CLOSE-PROXIMITY MEASUREMENT OF TIRE-PAVEMENT NOISE ON THE MINISTRY OF TRANSPORTATION OF QUEBEC'S ROAD NETWORK

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ABSTRACT: In the spring of 2005, the Ministry of Transportation of Quebec (MTQ) developed a road dynamic audiometer (RDA) in order to use the close-proximity (or CPX) method to measure the noise generated by the interaction of a vehicle tire on pavement. A condition survey was conducted on several pavement types using the RDA. Parts of this survey were carried out simultaneously using the NCAT-CPX trailer, in cooperation with Auburn University in Alabama. The sound pressure level readings were taken in order to evaluate the quality of the measurements obtained with the RDA, and to compare the results on various textures of Portland cement concrete (PCC) pavement and on hot-mix asphalt (HMA) overlays of various ages.

For surfaces that are 5 years old or less, PCC pavements are found to be noisier than asphalt pavements. The type of texturing used on PCC pavements has a significant effect on the tire-pavement noise that is generated. Although the sound pressure level is similar in certain cases, abrading, exposed aggregates, and longitudinal tining seem to reduce or eliminate the discrete frequency peaks around the 1000 Hz level that are associated with transverse tining and that are presumed to be more disturbing for neighbouring residents. Those results highlight the importance of analyzing the sound pressure level by frequency spectrum. Measurements carried out on a PCC pavement with a deep transverse tining also exhibit a reduction in tire-pavement noise of 3.7 dBA after resurfacing with HMA.

1. INTRODUCTION

In the spring of 2005, the Ministry of Transportation of Quebec (MTQ) developed a road dynamic audiometer (RDA) in order to use the close-proximity (or CPX) method to measure the noise generated by the action of a vehicle tire on pavement. A condition survey was conducted on the Quebec road network using the RDA. Parts of this survey were carried out simultaneously using the continuous measurement apparatus of the National Center for Asphalt Technology (the NCAT-CPX trailer), in cooperation with the Highway Research Center (HRC) of Auburn University in Alabama.

The sound pressure level readings were taken in order to evaluate the quality of the measurements obtained with the RDA, which has an open-air microphone configuration, by comparing them to the measurements taken using the NCAT-CPX trailer, whose microphones are isolated in an acoustic enclosure. The surveys were also intended to measure noise on Portland cement concrete (PCC) sections of various textures, as well as on hot-mix asphalt (HMA) of various gradations and ages. A frequency spectrum analysis based on these sound pressure level surveys made it possible to demonstrate the effect of wind, temperature, and the surface texture of the PCC on the sound pressure level by frequency. The frequency spectrum of a noisy PCC pavement with a HMA overlay was also analyzed.

2. TIRE-PAVEMENT NOISE

Sound is produced by fluctuations in air pressure, which generate longitudinal compression and dilatation waves of a given amplitude and frequency [1]. The amplitude, or sound pressure level (SPL), of a sound is generally measured using a logarithmic scale known as the decibel (dB) scale. The human ear can hear sounds between 0 dB and 120 dB. In order to take into account the fact that the human ear is not equally sensitive to all frequencies, the levels of each frequency band are adjusted with the A-filter, which is denoted as dBA. This scale is commonly used in tire-pavement noise measurement.

When several noise sources are present, it is not possible to simply sum the sound pressure levels. For example, combining the noise from two 70-dBA point sources produces the equivalent of 73 dBA. For a linear noise source such as road traffic, the sound is attenuated by approximately 3 dBA when the distance between the source and the measurement point is doubled. In addition, doubling the volume of traffic is equivalent to increasing the noise measured on the side of a roadway by approximately 3 dBA.

At high speed, the noise caused by tire-pavement interaction predominates over noises of mechanical origin. The mechanisms associated with tire-pavement noise are complex, and can be categorized as follows: radial vibrations, tangential vibrations, suction, and air pumping [1]. Radial vibrations result from the impact of the tire on irregularities in the pavement. Tangential vibrations are caused by adhesion and slippage of the tire on the pavement. Suction noise is created when the adhesion of the tire to the pavement is broken. Finally, the compression and release of the air trapped in the tire cavities create air pumping. These vibrational and aerodynamic phenomena generate sounds of various frequencies.

The noise generated by the tire-pavement interaction is amplified by the reflection of the sound in the cavity formed between the surface of the rolling tire and the pavement (horn effect) [1]. The resonance of the air trapped inside the tire and in the tire cavities (Helmhotz resonance) can also amplify the sound. Conversely, a porous pavement surface with interconnected air voids reduces the quantity of trapped air between the tire and the pavement, and allows for better absorption and dispersion of sound.

It is well known that the frequency spectrum associated with tire-pavement noise exhibits a pronounced peak between 700 and 1300 Hz [1, 2, 3]. This peak can be accounted for by a number of factors that act on these frequencies: the A filter, tire tread patterns, radial and tangential vibrations, amplification mechanisms, the surface texture of the road, etc. The peak is more prominent for cars than for heavy trucks [2]. In addition, the shape of the frequency spectrum is similar for a wide range of tire and surface types, and the tire-pavement noise is often concentrated around the peak at 800-1000 Hz.

It was observed that the frequencies that are affected by wind are below 1000 Hz [1]. Despite the fact that tire-pavement noise specifically affects the frequency range between 315 and 4000 Hz, wind has a significant effect between 315 and 1000 Hz. On the other hand, the effect of pavement temperature on tire-pavement noise measurements is strongest for the higher frequencies, between 1000 and 4000 Hz.

When the frequency spectrum is presented in narrow bands (e.g.: 1/12 octave bands), it can be observed that this peak is not caused by a single tone, but by several tones or minor peaks concentrated in the same area [2]. This is typical of a random geometry in the tire tread pattern. Finally, the passage of a tire from a noisy surface to a quieter porous surface often results in a shift of the peak from 1000 Hz toward 600-800 Hz, and gives rise to a reduction in the sound pressure level of the peak [2].

3. METHODOLOGY

In accordance with the draft ISO/CD 11819-2 standard on close-proximity measurement of tire-pavement noise [4], three microphones arranged at angles of 45°, 90°, and 135° to the direction of travel are mounted on a minivan, near the tire-pavement interface, in order to measure the sound pressure level under real driving conditions (Figures 1 and 2). The close-proximity method is well suited for comparing different pavement textures. In addition, it is quick, and it offers good repeatability.

Unlike pass-by methods of measurement carried out on the side of the roadway, the close-proximity method does not take sound propagation in the surrounding area into account, and represents the noise generated by the tires of a reference vehicle rather than a heavy vehicle. The measurement is relative, because the sound sensors are in the open air rather than in a controlled environment and isolated from external noise.


Figure 1 – The road dynamic audiometer (RDA)


Figure 2 – Arrangement of microphones on the RDA (Uniroyal Tiger Paw All-Season tire; tread depth: 6 mm; tire pressure: 240 kPa)

Only frequencies between 315 Hz and 4000 Hz are retained for analysis. In order to apply the weighting factors for the A filter, the original signal is broken down into standardized frequency bands (1/3 octaves).

