The Language of Noise and Quieter Pavements

Concrete Pavement Surface Characteristics Program

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Introduction

Over the last few years, the National Concrete Pavement Technology Center has helped the transportation industry identify concrete pavement options that are quiet while still being safe, durable, and cost-effective.

The multi-year Concrete Pavement Surface Characteristics Program (CPSCP) was initiated in 2004, from which several products are emerging. Among these are better practices for design and construction, a set of construction specifications, and guidance on how to select the right texture for a given project.

As part of this program, the world's largest database of noise data for concrete pavements has also been collected and analyzed. While care has been taken to develop products that are readily implementable by the concrete paving industry, there remains the challenge of introducing aspects of a whole new discipline to our industry—that of acoustics and noise control.

This document serves as both a brief tutorial and a handy reference for those wishing to understand the findings from the CPSCP and other projects that address tire-pavement noise or quieter pavements. It provides an introduction to the language that is commonly used in the acoustics world, and explains how this language is applied to pavements.

What is sound?

Sound is small but fast changes in air pressure. Sound can be caused by mechanical vibrations, such as the tapping of a drum. Sound can also be aerodynamic, such as the sound from a person whistling. And, in some cases, sound is even caused by thermal changes, such as thunder from lightning.

Longitudinal grooving and turf drag test section from the Concrete Pavement Surface Characteristics Program

Sound and noise

Sound is everything that we can hear, but noise is what we hear that we also find objectionable. As such, all noise is sound, but not all sounds are noise. Furthermore, what is noise to one person may not be noise to another. While "sound" and "noise" are often used interchangeably, there is a difference.

dB

dB is shorthand for the engineering unit called a decibel, which is a unique measure of the small air pressure fluctuations that make up sound. More specifically, a decibel is the unit for sound level. Most are familiar with pressure, which can be measured in units of Pascals (Pa). Sounds we can hear can be from changes in pressure as little as 0.00002 Pa. However, at some point in our lives, we may experience sounds that measure 100 Pa or more. With such a wide range in these pressure changes, a logarithmic conversion is made, using a reference value selected so that 0 dB is about the quietest sound that a person can detect.

The mathematics for this can be found elsewhere; however, Figure 1 illustrates a commonly cited "noise thermometer" showing typical sound levels that people experience. What is also important to know is how much of a change in sound level is significant. Most people cannot perceive a change of 1 to 3 dB, unless the sounds are heard back to back. A change in 5 dB can be noted by most people, but it isn't until a larger increase of 10 dB that most people would claim something is twice as loud.

Pitch

The pitch or frequency of a sound is related to how rapidly the small air pressure changes are occurring. The units for frequency are cycles per second, also called Hertz (Hz). When the frequency is doubled (e.g., from 1,000 Hz to 2,000 Hz), the frequency is said to increase by one octave. Often times, third-octaves are also used to differentiate frequencies. An increase in third-octave means an increase in frequency of about 25% (e.g., from 1,000 Hz to 1,250 Hz).

People with good hearing can detect sounds ranging from 20 to 20,000 Hz, but not with the same sensitivity over the entire range. Furthermore, as we age, or if our hearing becomes damaged, we tend to lose additional sensitivity at some frequencies, particularly those on the higher end of this range. Because of our varying sensitivity to different frequencies, sound levels are often reported as A-weighted, or in units of dBA or dB(A).

