Sustainable Road Surfaces for Traffic Noise Control

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SILVIA PROJECT REPORT

END$_T$

Expected pass-by Noise level Difference from Texture level variation of the road surface

P. Klein, INRETS
J-F Hamet, INRETS

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END$_T$: Expected pass-by Noise level Difference

from texture level variation of the road surface

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1 Introduction

Texture is the core influencing parameter of a road surface on tyre/road noise emission. Its influence is known for impervious surfaces. The higher the megatexture levels, the higher the noise levels in the low and medium frequency range. The higher the macrotexture levels, the lower the high frequency noise levels. Various single number ratings have been suggested to characterize this influence. The $ERNL_V$ [1] for instance predicts the pass-by tyre noise $dB(A)$ level for impervious surfaces from the 80 mm and 5 mm octave-band texture levels $L_{T_{80mm}}$ and $L_{T_{5mm}}$ as follows:

$$ERNL_V = c(V) + .50 L_{T_{80mm}} - .25 L_{T_{5mm}} dB(A)\,. \qquad (1)$$

Similar to the other number ratings, the $ERNL_V$ is not applicable to porous surfaces. The first reason concerns the pavement texture itself. The $L_{T_{80mm}}$ dependant term of the $ERNL_V$ corresponds to the tyre belt vibration noise due to the geometric irregularities of the road surface. Taking abruptly the texture information for porous surfaces, which present pronounced dips, may overestimate the interaction between the tyre and the road surface and consequently the predicted noise level. The second reason concerns the pavement porosity which requires to take into account additionnal parameters in the rolling noise prediction: the air-flow resistance of the road pavement (which affects the air-pumping phenomenon) and the acoustic absorption of the surface.

Two single number ratings are proposed in [2] for quantifying the effect of the acoustic absorption on the pass-by noise level, indepedently of the other parameters.

This report addresses the influence of the texture. In a previous work [3], the correlations between the enveloped texture levels and the calculated radiated acoustic power levels due to the tyre vibration phenomenon have been studied. Based on these results, a single number rating for texture influence is proposed applicable to conformity of production purposes.

2 Enveloped texture and rolling noise power levels correlations

The relationship between texture and noise has been addressed in [3]. The approach consists in evaluating the regressions between road texture 1/3 octave levels and tyre-road noise 1/3 octave levels (similar to [4]). The texture spectra are however considered in the frequency domain (using the correspondence $t = x/V$). The correlation coefficients C_{ij} between texture levels in the frequency band f_i and noise levels within the frequency band f_j are evaluated. The highest values are observed along the diagonal, i.e. for C_{ii}. The regressions are thus performed on the diagonal elements only, i.e. between texture levels and noise levels within the same frequency band f_i. Due to the $f = V/\lambda$ correspondence, the regressions may be speed dependent.

The measured texture data used in [3] are the set of 214 texture profiles measured by TRL in the frame of the SILVIA round Robin Test [5]. The noise data are calculated values : they are obtained by running the INRETS dynamic rolling model on the measured TRL profiles. The INRETS model evaluates the acoustic power radiated from the tyre vibrations when rolling on the profile. It does not address the air-pumping phenomenon.

One tyre/road interaction parameter of the model is the tyre rubber stiffness. Evaluations have been made for two values of this rubber stiffness: 65 MN/m^3 (intended to correspond to a soft rubber) and 417 MN/m^3 (intended to correspond to a hard rubber). The profiles come out to be almost totally enveloped during the rolling process in the soft rubber case, while the penetration depth ranges between 1 mm and 3 mm in the hard rubber case. For each rubber stiffness, two rolling speeds have been considered: 80 km/h and 130 km/h. The results used in this report are the one obtained with the hard rubber stiffness because it yields a penetration depth which appears closer to reality.

Evaluations of the texture/noise regressions have been performed in [3] using, for the noise aspect the power noise levels obtained from the INRETS dynamic model and, for the texture aspect different types of information : the measured texture, the enveloped texture, the contact pressure associated to the enveloped texture, the contact pressure (at the center of the contact zone) of the rolling process, the hub force (sum of the contact forces) of the rolling process.

