Measuring And Reporting Tire-Pavement Noise Using On-Board Sound Intensity (OBSI)

Concrete Pavement Surface Characteristics Program

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Introduction

The key recommendations developed out of the Concrete Pavement Surface Characteristics Program (CPSCP) are largely based on tire-pavement noise tests conducted worldwide using the On-Board Sound Intensity (OBSI) method. OBSI measures tire-pavement noise at the source using microphones in a sound intensity probe configuration mounted to the outside of a vehicle, near the tire-pavement interface. Measurements are performed while the test vehicle drives across the pavement of interest.

The purpose of this technical brief is to describe the OBSI test method, some of the history behind its development, the test setup, important factors that must be controlled during the test, the general test procedure, and how to report and interpret the results.

What is sound intensity?

Sound is caused by small and rapid pressure changes in the air. Our ears respond to these changes in sound pressure, and, likewise the changes can be measured with a microphone. When a sound level (such as 90 dBA) is reported, it is most often a measure of the amplitude of sound pressure changes. Sound intensity is different from sound pressure in that it has both amplitude and an associated direction. Intensity is related to the flow of acoustic energy and, more specifically, it is the acoustic power per unit area (units of Watts/m^2). Because it includes direction, it is not as simple to measure as sound pressure, but one common technique is to use a probe consisting of two microphones spaced apart by specified distance. Measuring both the amplitude and phase of sound at the two microphones gives the probe directional characteristics and allows for the direction of sound sources to be determined. Figure 1 shows an example of a sound intensity probe used to measure tire-pavement noise. In this case, the microphones are in a side-by-side configuration.

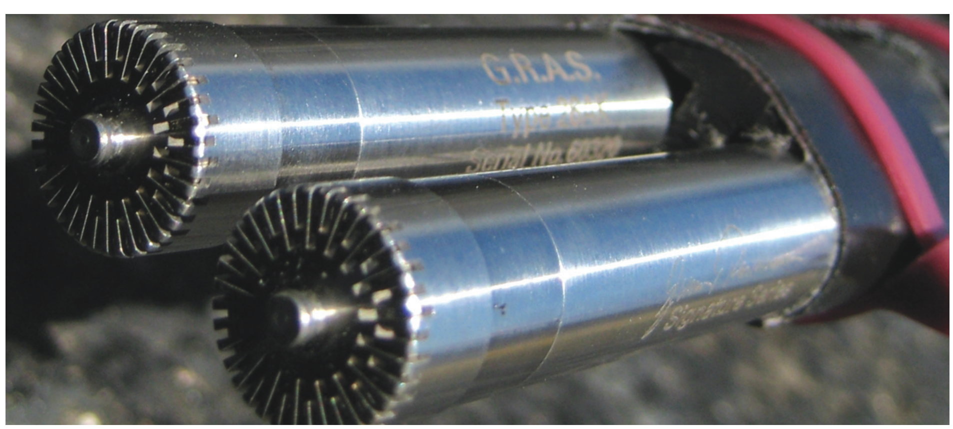

Figure 1. Sound intensity probe used for OBSI testing showing two 1/2 in. microphones (photo does not show foam windscreen required during testing)

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Why measure sound intensity instead of sound pressure?

There are several advantages of using sound intensity instead of sound pressure for measuring tire-pavement noise at the source. First, the directional characteristic of the probe makes it better suited for measuring a specific noise source, while attenuating sounds from other sources in other directions (such as engine or exhaust noise). Second, sound intensity is much less contaminated by "random" noise, such as wind noise generated as the vehicle is moving. Third, because sound intensity measures the acoustic energy propagating away from the source to the roadside, it correlates well with sound measured at the roadside (known as pass-by or wayside measurements).

What is the history of the OBSI method?

Sound intensity has always been part of acoustic theory, but, until the 1970s, it was not readily measured due to its computational demand. As computers became smaller, faster, and less expensive, instrumentation capable of measuring sound intensity was developed and, more specifically, the two-microphone technique. In the 1980s, General Motors Corporation pioneered the application of the two-microphone sound intensity method to automotive noise measurements, and Dr. Paul Donavan, in particular, applied the method to measuring tire noise. This work resulted in Road Tire Noise Evaluation Procedure GMN 7079TP.

