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MODIFIED TIRE-PAVEMENT NOISE MEASUREMENT TECHNIQUES FOR NOISE ASSESSMENT ON ASPHALT-RUBBER ROADS

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Abstract

This paper investigates the availability of recognized standards for measuring tire/pavement noise by determining the existence of a common or certified standard in measuring ARC road noise. The possibilities for establishing a common standard or making enhancements to the current standards for accurately measuring traffic noise in North America are also studied. Two different noise measurement studies are conducted on both conventional and ARC roads. The noise measurement study is based on the Statistical Pass-by method per International Standards Organization ISO 11819-1 while the other measurement study is based on the Close-Proximity Method based on International Standards Organization ISO 11819-2. Modifications have been made to the noise evaluation techniques in order to suit the local environment during measurements. The paper focuses on the advantages and disadvantages of implementing both noise measurement methods. Theoretical calculations are incorporated in order to the estimate the noise level errors during measurement. Simulations are performed to determine the influence of the receivers' distance on the accuracy and reliability of the test measurements. Comparisons and recommendations are made for both methods under different measurement conditions and requirements.

1. INTRODUCTION

As technology advances, more roads are built and more vehicles are made in order to meet the demand and desire of human to reach every part of the world with ease. Traffic volumes are ever-increasing and hence traffic noise pollution is becoming one of the most critical issues in society. Traffic noise control technology is gaining more attention from society nowadays and many traffic noise control measures have been implemented. Many researches have shown that one of the common noise sources is produced by the interaction between pavement and vehicle tires. It is also believed asphalt rubber concrete (AR) pavement possesses the capability to reduce traffic noise. In the recent years, ARC pavement has drawn the attention of both industry and environmental health administrators as this pavement possesses good traffic noise reduction capability and higher retention capacity. It is believed that ARC road has the ability to absorb the noise generated from the contact between the tire and road. Many acoustical measurements have been taken in order to prove that ARC pavement is capable of reducing traffic noise. Therefore, it is important to have a standard guideline for collecting acoustical measurements and interpreting the results accurately in order to prove the capabilities of rubber asphalt pavement.

Currently, there are many guidelines and recommendations available for measuring the acoustical properties and interpreting the results. Standardized measurement methods have been established and revised throughout the years by many renowned researchers. These methodologies have been revised in order to minimize problems that may occur and may not be foreseen by a less experienced researcher when adopting the measurement methods. Standardizing the measurement method is also useful for researchers because it becomes possible for researchers from around the world to compare their data. Therefore, applying the internationally recognized acoustical measurement standards is a good way to start any sound measurement experiment.

2. THEORETICAL MEASUREMENT METHODS

There are two common traffic noise measurement methods from the International Standards Organization. These are mentioned in ISO 11819 (part 1 and 2). Both ISO 11819-1:1997(E) and ISO 11819-2:2000(Draft) specify the method for comparing traffic noise on different road surfaces for various compositions of road traffic for the purpose of evaluating different road surfaces and types [5]. These were developed to relate the road surface characteristics to the emission and propagation of road traffic noise as it is believed that the road characteristics, notably the texture and the porosity, can influence the propagation of sound especially sound propagation close to the road pavement surface.

The ISO 11819-1 traffic noise measurement method is also commonly known as the Statistical Pass-By (SPB) method. In this method, the maximum A-weighted sound pressure levels of a statistically significant number of individual vehicle pass-bys are measured at a specified road-side location together with the vehicle speeds [5]. Traffic flowing on the road section should contain a sufficient numbers of vehicles from each category. The selection of the test site must have the following conditions; the road shall be extended at least 30 m on both sides from the microphone and the distance is increased to 50 m for the “high” road speed category [5]. 25 m of space around the microphone shall be free of any reflecting objects other than the ground is usually adequate to ensure that approximate free field conditions exist. The condition of the pavement surface is also important. Measurements shall be carried out only when the road surfaces are dry [5]. The SPB method also recommends discarding the measurements that disturbed by wind gusts, background noise or by other sources. A-weighted sound pressure levels from activities other than traffic on the road site shall be at least 10 dB below the maximum sound level during pass-bys recorded from the vehicles included in the database, particularly for the quietest vehicles recorded [5]. The microphone location plays a very important role in measuring the traffic noise. Therefore, this is a very important criterion in the SPB method. It is written in the guidelines that the horizontal distance from the microphone position to the centre of the vehicle travel lane shall be 7.5 m ± 0.1 m. The microphone shall be located 1.2 m ± 0.1 m above the surface of the road lane [5].