The sum of the 1/3-octave bands is used to obtain the value of the segment surveyed in dBA. The root mean square value for each of the digital signals (44,100 values per second) is calculated for 20 m segments, as recommended in the draft ISO standard. A correction factor is then applied in order to take into account minor variations in vehicle speed (reference: 100 km/h) and pavement temperature (reference: 20°C), as recommended in the draft standard. The next step is to calculate the arithmetic average of the data recorded by the three microphones, and then the mean of all the segments in the sector under study, in order to obtain a mean value for the sound pressure level in dBA. The algorithm used to obtain the frequency spectrum from the original signal as a function of time is a Fourier transform (FFT).

The RDA was used on the MTQ road network in 2005 in order to evaluate the sound pressure level on more than 30 sections of flexible and rigid pavements. These sections, which vary in length from 500 m to more than 6 km, included recent PCC pavements (5 years old or less) with a variety of surface textures (transverse tining, longitudinal tining, abrading, exposed aggregate) and HMA overlay pavements between 0 and 10 years old (ultra-thin and thin gap-graded HMA, stone matrix asphalt, dense-graded HMA). At least two passes were systematically carried out on each test section.

Some of these surveys were also carried out simultaneously using the NCAT-CPX trailer, in cooperation with Auburn University, in order to compare the open-air measurements with those done in an acoustic enclosure. The characteristics of the NCAT-CPX trailer are described in the references [5, 6]. The sound pressure level of a PCC highway with 6 lanes with a deep transverse tining texture that is considered to be noisy for the neighbouring residents was also evaluated before and after resurfacing with HMA.

4. RESULTS

The noise surveys carried out on HMA pavements and on PCC pavements are presented in Tables 1 and 2, respectively, in decreasing order of sound pressure level. Surveys that were carried out with wind speeds in excess of 20 km/h bear the annotation “wind gusts”. These results should be considered with caution, because the draft ISO standard recommends that testing using open-air microphones not be conducted when the wind speed exceeds 15 km/h. This will be dealt with in greater detail in Section 5.3. The shaded lines in Table 2 show sections with sound pressure levels that are too high, according to earlier surveys carried out using the NCAT-CPX trailer in 2004 [5], and are not included in the overall analysis. However, they are considered separately in Section 5.5.

Table 1 – Comparison of sound pressure levels of various HMA overlays (in decreasing order of sound pressure level)

No.	Location	Type of pavement and texture	Year of construction	Surface temp. (°C)	Mean sound pressure level (dBA)	Stand. dev.
C1	A-20 St-Jean-Port Joli	Ultra-thin gap-graded HMA, 15 mm thick, cracking with presence of sealant, depressed transverse cracks creating bumps.	1998	21	109.9	0.24
C3	A-20 Berthier-sur-mer	Stone matrix asphalt (SMA). Presence of crack sealing.	2002	21	109.8	0.35
B4	A-15 Montréal	Old HMA overlay in good condition over jointed plan concrete pavement (JPCP)	1994-1995	30	109.3	0.38
C2	A-20 Cap-St-Ignace	EGA-10 HMA. No surface defects.	2004	21	108.2	0.21
C12	R-112 Bury	Stone matrix asphalt (SMA), no cracks. **Wind gusts.**	2004	15	108.0	0.44
A2	A-50 Mirabel	EG-10 HMA (46 mm) over EB-10C HMA (29 mm)	2004	40 10 (wind)	107.8 (108.7)	0.44 (0.40)
A3	A-640 St-Eustache	Thin gap-graded HMA, 25-30 mm thick. Performance contract.	2004	38	107.8	0.47
A6	A-15 Décarie	Steel-slag EG-10 HMA (50 mm) over EB-10C HMA (25 mm) over jointed plain concrete pavement (JPCP).	2003	17	107.4	0.34
C7	A-15 Boisbriand (1)	EG-10 HMA (50 mm) over jointed plain concrete pavement (JPCP) with very deep transverse tining.	2005	14	107.3	0.32
A4	A-15 Laval	EG-10 HMA.	2004	14	107.0	0.61
A5	A-13 Dorval	EG-10 HMA (50 mm) over jointed plain concrete pavement (JPCP).	2004	33	106.3	0.28
A1	A-50 Lachute	EG-10 HMA (42 mm) over EB-20 HMA (50 mm)	2004	48	105.1	0.42

(1) Average of 6 full travel lanes over 6 km.

Table 2 – Comparison of sound pressure levels of various PCC pavements (in decreasing order of sound pressure level)

No	Location	Type of pavement and texture	Year of construction	Surface temp. (°C)	Sound pressure level (dBA) (2)	Stand. dev.
C16	A-40 West Montréal	Diagonal random transverse tining on continuously reinforced concrete pavement (CRCP). Tining depth: 6 mm. Contract #1. **Wind gusts.**	2004	10	112.5	0.61
C13	A-40 West Montréal	Diagonal random transverse tining on CRCP. Tining depth: 6 mm. Contract #2. **Wind gusts.**	2004	10	112.2	1.0
C9	A-40 Anjou	Steel ball abrading on jointed plain concrete pavement (JPCP). Cyenite aggregate. **Wind gusts.**	2005	11	112.1	0.45
C10	A-40 Anjou	Steel ball abrading on JPCP. Granite aggregate. **Wind gusts.**	2005	11	111.7	0.41
B2	A-20 Boucherville	Diagonal random transverse tining on JPCP. Tining depth: 10 mm.	2002	28	111.4	0.77
B5a	A-15 Boisbriand(1)	Diagonal random transverse tining on JPCP. Tining depth: 10 mm. Noise problem for neighbouring residents.	2002	16	111.0	0.87
C15	A-40 West Montréal	5-20 mm exposed aggregate on CRCP. Contract #1. **Wind gusts.**	2004	10	110.5	0.29
B1	A-15/132 La Prairie	Diagonal random transverse tining on JPCP. Tining depth: 6 mm. Presence of short diamond ground sections.	2002-2004	38 10 (wind)	110.1 (112.0)	1.3 (1.2)
B6	A-40 Anjou	Steel ball abrading on JPCP.	2005	29	109.9	0.54
C14	A-40 West Montréal	5-14 mm exposed aggregate on CRCP. Contract #2. **Wind gusts.**	2004	10	109.9	0.37
C4	A-15 Montréal	Steel ball abrading aged 1 to 2 weeks on JPCP.	2005	15	109.7	0.43
B3	A-13 Laval	Perpendicular random transverse tining on JPCP, extremely worn grooves	2000	31	109.4	0.50
B5b	A-15 Boisbriand	Microgrinding on very deep (10 mm) transverse tining on JPCP (last km of lane 1 north)	2005	14	109.4	0.51
C12	A-40 West Montréal	Longitudinal tining on CRCP. Contract #2**. Wind gusts**.	2004	10	109.3	0.42
C6	A-40 Saint-Laurent	Diagonal random transverse tining on new CRCP (2005). Tining depth: 3 mm **Wind gusts.**	2005	12	109.1	0.69
C8	A-10 Brossard	Diagonal random transverse tining on CRCP. Tining depth: 3 mm.	2005	14	108.9	0.45
C5	A-40 Saint-Laurent	Steel ball abrading on new CRCP (2005). **Wind gusts.**	2005	12	108.8	0.47

(1) Average of the 7 travel lanes minus the asphalt-overlay viaduct, except L1 south, 2nd pass excluded.