As illustrated in Figure 2, A-weighting emphasizes sound in frequencies that

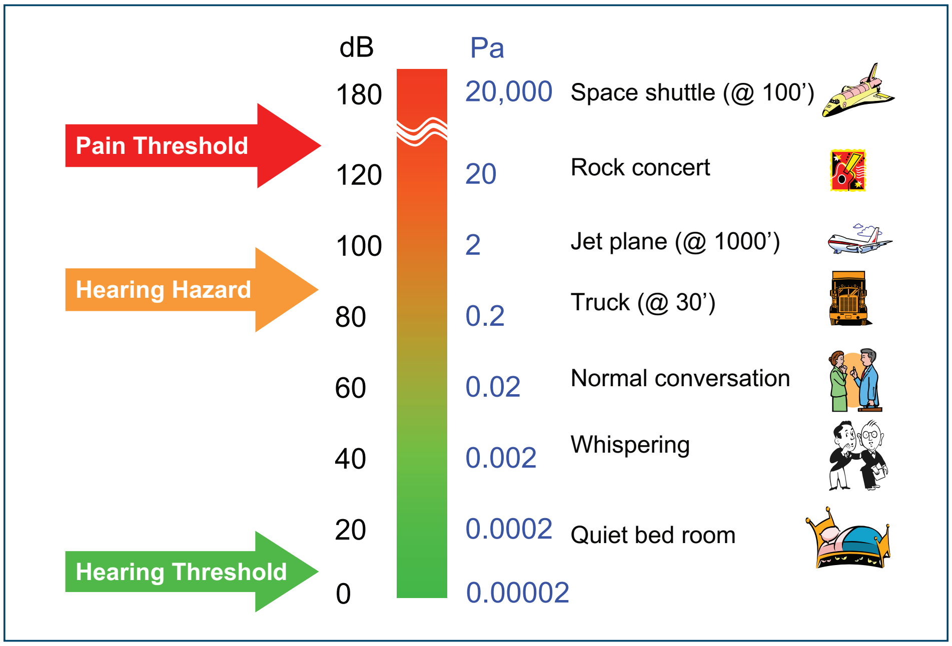

Figure 1. Conversion from pressure to sound level, and typical experiences

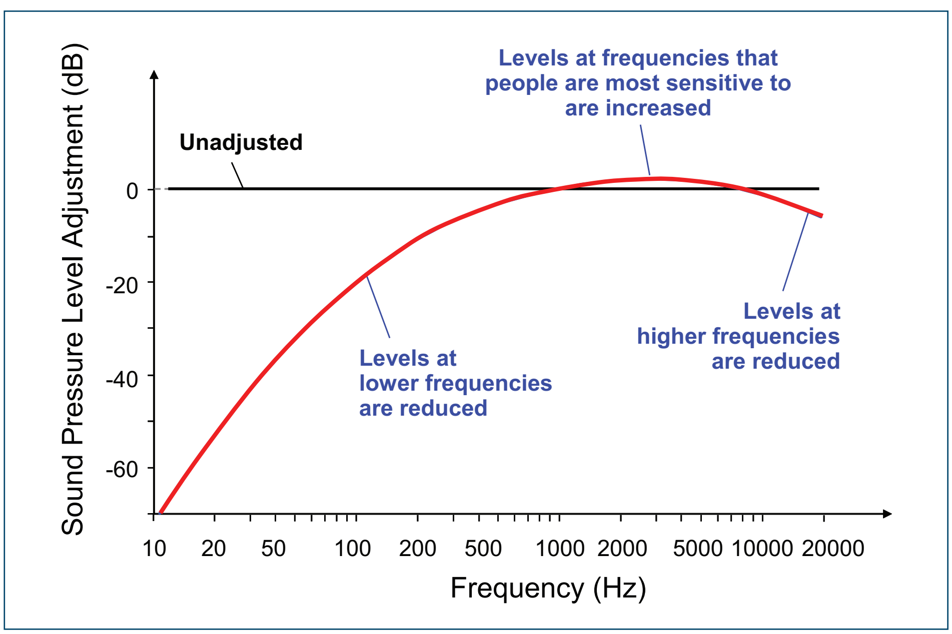

Figure 2. A-weighting as a means to calculate sound levels relevant to human hearing

people are most sensitive to, and reduces sound that is in the range that people are less sensitive to. A-weighted sound levels are the most common means of reporting highway-related sound measurements.

Propagation

The process of noise control engineering often looks at sound in terms of its source, propagation, and receiver. To predict how a receiver will detect sound, the position and intensity of the source must be known, along with the propagation path. If there is open space between the source and receiver, this calculation is simple.

As a rule of thumb, sound from a roadway (often modeled as a line source) will experience a decrease in level of 3-5 dB per doubling of distance from the source. This calculation becomes increasingly complex, however, as things begin to block or reflect the sound (such as noise barriers). The weather (especially temperature and wind) can also have a significant effect on propagation, particularly at longer distances (of 300 ft or greater). This is illustrated in Figure 3.