In the draft of ISO 11819-2 "The Close-Proximity (CPX) Method" specifies a method based on test tire rolling on the road or the test track surface with measuring microphones located close to the tire surface [2]. In the CPX method, the average A-weighted sound pressure levels emitted by two or four specified reference tires are measured over an arbitrary or a specified road distance, together with the vehicle testing speed [2]. Data are collected by at least two microphones, located close to the tires. For this purpose, a special test vehicle is made which is either self-powered or towed behind another vehicle. The noise generated by a standard tire is measured by two microphones in an enclosed acoustic chamber to isolate the sound from passing traffic. The acoustic chamber is required because sound pressure microphones will measure the sound from all directions and thus there is a need to isolate the sound from other traffic and other sound reflective surfaces [2].

The tests are performed with the intention of determining a “Tire/road sound level”, L_{tr}, at one or more of the nominated reference speeds (50, 80 and 110 km/h) [2]. If testing close to one of the reference speeds is impractical, testing over a wider range and using an appropriate method of normalizing for speed deviations is an option. For each reference tire and each individual test run, the average sound levels over short measuring distances (segments of 20 m each), are recorded with the corresponding vehicle speeds [2]. The sound level of each segment is normalized to the reference speed by a simple correction procedure. Averaging is then carried out according to the purpose of the measurement (measuring a particular segment or a number of consecutive segments – a section). The resulting average sound level for the two mandatory microphones at the reference speed is called the “Tire/road sound level”, L_{tr} [2]. One L_{tr} is produced for each reference tire and each reference speed.

3. FIELD MEASUREMENT METHOD

In 2005 a 10.30 km stretch of Asphalt Rubber test road pavement was constructed on Highway 11 which connects the City of Regina to the City of Saskatoon in the province of Saskatchewan. Highway 11 consists of two north and southbound lanes and two different types of pavement have been constructed in both directions; one is the conventional asphalt pavement (normal asphalt pavement) in the passing lane while the other is the ARC pavement in the driving lane. There is also another section on Highway 11 that is repaved with conventional asphalt concrete. Both sections are repaved during the same time period. A series of traffic noise monitoring studies are conducted on the rubber asphalt and conventional pavement.

Two different methods have been used in the noise monitoring study. One is the SPB method incorporated with the Time – averaged Traffic Noise measurement method, while the other is the CPX method. Both methods are adopted and integrated to perform noise measurements at the test site. A comprehensive study is conducted using the noise measurement methods in order to establish a fully recognized and reliable database.

The time-averaged Traffic Noise measurement is a 24-hour continuous data collection using the sound level instrument. The data will be collected in the form of 1/3 Octave frequency bands and A-weighted sound levels and recorded as a 30-second equivalent noise level, L_{eq}. For the Time-averaged traffic noise method, sound pressure is averaged and converted into L_{eq}. The L_{eq} represents the average noise exposure throughout the elapsed time. This method can be used to evaluate the tire/pavement noise where the pass-by vehicles are not sufficiently isolated. This method provides information on the impact of the pavement on the environmental noise characteristics over a particular time interval. The environmental conditions such as the traffic mix, traffic volume and meteorological conditions are not controlled. On the other hand, the SPB method is used to collect the maximum sound power of each passing vehicle by calculating a statistical index for the noise level of the vehicle type. This method accounts for all aspects of the traffic noise at the sideline of the highway including noise from the engine, exhaust and the aerodynamic noise. By comparing the noise levels between different pavements, this method provides information on the impact of the pavement and its contribution to traffic noise. This method has many limitations in the setup in order to guarantee the reliability of the results obtained.