(2) The shaded surveys are excluded from the overall analysis because the wind effect was too pronounced.

5. ANALYSIS

5.1 Rigid pavements versus flexible pavements

The results presented in Tables 1 and 2 (excluding the shaded surveys, which were conducted with wind speeds exceeding 15 km/h) reveal that, in the case of new pavements, PCC sections are noisier than HMA sections. For PCC sections that are 5 years old or less, the sound pressure levels are between 108.8 dBA and 111.4 dBA. For HMA sections that are 2 years old or less, the sound pressure levels lie between 105.1 dBA and 108.2 dBA. HMA that are between 7 and 10 years old present sound pressure levels ranging from 109.3 dBA to 109.9 dBA. It is a recognized phenomenon that noise levels for HMA overlays increase over time, due to clogging of surface pores and the appearance of cracks. For PCC, abrasion of the surface texture over time helps to reduce tire-pavement noise. In the Québec context, these factors require further evaluation through periodic surveys in the coming years.

5.2 NCAT-CPX and RDA comparison

As discussed earlier, some of the work during the 2005 survey was carried out simultaneously (i.e.: under the same atmospheric and ambient-noise conditions) using the NCAT-CPX close-proximity trailer and the RDA.

Although both apparatuses meet the requirements of the draft ISO standard on the close proximity (or CPX) method, there are differences between them. The most significant difference relates to control of the ambient noise outside the vehicle. The microphones of the NCAT-CPX trailer are isolated in an acoustic enclosure mounted on a trailer, which makes it possible to eliminate external noises that are not caused by tire-pavement contact. [5, 6].

The microphones on the RDA are mounted near the left rear wheel of the vehicle, and in the open air, rather than in a closed environment that is cut off from external noise (see Figure 1). However, these microphones are unidirectional, and capture the sounds that are produced directly in line with the microphone. They have limited sensitivity to sounds coming from the sides, and a protective foam covering helps to attenuate wind noise. Nevertheless, the draft ISO standard stipulates that the external noise from the vehicle or the surrounding traffic must not exceed 6 dB in the 500-4000 Hz frequency range in 1/3-octave bands, and 4 dB in the 315-400 Hz range [4]. This corresponds to approximately 10 dBA for the total mean value, including all octave bands.

Figure 3 compares the sound pressure levels that were measured simultaneously by the RDA and by the NCAT-CPX trailer. Although the values from one apparatus to the other cannot be compared, the rankings of the test sites from noisiest to least noisy are similar. PCC pavements with deep transverse tining rank highest. Mixed pavements, or in other words, jointed plain concrete pavement with a HMA overlay (sections B4 and A6), are rated as noisier by the NCAT-CPX relative to the other HMA pavement sections. All of the HMA pavements rank at the bottom of the list, with sound pressure levels ranging from 97.4 dBA to 95.3 dBA, with the least noisy being the EG-10 HMA on A-50 in Lachute (A1). This segment also ranks as the quietest in the RDA surveys.

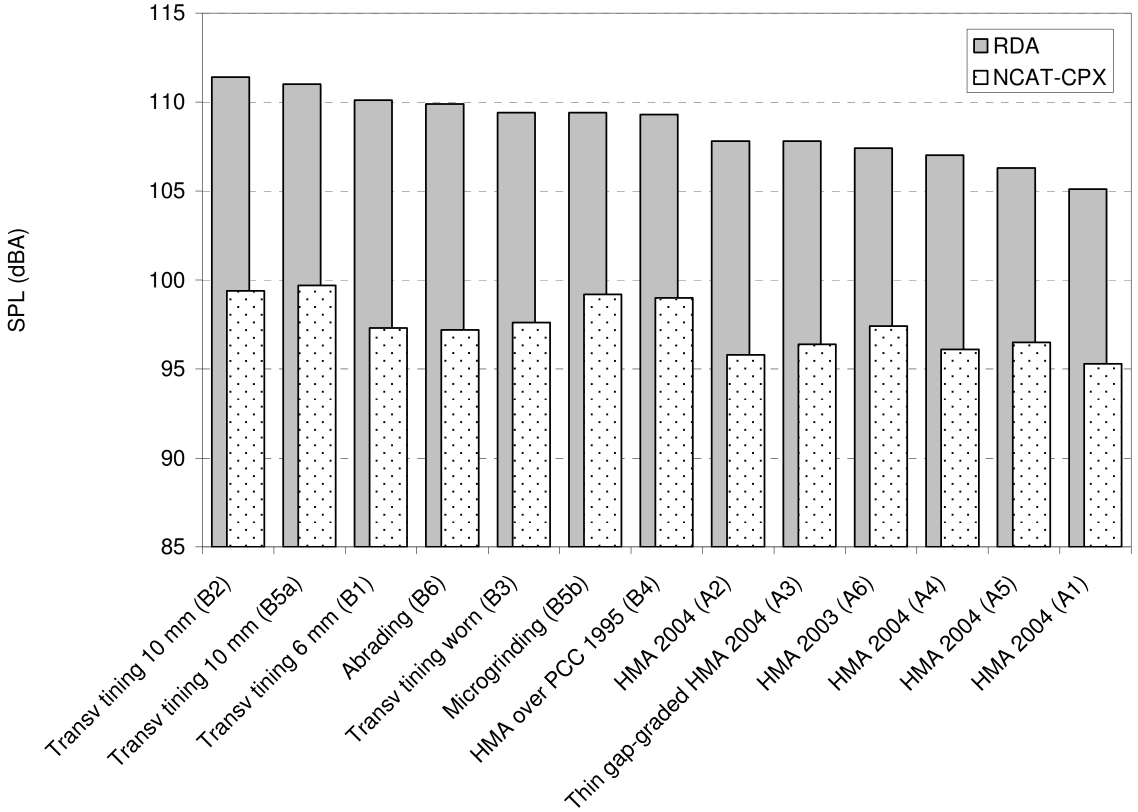

Figure 3 – Comparison of sound pressure level measurements using the NCAT-CPX trailer with an acoustic enclosure and open-air measurements using the RDA. Mean difference: 11 dBA

The difference between the sound pressure levels measured using the NCAT-CPX trailer and those measured using the RDA ranges from 10 dBA to 12.8 dBA, which largely represents the ambient noise that is taken into account by the RDA. This seems to be consistent with the value of 10 dBA that is prescribed by the draft ISO standard as being acceptable for ambient noise when no acoustic enclosure is used.

There are other factors that may explain the difference in the sound pressure levels measured by the two types of equipment, to a lesser extent. The NCAT-CPX trailer uses 50 m measurement segments, compared to the 20 m segments used by the RDA. Calculating the mean noise over a greater distance mitigates the effect of isolated surface defects such as cracks. Also, the tread pattern and tread depth of the reference tire also differ between the two apparatuses.