The best texture/noise correlations have been found using the hub force. This comes out however not to lead to a tool adapted to practical situations since it requires the use of a rather complicated rolling model.

The next best correlations were obtained using enveloped texture. INRETS envelopment procedure is based on the contact between the profile and a semi infinite elastic space characterized by its Young's modulus E [6]. The model is easier to use than the rolling model. The value of E has been determined in by using the set of profiles and looking for the best enveloped texture/noise correlations. The same value $E = 1\ MN/m^2$ has been found to be adapted to the two speeds considered for the simulations: $V = 80$ km/h and $V = 130$ km/h.

The slopes of the regression lines between the enveloped texture levels for $E = 1$ MN/m2 and the noise power levels are listed in table 1 for $V = 80$ and 130 km/h. These coefficients allow to evaluate the noise power level variation correponding to an enveloped texture variation in each frequency band where the tyre belt vibration noise predominates whith respect to the air-pumping phenomenon ($f \leq 1$ kHz). The differences between $V = 80$ and 130 km/h are not negligible, especially for the frequencies near 1 kHz.

f (Hz)	250	315	400	500	630	800	1000
b_i @ 80 km/h	0.81	0.76	0.68	0.68	0.65	0.53	0.31
b_i @ 130 km/h	0.98	0.95	0.93	0.81	0.76	0.78	0.50

Tab. 1: Regression slopes for $V = 80$ and $V = 130$ km/h

3 The single number rating END_T

The results reported in [3] are based on calculated power noise levels, not on actual pass-by noise levels. They enable to evaluate the difference between the rolling noise levels on two road surfaces from the texture level differences measured on these road surfaces. They do not enable to evaluate a pass-by noise level from a road texture level, at least not at this stage of the research.

The single number rating, intended to quantify the influence of texture on the pass-by rolling noise in dB(A), addresses thus only the level variation. It is adapted to checking the (texture) homogeneity of the road surface on the acoustic point of view, and to the Conformity of Production procedure.

The single number rating proposed here is based on the enveloped texture information. This seems a good compromise between calculation simplicity (envelopment procedure as compared to dynamic rolling) and pertinent texture information (using enveloped texture yields a better correlation than using rough texture).

It is given by the relation :

$$END_T = 10 \log \frac{\sum_i 10^{(L_{m_i} + b_i . \Delta L_{eT_i})/10}}{\sum_i 10^{L_{mi}/10}} \,. \tag{2}$$

where L_{mi} is the third-octave noise level measured at the labelling, ΔL_{eT_i} the third-octave enveloped texture level difference at a given speed V between the enveloped texture measured at the labelling and the enveloped texture measured at the COP (or at different locations along a same surface, for a homogeneity checking), and b_i the regression slope calculated for each third-octave band below 1 kHz or 0 above 1 kHz. As already written, there are non negligible differences between the regression slopes obtained for $V = 80$ km/h and those obtained for $V = 130$ km/h. These coefficients b_i depend, strictly speaking, on the rolling speed. Fixed values are however proposed (Table 2), which are the average values of the regression slopes obtained for $V = 80$ km/h and $V = 130$ km/h, rounded down to 0 or 0.5.

f (Hz)	b_i	f (Hz)	b_i
250	0.9	1250	0.0
315	0.85	1600	0.0
400	0.8	2000	0.0
500	0.75	2500	0.0
630	0.7	3150	0.0
800	0.65	4000	0.0
1000	0.4		

Tab. 2: The coefficients b_i

The case of impervious surfaces

The formulation above addresses the frequency range where the tyre belt radiation predominates. For impervious surfaces where air pumping phenomena occur, a term corresponding to the texture influence in the high frequency range is thus added to the END_T. This proposed additional term is the $L_{T_{5mm}}$ coefficient of the $ERNL_V$. The resulting formulation for END_T is thus :

$$END_T = 10 \log \frac{\sum_i 10^{(L_{m_i} + b_i . \Delta L_{eT_i})/10}}{\sum_i 10^{L_{mi}/10}} - .25 \Delta L_{T_{5mm}} \,, \tag{3}$$

where $\Delta L_{T_{5mm}}$ is the texture level difference in the 5 mm wavelength octave band between the labelling and the COP.