Figure 1 shows the top view of the dimensions of the test section on Highway 11 and the noise monitoring study setup. Figure 2 shows the on-going traffic noise measurement where the microphone is setup 15 m away from the center of the driving (test) lane.

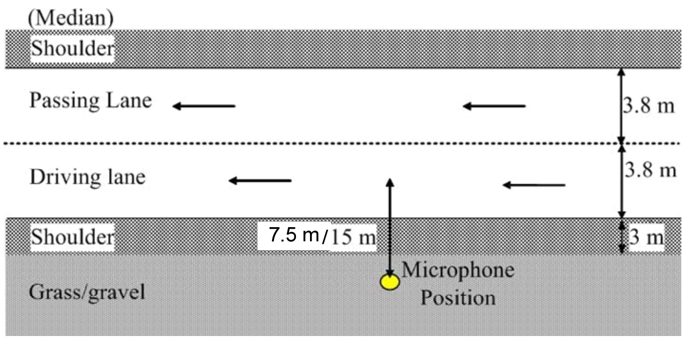

Figure 1. Top view of noise measurement study using SPB method equipment setup on Highway 11, Saskatchewan, Canada

Figure 2. Noise measurement study equipment setup at the Highway 11, Saskatchewan, Canada

The ISO 11819-2 specifications are followed for the noise measurement study using the CPX method. Three microphone positions are considered (Figure 3). The “Inner” position is specified by ISO 11819-2 specifications while the other two positions are measured for further study. For each microphone position, the tire/pavement noise data is be collected while the vehicle travels under 50 km/h, 80 km/h and 110 km/h. At least six sets of 10 seconds noise data collection are acquired for each speed category. The tests are implemented on both the ARC and conventional road. Both noise measurement tests are conducted on the driving lane where the test for the conventional pavement is conducted on another section on Highway 11 that constructed at the same time as the ARC pavement. Two different types of tires (old and new) are used to study the noise characteristics. The P225/60R16 tire size is used as it is the most popular radial passenger tire size in the 2005 replacement market according to the 2006 Modern Tire Dealer’s Fact Issue [11]. Figure 4 shows the custom build trailer used in the noise measurement study. The microphones are mounted in the trailer acting as the acoustic chamber to isolate any noise from the surroundings. Inside of the trailer is also covered with the sound insulation material (anechoic wedge acoustical foam) to reduce any reflecting sound from the trailer to the microphone as much as possible. Figure 5 shows the process of the noise measurement being conducted using the trailer. The run is repeated several times to collect noise data for each speed category and type of tires.

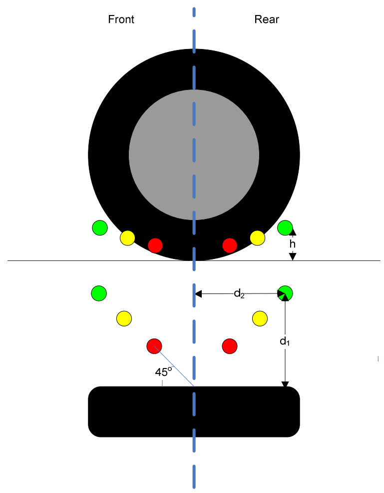

Figure 3. Real-life noise measurement study equipment setup at the Highway 11, province of Saskatchewan

Table 1. The microphone positions tested.

Microphone position	H (mm)	d_1 (mm)	d_2 (mm)
"Inner" (ISO Recommended)	100	200	200
"Middle"	150	300	300
"Outer"	200	400	400

Figure 4. Custom-build trailer for traffic noise measurement study using CPX method