5.3 Wind effect

Among other things, the numerous surveys carried out on section C7 after HMA resurfacing of the PCC slabs demonstrated the effect of wind on the measurement of sound pressure levels. Environment Canada data showed that the wind speed (on an hourly basis) exceeded 20 km/h at the time of some of the surveys on the new HMA. The draft ISO standard recommends that testing not be conducted using open-air microphones when the wind speed exceeds 15 km/h.

Depending on the lane and the direction of travel surveyed, it was observed that a wind speed in excess of 20 km/h could increase the mean sound pressure level by 1.5 dBA (lane 2 northbound) or reduce it by 0.5 dBA (lane 3 southbound) relative to a survey under windless conditions.

Figure 4 presents the average frequency spectrum of the surveys conducted in lane 3 southbound (downwind) and in lane 2 northbound (upwind). These two lanes have identical pavements, and therefore, the difference in the frequency spectrum is due solely to the noise caused by the wind on the microphones. It can be observed that the frequencies most affected by wind are those below 1000 Hz. This is consistent with the results presented in reference [1]. In light of this, it is important to make every effort to ensure that surveys are carried out when the wind speed is lower than 15 km/h.

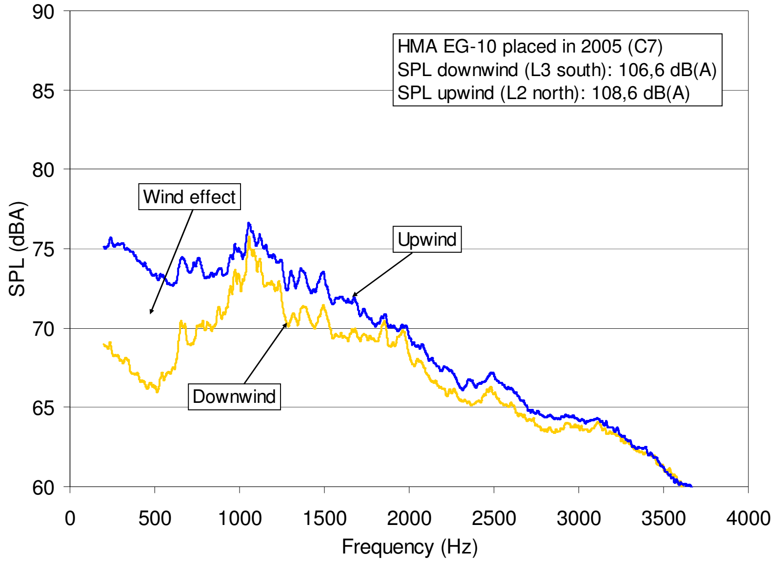

Figure 4 – Effect of wind on the frequency spectrum of the sound pressure level of a HMA

5.4 Effect of temperature

The mechanisms that explain the effect of pavement temperature on the measurement of sound pressure levels are not well understood [1]. In addition, the correction equations in the literature vary widely. In general, the relationship between sound pressure level and temperature is linear. Rough textures are more affected by temperature variations than smooth textures, with a reduction of 2 dBA to 4 dBA for each increase of 30°C. The type of tire used also affects this relationship.

Surveys were carried out on the PCC section B1 and on the HMA section A2 at two pavement temperature, 40° and 10°C. This was done in order to validate the sound pressure level correction for a temperature of 20°C, as represented by the following equation [1]:

$$\mathrm{Lcorr}\,(\theta\mathrm{ref}) = \mathrm{Lmean}(\theta) + K(\theta\mathrm{ref}-\theta) \tag{1}$$

where: Lcorr (θref): corrected reading in dBA
Lmean (θ): mean reading in dBA
θ: pavement temperature in °C
θref: reference temperature, 20°C
K: temperature coefficient, passenger car
where: $K = -0.03$ dBA/°C if $\theta > 20$°C
$K = -0.06$ dBA/°C if $\theta < 20$°C

Table 3 presents the results for the sound pressure levels. The ratios of the difference for the sound pressure level over the difference in temperature obtained for PCC (-0.11 dBA/°C) and for HMA (-0.078 dBA/°C) are high compared to the values found in the literature [1]. The authors state that the ratio should lie between –0.03 and –0.09 dBA/°C for automobile tires. A higher ratio is observed for PCC, which has a rougher texture. It should also be noted that wind gusts were observed during the surveys at 10° and 13°C, which may have increased the sound pressure level.

Table 3 – Effect of pavement temperature on sound pressure levels

	Temperature (°C)	Sound pressure level (dBA)	Difference
Concrete cement (section B1)	38	109.5	ΔT=28 ΔdBA=3.2 -0.11 dBA/°C
	10 (wind gusts)	112.7	
EG-10 HMA (section A1)	40	107.0	ΔT=27 ΔdBA=2.1 -0.078 dBA/°C
	13 (wind gusts)	109.1	

The temperature effect is greater for higher frequencies, between 1000 and 4000 Hz [1]. The frequency spectra for sections B1 (PCC) and A2 (HMA) shown in Figures 5 and 6 are consistent with this.

In light of these initial findings pertaining to the effect of pavement temperature, equation 1, which is recommended in the draft ISO standard, does not seem to reflect conditions in Québec. Additional surveys will be carried out in 2006 in order to determine a more appropriate relationship.

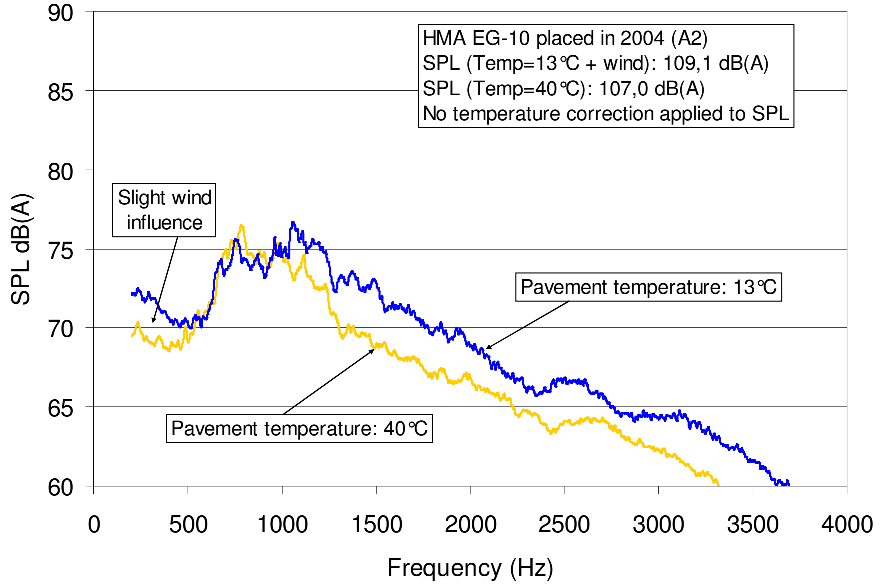

Figure 5 – Effect of pavement temperature on the frequency spectrum of a HMA overlay (section A2)