In the early 2000s, while at Illingworth & Rodkin, Inc. of Petaluma, California, Donavan continued development of what is now the OBSI method for measuring tire-pavement noise. With the assistance of the California Department of Transportation (Caltrans), including Bruce Rymer, and Larry Scofield with the Arizona Department of Transportation (ADOT), numerous refinements to the method were made in the early years of its use. The CPSCP adopted the OBSI technology in 2005 and, since then, has also contributed to its evolution. The OBSI technique employed today uses a dual probe fixture configuration and a Standard Reference Test Tire described by the ASTM International standard F2493. Work has been conducted in parallel under the National Cooperative Highway Research Program (NCHRP) project 1-44 to document the more critical aspects of the OBSI test protocol; this work was published as NCHRP Report 630.

In recent years, standardization efforts were initiated, and the acronym OBSI was adopted. The OBSI method was first standardized for the highway community by the American Association of State Highway and Transportation Officials (AASHTO) in 2008, and has undergone annual updates as provisional standard TP 76, "Standard Method of Test for Measurement of Tire/Pavement Noise Using the On-Board Sound Intensity (OBSI) Method." In addition to other industry experts, members of the CPSCP team have been integral to the development of the AASHTO standard by way of a Federal Highway Administration (FHWA) Technical Working Group on tire-pavement noise.

How are sound intensity probes positioned during OBSI testing?

Research has shown that tire-pavement noise can be well described by measuring at two principal locations near the tire-pavement interface. These locations are defined as the leading and trailing edge of the contact patch. As illustrated in Figure 2, the OBSI test procedure specifies that the probes be located close to these spots: more specifically, 4 in. horizontal from the tire sidewall, 3 in. vertical above the pavement, and 4.125 in. in front and behind the axle centerline.

A special fixture is used to mount to the probes at the specified locations. Early versions of the test procedure used a fixture that positioned only a single sound intensity probe (Figure 3, top). With this single probe fixture, two runs were necessary to measure

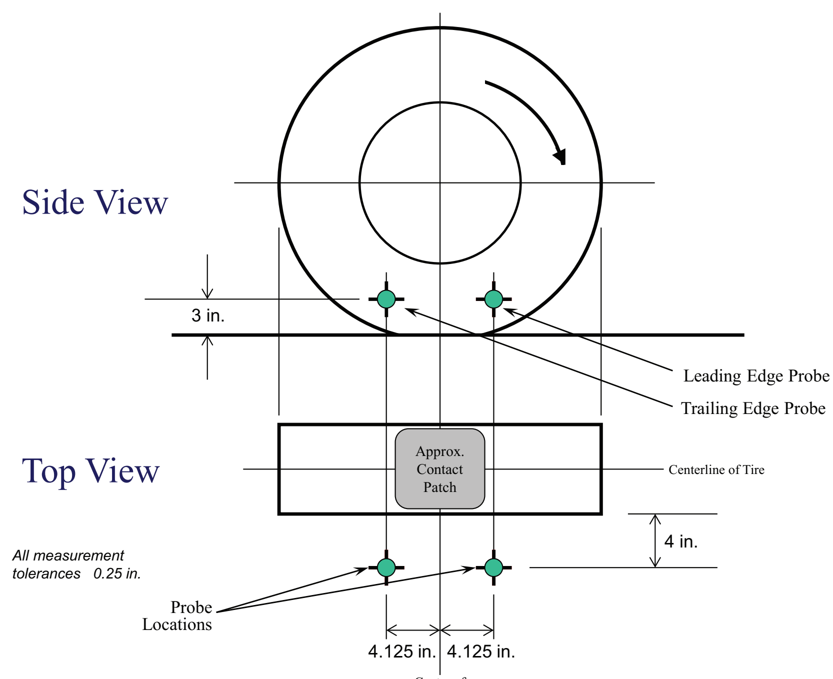

Figure 2. Sound intensity probe positions with respect to the tire-pavement interface

both noise sources: a first run with the probe positioned at the leading edge and a second with the probe positioned at the trailing edge. Driven by demand for increased test efficiency, most OBSI systems in use today employ a dual-probe configuration (Figure 3, bottom), where the measurements are collected simultaneously. Both configurations have been used over the course of CPSCP measurements.

What factors must be controlled during testing?

Experience and research shows several factors that must be controlled during the OBSI test. Among the more significant are the test tire, vehicle speed, and vehicle noises.

