference levels specified in Table 1

For the determination of the speed coefficient β_m, a linear regression of the overall CPX levels obtained versus $\log_{10}(v/v_{refCNOSSOS\text{-}EU})$ must be performed and the slope s_m of this regression calculated. Then for each vehicle category m, the speed coefficient β_m is expressed by:

$$\beta_m = s_m - 30 \qquad (10)$$

The factors “30” in equations (8), (9) and (10) result from the speed correction approximation discussed in 2.3.3. The estimated error is however small between 70 and 80 km/h as it can be visualized in figure 6.

4. CONCLUSIONS

The paper has presented how a measurement procedure for the acoustic characterization of road surfaces based on CPX measurements could be used for deriving road surface correction coefficients to be used for road traffic noise calculations as required by the European Directive 2015/996/EC. The theoretical principles and the supporting data were presented and show that a consistent and multi-purpose procedure can be established. Some approximations were necessary and still need experimental validation. The established procedure is now sufficiently finalized to be tested on real cases in the future.

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