Traffic noise

All of the sound generated by traffic is traffic noise. It includes sound from the combination of propulsion, tire-pavement, and aerodynamic sources. Propulsion sounds include those generated by the engine, exhaust, intake, and other powertrain components. Tire-pavement noise is generated as tires roll along the pavement, and aerodynamic sounds are due to turbulence in the airflow all around the vehicle.

For most cars today, steady speeds greater than about 20 mph will result in most of the noise coming from the tire-pavement interaction. This speed is often referred to as the crossover speed. For trucks, the crossover speed is a little higher, because their propulsion systems are louder.

As a rule of thumb, an increase in speed of 10 mph increases the sound level by 2 to 3 dBA. Braking (especially engine braking), accelerating, climbing, and cornering further increase traffic noise.

Keeping noise under control

The amount of traffic on a roadway affects the sound level, but to a limited degree. All else being equal, cutting the amount of traffic on a roadway in half reduces the sound level by only 3 dBA. A truck is typically 8 dBA louder than a car, so reducing the percentage of trucks on a roadway would also reduce highway noise. Other effective methods are identified in the Federal Highway Administration (FHWA) noise policy found in 23 CFR 772.

According to the FHWA, noise barriers (sound walls and/or earthen berms) are the most commonly used option to reduce traffic noise, but should only be used when mitigation is found to be feasible and reasonable.

The height of the barrier is an important factor because the line of sight between the source and the receiver must be broken for the barrier to be effective. The effectiveness of a barrier is also a function of how far away a receiver is. Directly behind a barrier, a decrease of 5 to 10 dBA can be expected. Beyond 300 to 500 ft from a barrier, its effectiveness is limited. Also note, while trees and vegetation may block the line of sight, they often do little to reduce sound levels.

Tire noise

Controlling tire-pavement noise is logical because it's a dominant contributor to overall highway noise. Looking at some fundamentals, with respect to the tire, Figure 4 illustrates some of the relevant components that affect noise.

The blocks in a tire tread are significant because, as the tire rolls, they impact the pavement surface and create tread-pattern noise, which often includes distinct tread-passage frequencies. Manufacturing a softer tire reduces impact and noise (although it often reduces durability, as well). Randomizing the block sizes and/or making them angular in shape also reduces tread-pattern noise and/or minimizes the whine associated with some tires. Finally,

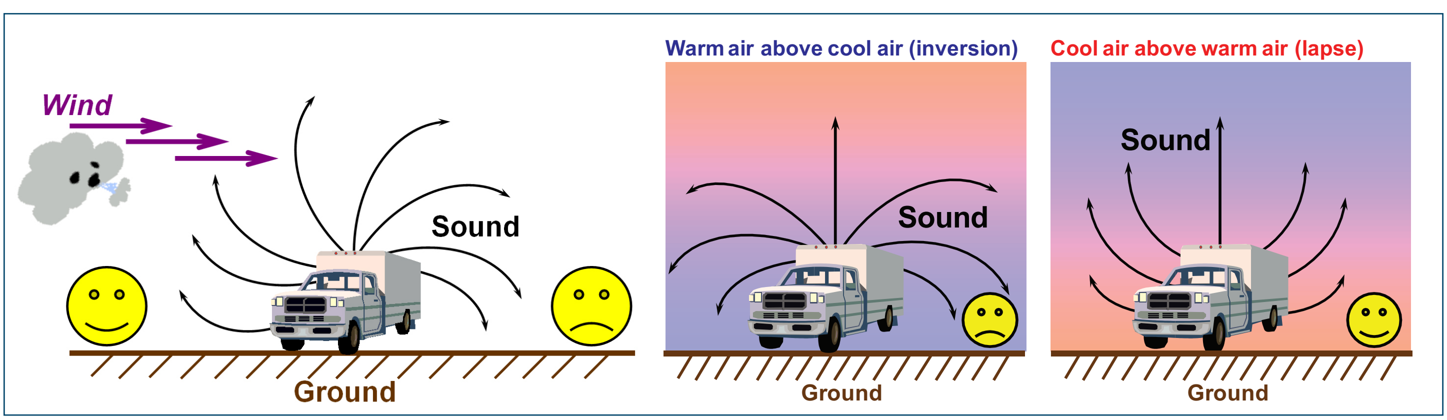

Figure 3. Sound propagation as affected by wind and temperature conditions

the grooves and sipes are also significant, because when they are in contact with the pavement, they can form pipes that resonate at specific frequencies, adding to overall noise.