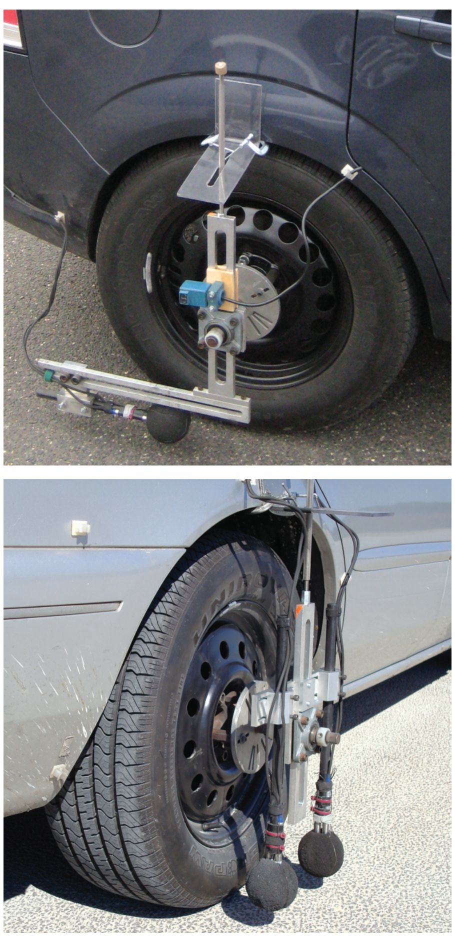

Figure 3. OBSI configurations with a single sound intensity probe (top) and dual probe (bottom)

Test tire

The current OBSI standard specifies use of an ASTM F2493 Standard Reference Test Tire (SRTT) (P225/60R16). However, at the beginning of the CPSCP project (through May 2006), OBSI testing was conducted using the de facto standard tire, a Goodyear Aquatred 3 tire (P205/70R15). Differences in tire construction include the tread pattern (Figure 4) and rubber compounds; both of these affect the noise measurements from these two tires. The difference in tire-pavement noise generated by these two tires was important to characterize so that data collected early in the CPSCP could be compared to that collected in recent years. This relationship is not a simple one, though. In terms of overall sound intensity level, the SRTT is quieter than the Aquatred by 1 to 3 dBA. The specific differences, however, are better determined by frequency, and furthermore by the nominal pavement texture being evaluated.

Vehicle speed

The OBSI standard specifies a vehicle speed of 60 mph. In situations where safety does not permit this speed, the variance must be clearly noted (given that the resulting measurement is affected). For small variations in speed (i.e., ±3 mph), a correction factor can be applied during post processing. For larger variations, error can be introduced if a single (generic) correction is applied. The relationship between speed and sound level varies significantly depending on the specific combination of tire and pavement surface.

Vehicle noise

The test vehicle must not make any abnormal noise that could contaminate the tire-pavement noise measurement. Examples include noise caused by foreign matter on the tire tread, suspension/shock squeak, wheel bearing squeal, and brake noises. Good practice is for the test operator to listen to the microphone signals during the data acquisition to identify if these or other abnormal noises are occurring.

How are test sections defined?

The AASHTO TP 76 OBSI standard requires test sections that are 440 ft long. At 60 mph, it takes the test vehicle five seconds to traverse a test section, and the results are an average over this five-second interval. While CPSCP testing is in general conformance with the AASHTO standard, test sections are of varying length. CPSCP testing was initiated years before the standard was developed and, more importantly, test section boundaries are determined based on a number of criteria. For example,

Figure 4. Standard tires used in CPSCP OBSI Testing – Goodyear Aquatred 3 (left) and ASTM F 2493 SRTT (right)

where there are multiple surface types "back-to-back" and test section limits are defined in part by these transitions. The CPSCP test sections have all been thoroughly documented, so that the exact same sections can be retested in subsequent years.

As part of the CPSCP testing, reflective cones are placed on the shoulder at the start and end of the test sections. An optical sensor mounted on the test vehicle detects the cones as the vehicle passes by, and that signal is integrated into the acoustic recording system and used as a trigger (Figure 5).