4 Estimation error

Estimation error on third-octave band levels

The confidence interval in dB for an estimation is given by :

$$]20 \log(1-\epsilon), 20 \log(1+\epsilon)[\,, \tag{4}$$

where ϵ is the error made on this estimation.

For a gaussian random time dependant function of spectral width B, the standard deviation of the error ϵ made on the evaluation of its root mean square value over a length of time T is given by

$$\sigma = \frac{1}{2\sqrt{BT}} \,. \tag{5}$$

The error ϵ has a probability of 90 % to be within the interval $]-1.6\sigma, 1.6\sigma[$.

The spectral width of the third-octave band centered on the frequency f_i is

$$B_i = (2^{1/6} - 2^{-1/6}) f_i = 0.23 f_i \,. \tag{6}$$

Then, assuming the texture to be a gaussian random variable, the 90 % confidence interval on the texture level in the third-octave frequency band centered on f_i is given by :

$$]20 \log(1-\epsilon_i), 20 \log(1+\epsilon_i)[\,, \tag{7}$$

whith

$$\epsilon_i = \frac{1.6}{2\sqrt{0.23 f_i L/V}} = 1.66\sqrt{\frac{V}{L f_i}}\,, \tag{8}$$

where $L = VT$ is the enveloped texture length available for the estimation.

Estimation error on the END_T

To evaluate an a priori estimation error on the END_T, it is necessary to use a reference spectrum L_i^{ref} as a substitute for the L_{mi} noise spectrum[1]. In the present report three reference noise spectra are used:

- the Dutch spectrum shape $L_{ref}^{(Dutch)}$,
- the French spectrum shape for impervious (dense) surfaces $L_{ref}^{(French-D)}$ (light vehicles),
- the French spectrum shape for open surfaces $L_{ref}^{(French-O)}$ (light vehicles).

These noise spectra are given in table 3 and drawn figure 1. The maximum third-octave band levels of these spectra are respectively at 1250 Hz, 1000 Hz and 800 Hz while the highest END_T-influencing frequency is 1000 Hz.

f (Hz)	$L_{ref}^{(Dutch)}$	$L_{ref}^{(French-D)}$	$L_{ref}^{(French-O)}$
250	-24.3	-22.7	-17.5
315	-22.6	-20.8	-15.6
400	-20.9	-19.6	-14.3
500	-17.4	-17.2	-12.1
630	-14.3	-14.0	-9.7
800	-10.9	-8.6	-7.4
1000	-7.1	-5.5	-7.8
1250	-6.3	-6.3	-8.8
1600	-7.7	-9.0	-10.2
2000	-9.5	-11.8	-11.5
2500	-12	-14.8	-14.2
3150	-14.8	-17.2	-17.0
4000	-17.7	-20.4	-19.6

Tab. 3: Dutch and French sectrum shapes (dB(A))

The confidence interval on the END_T is evaluated by considering the upper limit ${\epsilon_{END_T}}^+$ as the value obtained when the errors on the third-octave band texture levels reach their highest values $20\log(1+\epsilon_i)$ for all f_i and the lower limit ${\epsilon_{END_T}}^-$ as the value obtained when the errors on the third-octave band texture levels reach their lowest values $20\log(1-\epsilon_i)$ for all f_i. The ${\epsilon_{END_T}}^+$ and ${\epsilon_{END_T}}^-$ are given by:

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[1] The spectrum shape is sufficient

$$\epsilon_{END_T}{}^{+} = 10 \log \frac{\sum_i 10^{\left(L_i^{(ref)} + b_i 20 \log(1+\sqrt{2}\epsilon_i)\right)/10}}{\sum_i 10^{L_i^{(ref)}/10}} \qquad (dB_A) \qquad (9)$$

$$\epsilon_{END_T}{}^{-} = 10 \log \frac{\sum_i 10^{\left(L_i^{(ref)} + b_i 20 \log(1-\sqrt{2}\epsilon_i)\right)/10}}{\sum_i 10^{L_i^{(ref)}/10}} \qquad (dB_A) \qquad (10)$$