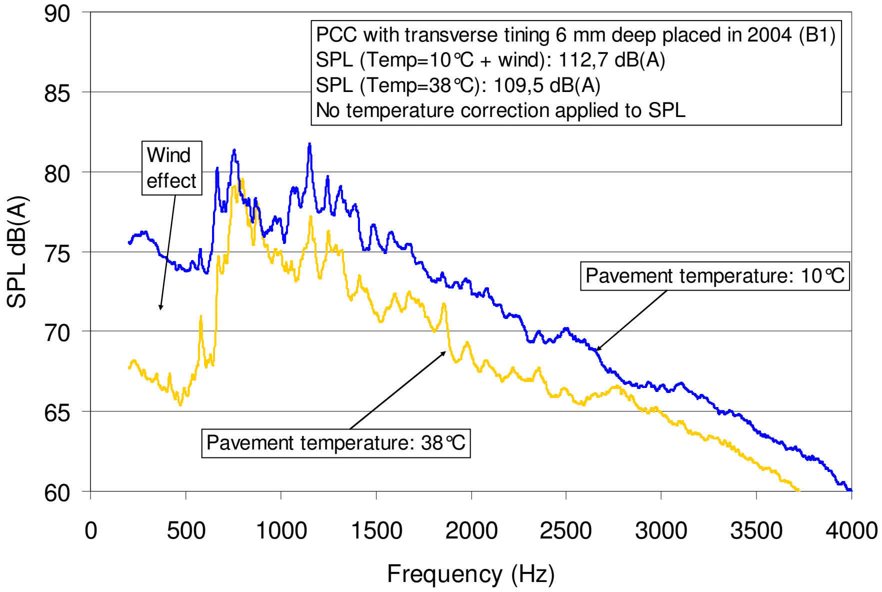

Figure 6- Effect of pavement temperature on the frequency spectrum of a PCC pavement (section B1)

5.5 PCC texture

The method currently used by the MTQ to texture fresh concrete is randomly spaced transverse tining, either perpendicular or diagonal to the direction of traffic [7]. Texturing of hardened concrete by diamond grinding or by abrading (steel ball blasting) is also used for the purpose of correcting evenness or restoring lost adhesion. Two other techniques (chemical stripping of surface aggregates or exposed aggregates and longitudinal tining) were used on an experimental basis in 2003 and 2004, and are currently being evaluated.

It is a recognized fact that transverse tining produces high noise levels when the grooves are wide, deep, and uniformly spaced [3]. The transverse tining used by the MTQ in 2002 and 2003 was randomly spaced, but quite deep (approximately 10 mm). Beginning in 2004, the groove depth was reduced in order to conform to MTQ standards, which specifies a width of 3 mm and a depth between 3 mm and 6 mm. For highways built in 2005, the grooves are 3 mm wide and 3 mm deep.

Excluding the surveys in Table 2 where the wind speed exceeds 15 km/h, we can see that the deep transverse tining used between 2002 and 2003 is the noisiest texture, with values between 111.0 dBA and 111.4 dBA. Beginning in 2004, the values for the shallow transverse tining range from 107.9 dBA to 110.1 dBA. The sections where abrading was used have sound pressure levels ranging from 108.4 dBA to 109.9 dBA. By comparison, longitudinal tining exhibits a sound pressure level of 109.3 dBA; the 5/20 mm exposed aggregate exhibits a sound pressure level of 110.5 dBA; and the 5/14 mm exposed aggregate exhibits a sound pressure level of 109.9 dBA. These differences are consistent with the surveys that were carried out on these sections in 2005 using the NCAT-CPX trailer, as presented in Figure 3.

Figure 7 compares the frequency spectra of all of the sections with transverse tining as a function of mean groove depth. For all sections, significant tonal peaks are observed between 700 Hz and 1000 Hz. The deeper the grooves, the more pronounced the peaks, and the higher the mean sound pressure level.

A comparison was also made of contiguous sections of a given PCC pavement that was texturized by abrading (C5) and by transverse tining (C6), because the ambient conditions during the survey are identical (Figure 8). This transverse tining, which was carried out in 2005, is relatively fine, with a groove depth of approximately 3 mm. Although the two techniques result in similar mean sound pressure levels, a small localized peak at 1000 Hz that is observed in the case of the transverse tining is not present at this frequency for abrading.

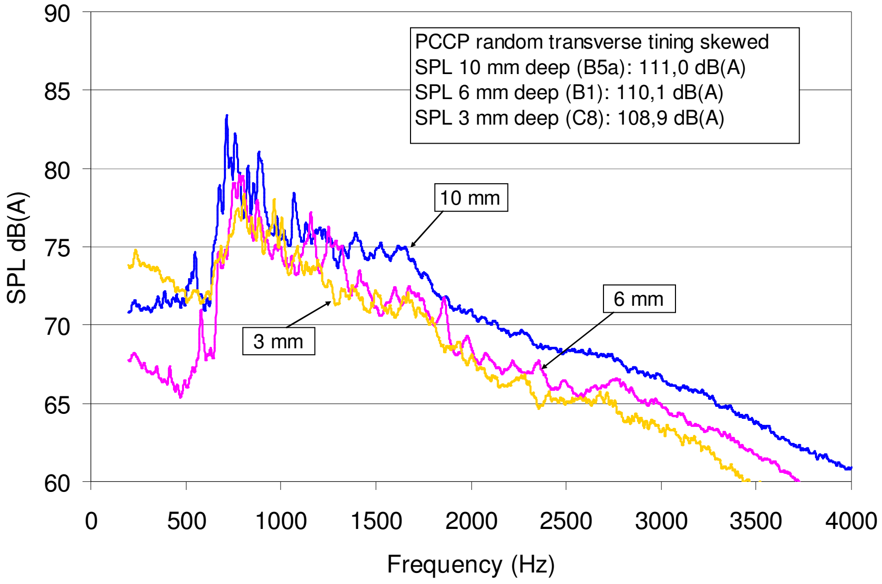

Figure 7 – Effect of the transverse tining depth of a PCC pavement on the frequency spectrum

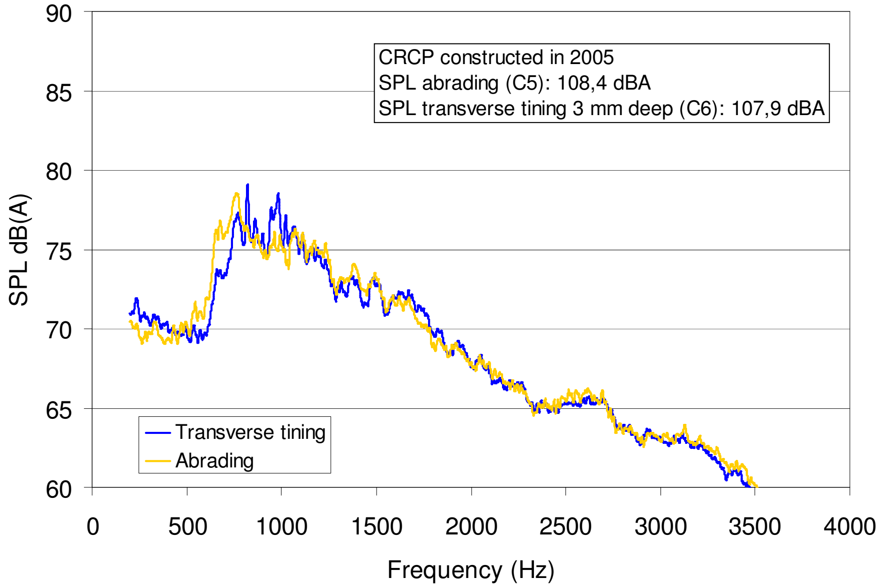

Figure 8 – Comparison of the frequency spectrum between abrading and transverse tining on two contiguous roadway CRCP sections