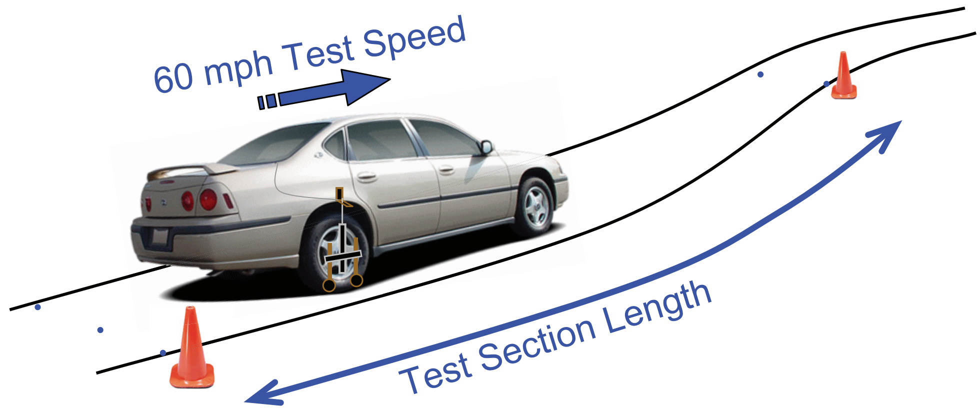

Figure 5. Vehicle with sound intensity probes mounted on the right rear wheel and traversing a test section

How is OBSI testing reported?

For an individual test section, a single OBSI level (units of dBA) is often cited. This value is a combination of the sound intensity measured at the leading and trailing edges of the tire-pavement contact patch, A-weighted, averaged over the length of the test section, and limited to the frequency range covered by the 400 to 5000 one-third octave bands. For concrete pavements, this level typically ranges from 99 dBA, for quieter pavements, to 108 dBA or more, for louder pavements.

When the frequency content of tire-pavement noise is of interest, the sound intensity spectrum may also be reported. As illustrated on the left in Figure 6, it is common to report one-third octave bands from 400 to 5000 Hz. To study the variability of the tire-pavement noise response over the length of a test section, A-weighted OBSI levels can be calculated using short interval averages, and plotted as a function of distance (Figure 6).

Finally, to help clearly visualize OBSI data, a tool has been developed that allows the results to be viewed in Google Earth. The tool also has the ability to view photographs and listen to the tire-pavement noise via an embedded audio player (Figure 7).

Conclusions

The OBSI technique has proven an invaluable tool during the course of the CPSCP. When combined with the results of the texture data, particularly that collected with RoboTex, relationships between texture and tire-pavement noise have been derived.

However, even casual observations are important, which are possible using tools such as Google Earth. Using OBSI, the location of the "quieter" and "louder" areas of pavement allow for a more thorough evaluation of the materials and construction elements at strategically-selected locations.

From this, better practices have been developed that will serve to reduce the sound generated on concrete pavements without compromising safety, durability, or cost.