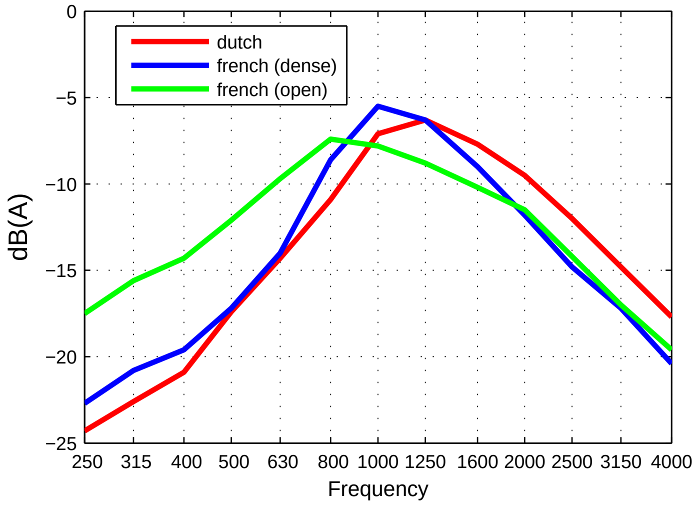

Fig. 1: Reference noise spectra

In these formula, the factor $\sqrt{2}$ before ϵ_i is due to the fact that the END_T is calculated from differences in texture levels which may be affected by the same uncertainties.

The $\epsilon_{END_T}{}^{+}$ and $\epsilon_{END_T}{}^{-}$ calculated with the 3 reference noise spectra are drawn in figure 2 as a function of the available texture length for 3 rolling speeds.

The required texture length to reach a 90 % confidence interval of ±1.0 $dB(A)$ is given in table 4 for each reference noise spectrum and each rolling speed.

Noise shape	$V = 50$ km/h	$V = 90$ km/h	$V = 130$ km/h
$L_{ref}^{(Dutch)}$	< 0.5	0.5	0.8
$L_{ref}^{(French-D)}$	0.6	1.1	1.6
$L_{ref}^{(French-0)}$	1.6	2.8	4.0

Tab. 4: Required texture length [m] to reach a 90 % confidence interval of ±1.0 $dB(A)$

Note If measurements are taken at 10 m interval using a static system with measurement length 1.2 m, the cumulated length for a 20 m section is 2 × 1.2 m. It is sufficient at $V = 50$ km/h for the 3 spectra, and at $V = 90$ km/h and $V = 130$ km/h for the Dutch and French dense spectra only.