Tire-pavement noise measurements were also carried out on a contiguous continuously reinforced concrete pavement (CRCP) that was texturized on an experimental basis by chemical stripping (exposed aggregates) and by longitudinal tining. An adjacent section with transverse tining allows for comparison of sound pressure levels under identical survey conditions. The frequency spectrum for each texture is presented in Figure 9. We can see the similar shape of the spectrum and the absence of the localized peak at 1000 Hz for the exposed aggregates and the longitudinal tining. The sound pressure level for transverse tining differs by 2.3 dBA from that for exposed aggregates, and by 2.9 dBA from that for longitudinal tining.

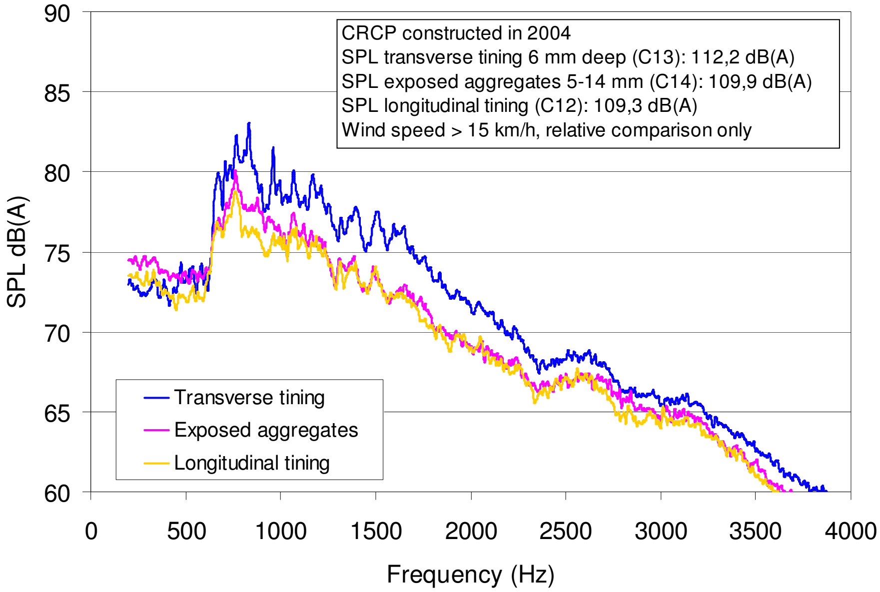

Figure 9 – Comparison of frequency spectra for transverse tining, exposed aggregates, and longitudinal tining on three contiguous PCC sections

The texture of the PCC sections surveyed using the NCAT-CPX trailer was also measured using a high-frequency single-scanning laser mounted on Auburn University's ARAN vehicle. These measurements were carried out in the right wheelpath. The relationship between the texture measurement of the PCC (mean texture depth) and the sound pressure level is shown in Figure 10. This graph also includes the MTQ PCC pavements that were surveyed using the NCAT-CPX trailer in 2004 [5]. It can be observed that, in the case of a PCC pavement, the greater the texture depth, the higher the sound pressure level.

5.6 Characteristics of HMA

It is well known that the gradation of an HMA overlay has a significant effect on tire-pavement noise. For example, thanks to their highly discontinuous gradation and the numerous and interconnected surface voids, open-graded pavements are less noisy. Air compressed by the tires of moving vehicles escapes more easily, with the result that the tires are subjected to fewer stresses, vibrate less, and generate less noise [1]. The age of a pavement is also an important noise factor. Over the years, the pores become obstructed, and surface distresses appear (cracks, ravelling, etc.).

The gradation curves for 9 of the 12 HMA tested are shown in Figure 11. The sound pressure levels for these HMA range from 105.1 dBA to 109.9 dBA. These HMA are all one-year old, with the exception of the seven-year old ultra-thin gap-graded HMA with numerous transverse cracks and the EG-10 dense-graded HMA that was placed in 2005, a few weeks before the noise measurements were taken.

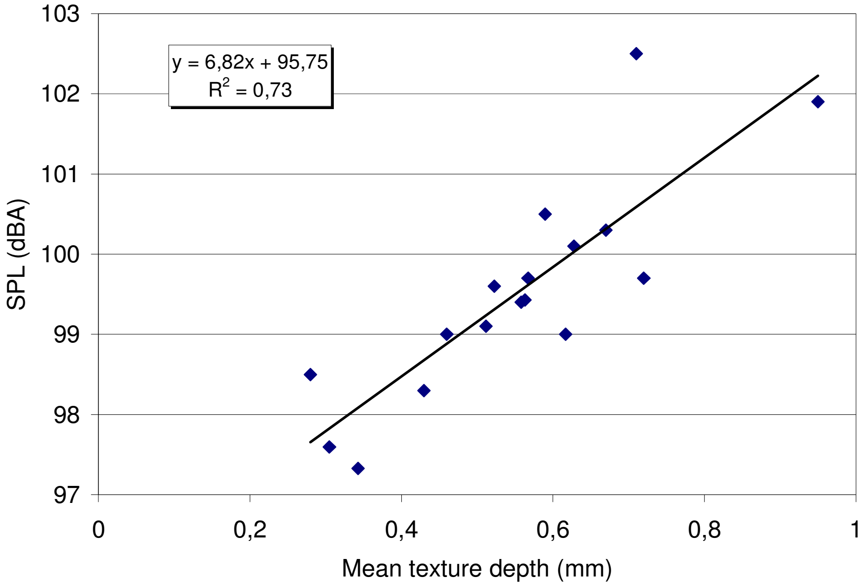

Figure 10 – Relationship between sound pressure level and texture in PCC pavements