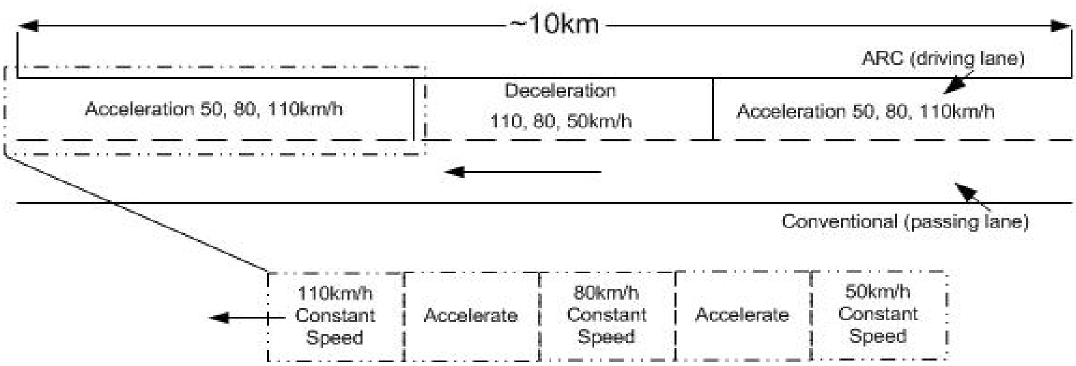

Figure 5. Test run process on the Highway 11, province of Saskatchewan

The Brüel & Kjær modular precision sound analyzer (Type 2260 Sound Investigator) along with the outdoor microphone unit (Type 4198) are used as the sound level instruments for both noise measurement studies. In the noise measurement study using the SPB method, an equivalent noise level, L_{eq} is obtained over a period of 24 hours. As the Time-averaged traffic noise method does not specify the environmental conditions or limitations for taking traffic noise measurements, the conditions stated in the SPB method are taken into account. For the noise measurement study using the CPX method, the microphones are mounted inside the trailer at the positions shown in figure 3. For every noise data, an equivalent noise level, L_{tr} is obtained for at least 10 seconds to meet the requirement of minimum measuring distance of 20m.

4. RESULTS AND DISCUSSIONS

As the 7.5 m microphone distance is the commonly used standard in the SPB method, the 15 m microphone distance is widely adapted in North America. Therefore, a traffic noise measurement study is conducted to investigate the influence of the microphone distance to the accuracy of the results. Figure 6 shows the noise level obtained from the traffic noise measurement study using the SPB method at 7.5 m and 15 m during the summer of 2006. A theoretical calculation is performed to find the noise level difference between the 7.5 m and 15 m microphone distances. As highways are often relatively straight with a uniform density for traffic along its length, the noise is often represented as a line source. The sound wave propagating from a line source forms a series of concentric cylindrical surfaces, having an axis along the line of the source. The sound pressure level (SPL) at some distance from the source can be predicted, from a known sound pressure level at some reference distance [8].

If the sound pressure level at d_0 is SPL0, the sound pressure level at d_1 is SPL1. Thus, for the line source:

$$SPL_0 - SPL_1 = 10\,Log\; d_1 - 10\,Log\; d_0 \qquad (1)$$

$$Sound\ level\ difference = SPL_0 - SPL_1 = 10\,Log\,\frac{d_1}{d_0}\,dB \qquad (2)$$

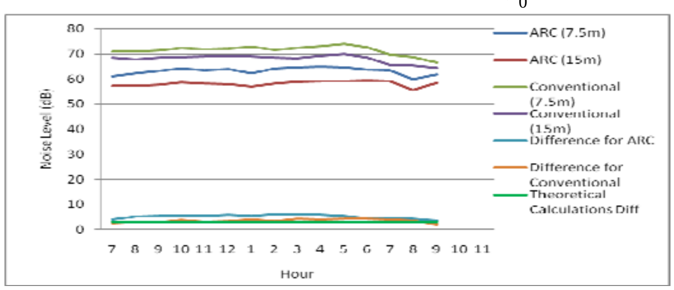

Figure 6. Noise level measured for 7.5m and 15m microphone distances and their differences