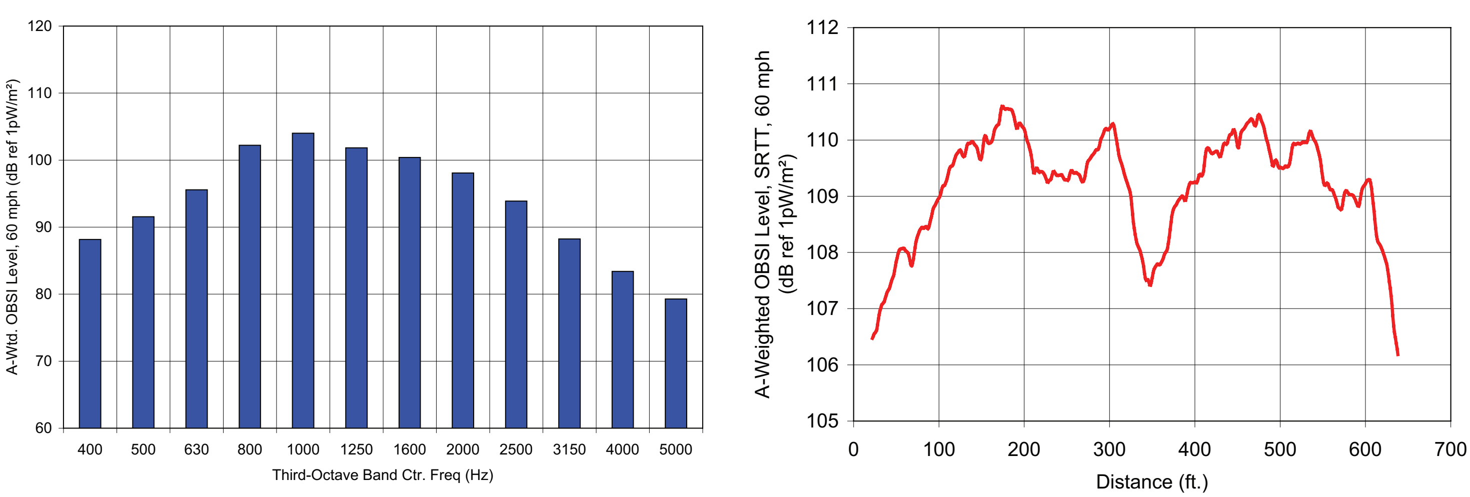

Figure 6. Results from OBSI processing: one-third octave spectral analysis (left) and OBSI level versus distance showing variability over the test section (right)

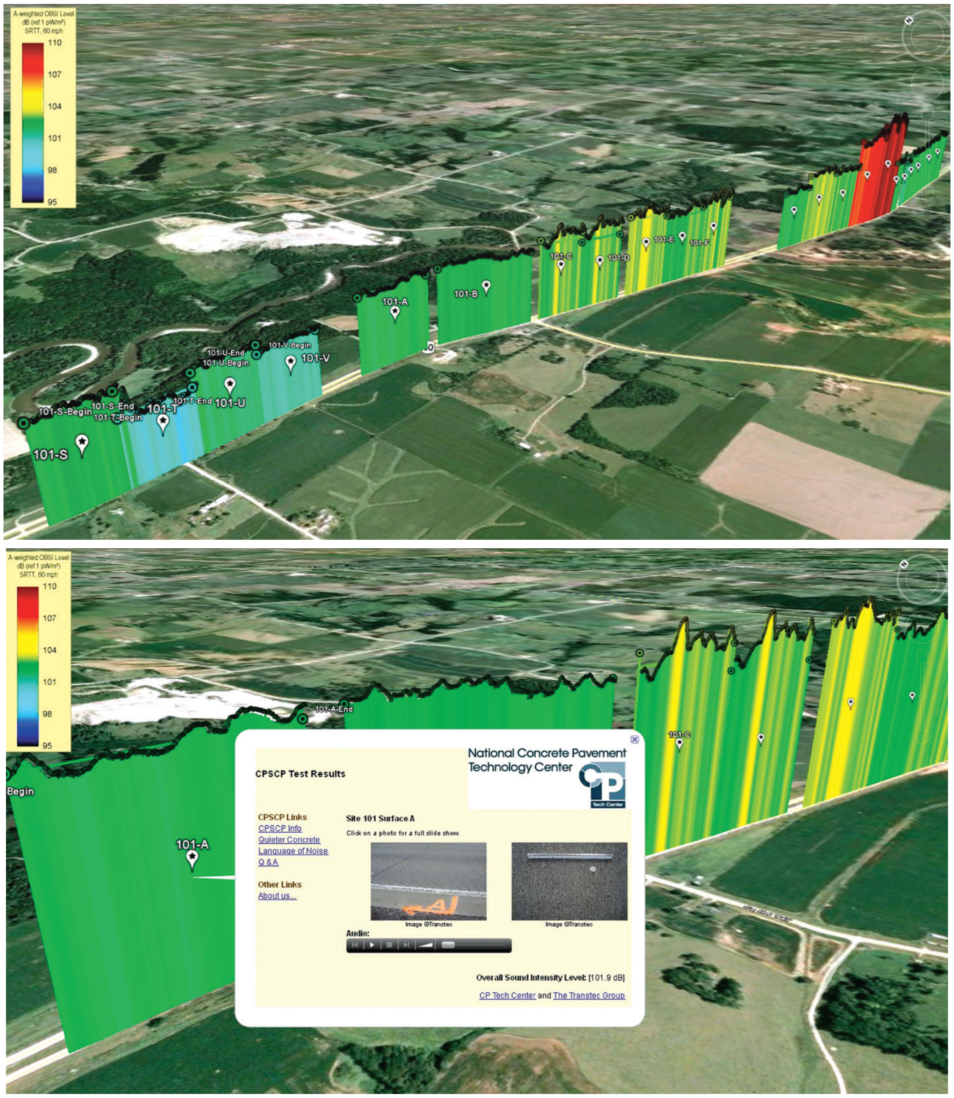

Figure 7. Google Earth reporting of OBSI results

For more information

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About the Concrete Pavement Surface Characteristics Program

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 Departments of Transportation (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.

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