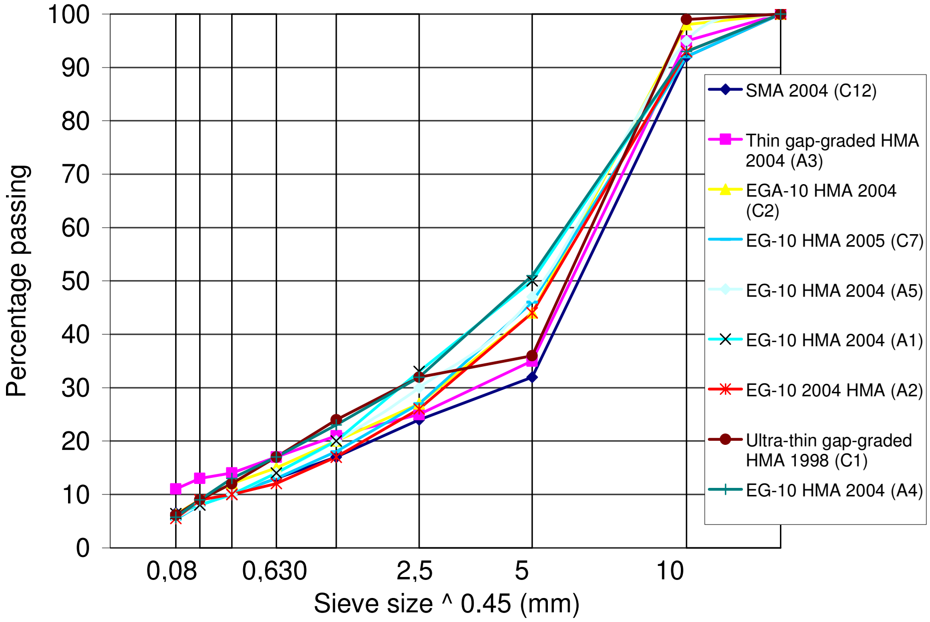

Figure 11 – Gradation curves for 9 of the 12 HMA sections

All of the HMA overlays tested have what is known as a negative texture. In the case of negative textures, the surfaces of pavements compacted using a smooth steel roller present aggregates that are all of the same grade, unlike so-called positive surfaces where the surfaces are irregular, as is the case with bituminous surface treatments. In addition, all of the HMA tested are based on aggregates with a nominal maximum particle size of 10 mm. The percentages of the aggregates passing the 5 mm sieve vary between 32% and 50%.

To begin with, and for the purpose of explaining the differences in noise level at the tire-pavement interface between the HMA overlays tested, Figure 12 presents the sound pressure level as a function of the coarse aggregate ratio (CA ratio), which is used to describe the extent of clogging of the coarse aggregates and voids in the coarse aggregate skeleton. For HMA with a maximum aggregate size of 10 mm, the CA ratio is defined using the Bailey method for optimization of HMA gradations [8], according to the following equation:

CA ratio = (% passing 5mm sieve - % passing 2.5mm sieve)/(100 – % passing 5mm sieve) (2)

The lower the CA ratio, the more open-graded and draining the asphalt, the more discontinuous its gradation curve, and the higher its porosity. In theory, a low CA ratio should result in measured noise values that are lower than those for HMA with higher CA ratio values. This is not the case in Figure 12. The limited sample of HMA tested, the inclusion of two fibre-reinforced HMA (EGA-10 and SMA-10) with a high mastic content that is capable of blocking the pavement pores, and a severely cracked ultra-thin HMA contribute to masking a possible pattern. In addition, there are a number of factors that can affect measured noise levels, including the smoothness of the pavement surface, the shape of the coarse aggregates and their arrangement at the pavement surface, and the packing density. These factors will be taken into account in the continuation of this study.

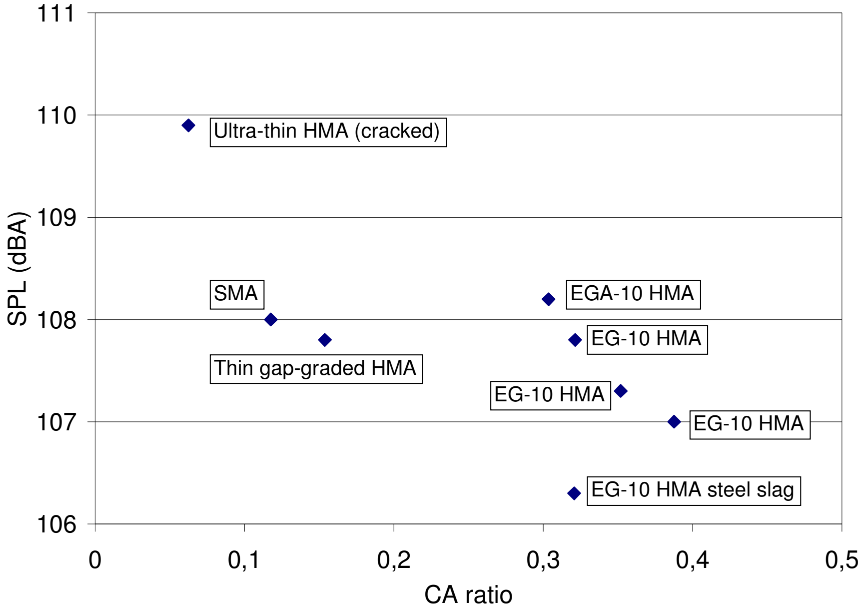

Figure 12 – Relationship between the sound pressure level and the coarse aggregate ratio

5.7 Asphalt resurfacing of a noisy cement concrete pavement

Noise measurements were taken with the RDA on highway 15 in Boisbriand/Sainte-Thérèse. These surveys were carried out in order to evaluate the difference in the sound pressure level before and after placement of an HMA overlay to cover a Portland cement concrete pavement textured by deep transverse tining (sections B5a, B5b, and C7).

Prior to the HMA resurfacing, the transverse grooves had undergone shallow diamond grinding in order to reduce the noise affecting neighbouring residents along a section of approximately 1 km long in the northbound slow lane. However, this microgrinding did not completely eliminate the transverse grooves. The RDA surveys showed that the characteristic frequency peaks of transverse grooves were still present (Figure 13), and that the sound pressure level was only reduced by 1.6 dBA (Figure 14). Because this improvement was not sufficient, the entire PCC pavement was resurfaced with EG-10 dense-graded HMA. This completely eliminated the peaks, and reduced the mean sound pressure level at the tire-pavement interface by 3.7 dBA compared to the deep transverse tining, and by 2.1 dBA compared to the microgrinding.

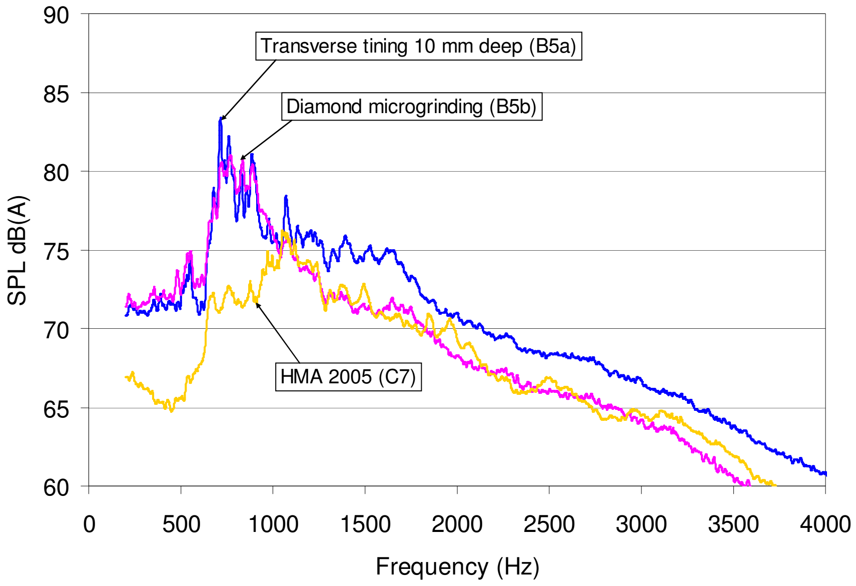

Figure 13 – Frequency spectra before and after resurfacing of a noisy PCC pavement