Pavement noise

Pavement texture is by far the most important characteristic that affects noise generation. The most significant is termed positive texture, or bumps that periodically protrude above an otherwise smooth surface. As illustrated in Figure 5, this texture impacts the tire, creating noise. Pipe resonances can also form within pavement texture, particularly on tined or grooved surfaces.

Conversely, if a pavement is too smooth, pipe resonances that form within the tire tread are increased. In the end, a quiet pavement is one that has very fine but negative texture. Complicating the quest for quieter pavements are these and other mechanisms that contribute to noise including friction/scrubbing (producing tire squeal, for example) and the amplifying effect of the tire sidewall.

Measuring things up

Numerous types of relevant measurements exist in this field, and the similarities and differences are important to recognize. First, noise measurements can characterize either the source or the receiver. Source measurements (where microphones are located a few inches from a rolling tire) are increasingly common, and include test methods termed on-board sound intensity (OBSI) and close proximity (CPX).

Use of OBSI equipment, as shown in Figure 6, is the most commonly used method in the United States, while the CPX method is commonly used elsewhere in the world. Two important considerations for any source measurement are the test tire and the test speeds. While standardized in recent years, historical data may not be directly comparable.

Wayside testing is relevant to receivers. It is commonly part of environmental studies and used to determine the need for noise mitigation. Two newer U.S.-based procedures worth noting include the statistical isolated pass-by (SIP) method and the continuous-flow traffic time-integrated method (CTIM). As illustrated in Figure 7, wayside testing requires measurement of sound levels at regulated roadside positions, along with vehicle speeds and classification (such as cars versus heavy trucks).

Given that pavement texture is so influential in the generation of tire-pavement noise, its measurement is also important. Traditionally, pavement texture was measured using the "sand

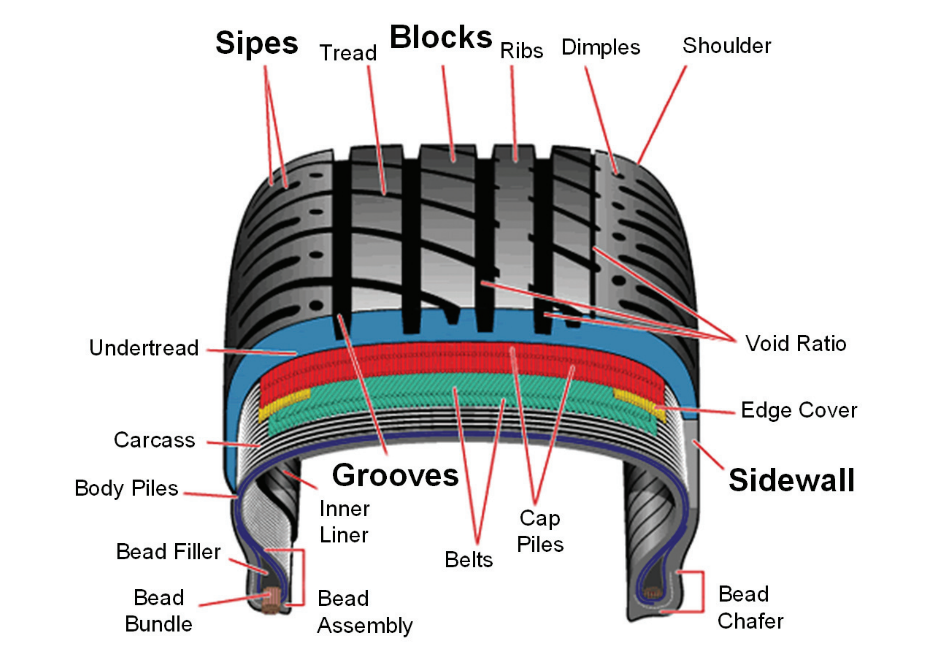

Figure 4. Typical components of a tire (relevant ones shown in boldface type)

Figure 5. Idealized textures for loud and quiet pavement

patch" technique for mean texture depth (MTD) or laser-based profilers, such as the circular track meter (CTM) to calculate mean profile depth (MPD). While these measures of texture are relevant to friction, they are poor indicators of noise. Recently developed texture measurement systems, such as the robotic-based texture (RoboTex) measurement system allow for more relevant texture metrics to be calculated (See Figure 8).