From figure 6, it is clear that the difference in noise levels obtained from the noise measurements on the conventional asphalt pavement is very similar to the noise level difference calculated using the theoretical equation. The difference in noise levels obtained from the noise measurements on the AR pavement is visibly higher than the noise level difference calculated using the theoretical equation. As the environmental conditions are similar for both types of pavement during the noise measurement study, the only different environment factor is the pavements' absorption properties. The higher noise level difference between the data from ARC pavement and the theoretical equation shows that the absorption properties have a visible effect on the different microphone positions used for measuring traffic noise on the ARC pavement. The 15 m microphone distance is a more suitable microphone position for the SPB method than the 7.5m microphone distance when comparing the traffic noise level from ARC and conventional asphalt pavement. This is because the effect from the pavements properties is more visible, which is also the main aim of the ISO 11819 standard on comparing traffic noise on different road surfaces for various compositions of road traffic for the purpose of evaluating different road surfaces and types [5]. Moreover, when the safety of personnel at the test site is concerned, a 15 m distance should be the optimum distance for studies conducted on high speed roadways as it provides a comfortable distance (>10 m) from vehicles travelling at high speeds. The width from the center of the test lane to the edge of the pavement is 5 m. A 15 m microphone distance also has the advantage of diminishing the influence vehicle size as the vehicle size and speeds recorded on Highway 11 vary. On top of that, noise measurements are performed in a free field and the influence of background noise, which is at least 30 dB less than the observed traffic noise levels, has very little impact on the measured results.

Similarly, three different microphone positions are studied during the traffic noise measurement using the CPX method. Figure 7 shows the noise levels obtained from the traffic noise measurement study using the CPX method at different microphone positions listed in Table 1 during the summer of 2006. From the figure, the “Inner” microphone position (as recommended by the ISO 11819 standard) is more sensitive to the surroundings especially on the aerodynamics effect in the trailer as the front microphone has lower noise level compare to the rear microphone, and also less sensitive to the absorption properties of the pavements because the noise levels difference between two pavements are similar for any microphone positions. With this, according to the results obtained in figure 7, the “Outer” position should be used when measuring noise levels on ARC pavement because the surrounding absorption properties are less influential when compared to other noise positions.

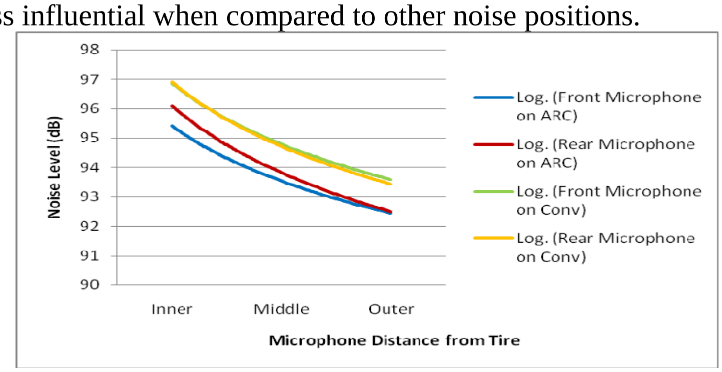

Figure 7. Noise level measured using the CPX method for different microphone positions on both conventional and ARC pavements travelling at 80km/h.

5. CONCLUSIONS AND FUTURE DEVELOPMENT

From the theoretical measurement methods studied, it is obvious that the recommended guidelines and specifications for acoustical measurements in different areas, including transportation acoustical measurement and traffic noise measurement under the influence of different road surfaces, is well established and widely accepted. However, as most of the detailed guidelines and recommendations are established mainly in European countries, many different environmental criteria in other continents or countries are not taken into account. Therefore, it is necessary to make further modifications on these specifications to suit or to take advantage of the local environment in Canada or in North America.

This paper focuses on comparing the different microphone positions guidelines commonly used in Europe and North America. From the results obtained using SPB method, on high speed roadways in an open free field with free flowing of vehicles, it is recommended that the 15 m distance of the receivers from the middle of the test lane shall be adopted. From the results obtained using CPX method, the "Outer" microphone position is recommended for its lower sensitivity to the unavoidable surrounding factors inside the test vehicle. In future, a mathematical model can be developed for calculating the measurement errors to further prove the reliability of the modifications made. All the comparisons made in this paper prove that the widely recognized traffic noise measurement method can be further improved and modified. By making modifications, a more practical and theoretically sound noise measurement method can be developed based on the current standards.

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