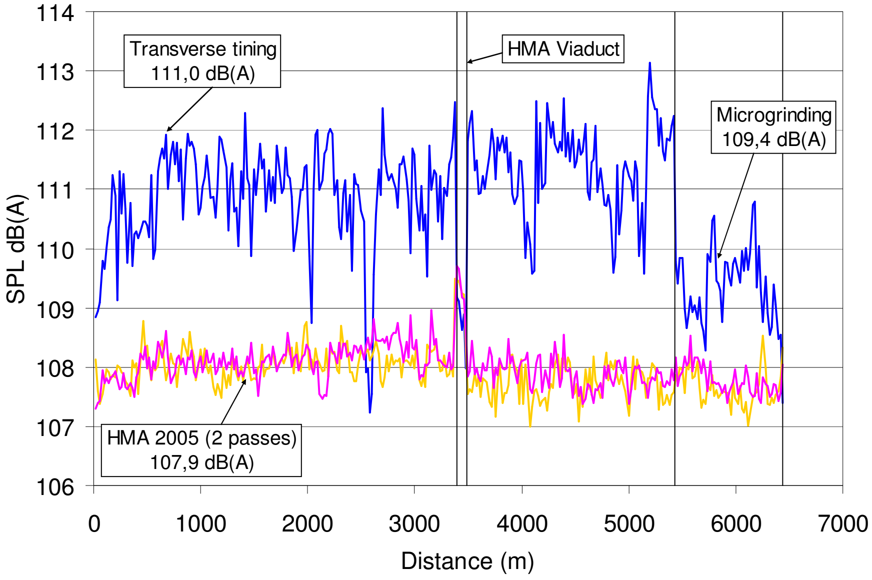

Figure 14 – Sound pressure level before and after resurfacing of a noisy PCC pavement (lane 1 northbound)

6. CONCLUSION

In the spring of 2005, the Ministry of Transportation of Quebec (MTQ) developed a road dynamic audiometer (RDA) according to the specifications of draft ISO standard/CD 11819-2 on close proximity measurement of tire-pavement noise. A survey campaign that was conducted in part using the NCAT-CPX trailer, in cooperation with Auburn University, made it possible to measure the sound pressure levels of a number of pavement types within the Québec road network. Despite the MTQ's limited experience with close proximity measurement of tire-pavement noise, the following findings were noted:

- In general, in the case of newer pavements, it was observed that PCC pavement sections are noisier than HMA pavement sections. Sound pressure levels for PCC sections that are 5 years old or less are between 108.8 dBA and 111.4 dBA. Sound pressure levels for HMA sections that were placed in 2004 and 2005 range from 105.1 dBA to 108.2 dBA.
- The results obtained using the NCAT-CPX trailer in the 2005 survey are comparable to the results obtained using the RDA in terms of the noise rankings of the test sections, as well as the differences in sound pressure level. This confirms the quality of the RDA measurements. The differences between the sound pressure levels measured by the open-air microphones of the RDA and those measured by the microphones of the NCAT-CPX using an acoustic enclosure lie between 10 dBA and 12.8 dBA.
- For an hourly wind speed of 20 km/h, the tire-pavement noise measured using the RDA can be artificially increased by 1.5 dBA or decreased by 0.5 dBA, depending on the direction of measurement. It is very important to ensure that surveys are only carried out when the wind speed is lower than 15 km/h.
- In light of the initial findings with respect to the effect of pavement temperature, equation 1 that is recommended in the draft ISO standard does not seem to reflect conditions in Québec.
- All of the PCC pavements with transverse-tining textures exhibit significant tonal peaks between 700 Hz and 1000 Hz. The deeper the grooves, the more pronounced the peaks, and the greater the mean sound pressure level on the test section.
- PCC pavements that are texturized by abrading, exposed aggregates, longitudinal tining, and fine transverse tining (3 mm in depth) tend to be quieter than those with the deep transverse tining (6 to 10 mm in depth) that was used in 2002 and 2003. In addition, these textures seem to attenuate the frequency peaks, which are presumed to be disturbing for neighbouring residents.
- It was not possible to establish a clear relationship between the coarse aggregate ratio (CA ratio) characterizing the voids in the coarse aggregate skeleton and the noise measured on HMA. However, in theory, a low CA ratio on an open-graded asphalt should result in lower noise levels.
- Microgrinding of a noisy PCC pavement section texturized by deep transverse tining (about 10 mm) failed to completely eliminate the transverse grooves, with the result that the frequency peaks that are characteristic of transverse tining were still present, and the sound pressure level was only reduced by 1.6 dBA. Resurfacing of the concrete slabs with EG-10 HMA succeeded in completely eliminating these peaks and reducing the mean sound pressure level by 3.7 dBA.

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REFERENCES

[1] Sandberg, U., Ejsmont, J. A. (2002), Tyre/road noise reference book. Published by Informex, Sweden, 616 pages.

[2] Sandberg, U. (2003), The multi-coincidence peak around 1000 Hz in tyre/road noise spectra. Paper presented at Euronoise 2003, Naples, Italy, Paper ID 498, 8 pages.

[3] Hoerner, T. E., Smith, K. D., Larson, R. M., Swanlund, M. E. (2003), Current practice of PCC pavement texturing. Paper presented at the 82nd Annual Meeting of the TRB, January 12-16, 2003, Washington, D.C., 19 pages.

[4] International Organization for Standardization (2000), Method for measuring the influence of road surfaces on traffic noise—Part 2: The close-proximity method, Draft Standard ISO/CD 11819-2, Geneva, Switzerland: ISO/TC 43/SC 1/WG 33, December 2000.

[5] Carter, A., Stroup-Gardiner, M. (2005), Field noise and texture evaluation of different pavement surfaces. Final report for phase I. Prepared for MTQ by Highway Research Center, Harbert Engineering Center, Auburn University, Alabama, February 8, 2005, 50 pages.

[6] Bennert, T., Hanson, D., Maher, A., Vitillo, N. (2005), Influence of pavement surface type on tire/pavement generated noise. Journal of Testing and Evaluation, March 2005, No. 2, ASTM publication, 7 pages.

[7] Thébeau, D. (2005), Techniques de texturisation des chaussées en béton de ciment. [Texturizing methods for cement concrete pavements] Bulletin d'information technique InfoDLC [InfoDLC Technical Information Bulletin], Vol. 10, no. 10, October 2005, Direction du laboratoire des chaussées [Pavements Laboratory Directorate], Ministère des transports du Québec, 2 pages. http://www1.mtq.gouv.qc.ca/fr/publications/reseau/infodlc/index.asp

[8] TRB (2002), Bailey Method for Gradation Selection in Hot-Mix Asphalt Mixture Design, Transportation Research Circular No E-C044, October 2002, 39 pages. http://gulliver.trb.org/publications/circulars/ec044.pdf