Figure 6. OBSI for measuring tire-pavement noise at the source

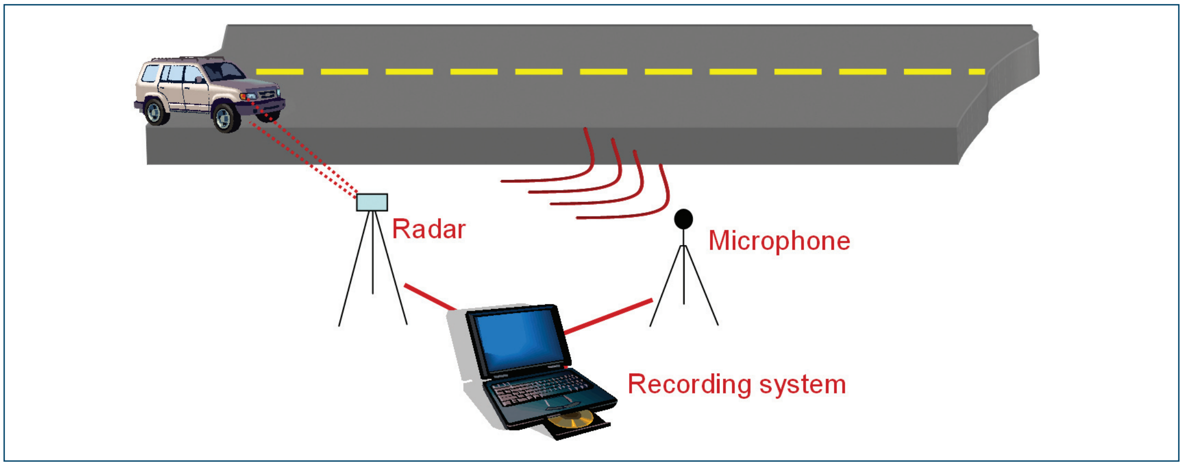

Figure 7. Wayside testing for measuring noise relevant to the receiver

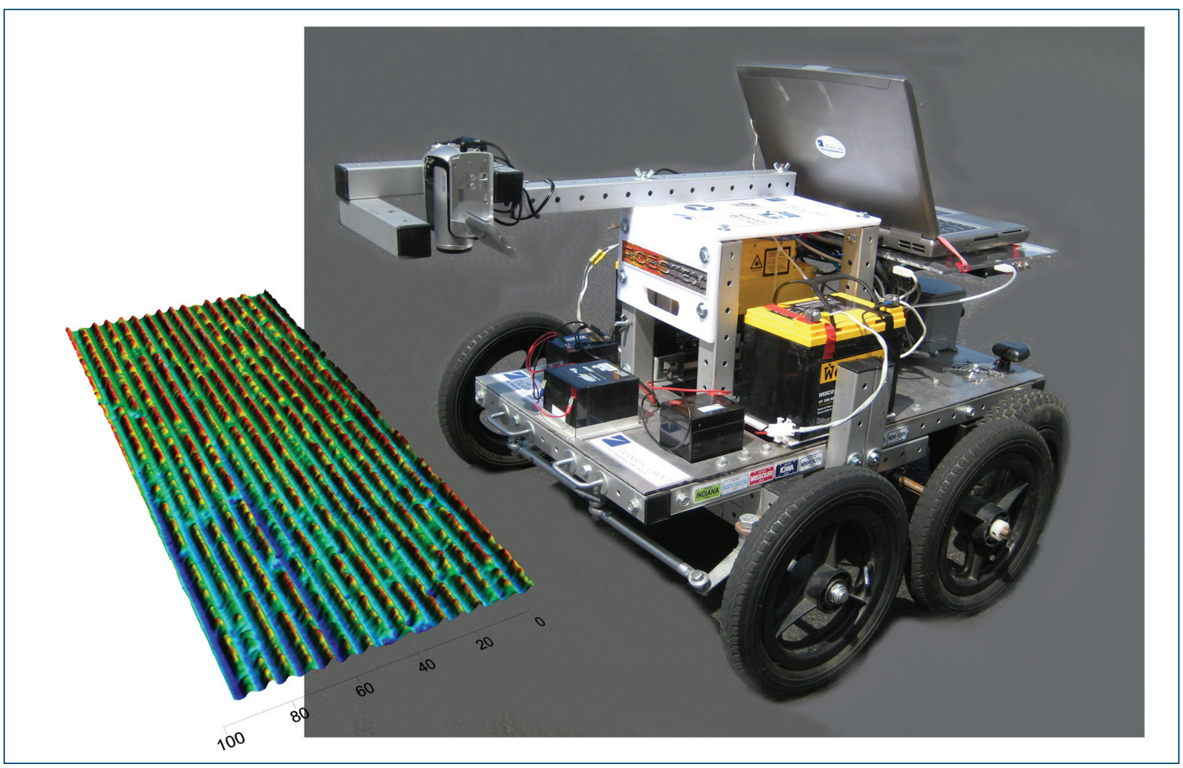

Figure 8. RoboTex equipment and sample texture measurement of a diamond ground concrete surface

Conclusions

The intent of this technical brief is to provide a quick overview of some of the more common jargon used in the field of tire-pavement noise and quieter pavements. While intended to serve as a quick tutorial, it does not delve into the level of detail that more-thorough texts provide.

Additional resources include the Little Book of Quieter Pavements, along with the associated one-day workshop, Tire-Pavement Noise 101, recently offered by the Federal Highway Administration (FHWA).

The Concrete Pavement Surface Characteristics Program will also include a number of important products to demonstrate that concrete pavements can be a viable option for quieter pavement. This primer highlights the foundation upon which those products stand.

For More Information

Robert O. Rasmussen et al., "The Little Book of Quieter Pavements," Report FHWA-IF-08-004, USDOT Federal Highway Administration, 2007.

Ulf Sandberg and J. Ejsmont, Tyre/Road Noise Reference Book, Informex, Handelsbolag, Sweden, 2002.

Robert O. Rasmussen et al., "Tire Pavement Noise 101: An FHWA Workshop," USDOT Federal Highway Administration, 2009.

Paul Donavan and D. Lodico, "Measuring Tire-Pavement Noise at the Source," National Cooperative Highway Research Program Report 630, 2009.

Cynthia Lee and G. Fleming, "Measurement of Highway-Related Noise," Report FHWA-PD-96-046, USDOT Research and Special Programs Administration, 1996.