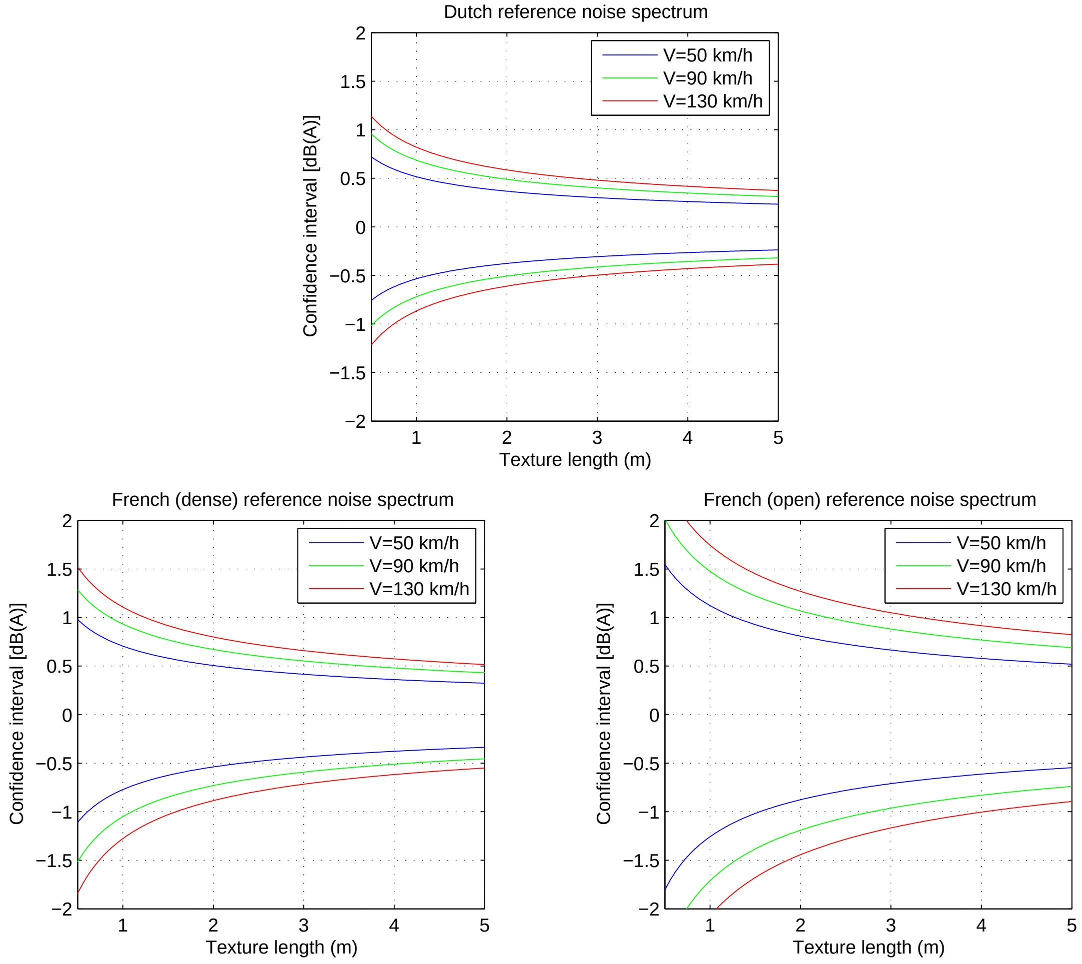

Fig. 2: Confidence interval (90 %) on the END_T vs. texture length

5 Conclusion

In this report one single number rating is proposed : the Estimated pass-by Noise level Difference from texture level variation of the road surface. It is given by

$$\begin{aligned} END_T &= 10\log\frac{\sum_i 10^{(L_{m_i}+b_i.\Delta L_{eT_i})/10}}{\sum_i 10^{L_{mi}/10}} && \text{(pervious surfaces)} \\ &= 10\log\frac{\sum_i 10^{(L_{m_i}+b_i.\Delta L_{eT_i})/10}}{\sum_i 10^{L_{mi}/10}} - .25\Delta L_{T_{5mm}} && \text{(impervious surfaces)} \end{aligned}$$

where

- L_{mi} is the third-octave noise level measured at the labelling,
- ΔL_{eT_i} the third-octave enveloped texture level difference at a given speed V between the enveloped texture measured at the labelling and the enveloped texture measured at the COP (envelopment parameter $E = 1$ MN/m2),

- b_i the coefficients given in table 2,
- $\Delta L_{T_{5mm}}$ is the texture level difference in the 5 mm wavelength octave band between the labelling and the COP.

An estimation of the confidence interval is also given; it depends on the length over which the profile is measured and on the used reference noise spectrum.

The END_T is appropriate for estimating the difference in pass-by noise resulting from a difference in enveloped texture level between 2 locations on a surface or between 2 realizations of the same product. It is thus adapted to checking the texture homogeneity of the road surface on the acoustic point of view, and to the Conformity of Production procedure.

Note It is recalled that this single number rating has been established based on a set of measured texture profiles which may not be representative of all road surface types and on noise data obtained by numerical simulation.

References

[1] U. Sandberg and J.A. Ejsmont. Tyre/road noise reference book. Informex, 2002.

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[5] J-F. Hamet and P. Klein. Round Robin Test - Texture measurement results - Spectra. *Technical Report SILVIA-INRETS-014-WP2*, INRETS, 2004.

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