Robert O. Rasmussen et al., "How to Reduce Tire-Pavement Noise: Interim Better Practices for Constructing and Texturing Concrete Pavement Surfaces," National Concrete Pavement Technology Center Report, 2008.

About the CPSCP

In December 2004, a coalition was formed between the National Concrete Pavement Technology Center (National CP Tech Center), the Federal Highway Administration (FHWA), the American Concrete Pavement Association (ACPA), and the International Grooving and Grinding Association (IGGA).

The mission of the program was to help optimize concrete pavement surface characteristics—more specifically, it was to find innovative solutions to make concrete pavements quieter without compromising safety, durability, or cost effectiveness.

The current program is now operating under Pooled Fund TPF-5(139) with the additional support of state DOTs, including California, Iowa, Minnesota, New York, Texas, Washington, and Wisconsin.

Recent focus is on identifying specific guidance to properly design and construct quieter concrete pavements. Innovative concrete pavement surfaces are also being evaluated to assess their potential as viable solutions.

For more information, contact Paul Wiegand of the National CP Tech Center at 515-294-7082 or pwiegand@iastate.edu.

About the National Concrete Pavement Technology Center

The mission of the National Concrete Pavement Technology Center is to unite key transportation stakeholders around the central goal of advancing concrete pavement technology through research, tech transfer, and technology implementation.

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