Tire–Pavement Noise Results From California PCCP and HMA Pavements

Erwin Kohler,[1] Linus Motumah,[2] Bruce Rymer,[3] and John Harvey[4]

ABSTRACT

Traffic noise generated by tire–pavement interaction is a matter of major concern for the California Department of Transportation (Caltrans). Research is underway in California and other States to evaluate tire–pavement noise characteristics of both concrete and asphalt pavements using the on-board sound intensity (OBSI) method, which allows for detailed characterization of noise levels at the source. In California, both concrete and asphalt pavement research studies are being conducted by the University of California Pavement Research Center (UCPRC) in collaboration with and funding from Caltrans. The concrete pavements and bridge decks study involves a total of 144 sections in different regions throughout the State. The surface textures evaluated in the study comprise of longitudinal tining, diamond grinding, diamond grooving, and burlap drag. Preliminary results indicate that diamond-ground surfaces can be the quietest of the concrete pavement surface textures. With only part of the test sections analyzed, OBSI levels from California concrete pavements range between 101.2 and 107.3 dB(A). The asphalt pavement research evaluates tire–pavement noise characteristics and performance properties of about 70 sections from throughout the State. This study considers acoustic and structural performance of four main asphalt surface types: open-graded asphalt concrete (OGAC), rubberized open-graded asphalt concrete (RAC-O), rubberized gap-graded asphalt concrete (RAC-G) and dense-graded asphalt concrete (DGAC). OBSI measurements indicate that average noise levels increased by 1.3 dB(A) from 100.8 dB(A) to 102.1 dB(A) over the 2-year period. Overall, a noise level of around 100.0 dB(A) measured at 60 mi/h (96 km/h) using the OBSI method appears to be a reasonable goal for both concrete and asphalt quieter pavements, based on the UCPRC data and other studies. Further analysis on the data being collected will answer questions about acoustic durability of different types of concrete and asphalt pavements.

INTRODUCTION

Considerable developments in the area of tire–pavement noise have occurred in California. Research in this area is managed through the California Department of Transportation (Caltrans) Quieter Pavement Research (QPR) program, under the overall technical direction of the Quieter Pavement Task Group, which includes the Divisions of Pavement Management, Environmental Analysis, Engineering Services, and Research and Innovation. The work started in the late 1990s with the construction of highway noise monitoring sections, and most notably with the development of the on-board sound intensity (OBSI) method. As part of the Caltrans QPR program, the

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University of California Pavement Research Center (UCPRC) adopted and evaluated the OBSI method in 2005, and began testing asphalt pavement sections in early 2006 (*1*, *2*).

There are reports of complaints about traffic noise dating as far back as the time of the Roman Empire. The "*roar of the iron-tyred wheels*" in London around 1870 has been documented (*3*). In the last decade traffic noise has become a growing public concern, while at the same time it has become more obvious that tire–pavement noise now constitutes a major problem in traffic noise in industrialized countries (*4*). Tire–pavement noise dominates highway noise at speeds as low as 35 mph. In recognition of this concern, the design, construction, and preservation of quieter pavements to reduce noise has received increasing attention in California as well as nationally and internationally. With the short-term benefits of quieter pavements at least partially documented, recent attention has focused on developing a better understanding of their long-term acoustic benefits (*2*).

The OBSI Method

The sound intensity method of measuring tire–pavement noise was originally developed in the early 1980s, and began to be adapted around 2002 in California to quantify tire–pavement noise performance of different pavement types (*5*). Early databases of Arizona and California pavements showed encouraging results regarding the use of the OBSI method. In 2004 Caltrans took the OBSI measurement process to Europe to collect data on a wide variety of quiet pavements in several countries (*6*).

Asphalt and Concrete Pavements Tire–Pavement Noise Evaluation

From analysis using the early Arizona and California database it was concluded in 2004 that, *"at least in the US, the absolute level of quiet PCC does not approach that of quiet AC"* (*7*). The concrete industry responded to this finding, and by 2005 had built test sections in Iowa through the National Concrete Pavement Technology Center (CP Tech Center). The CP Tech Center, with technical assistance from The Transtec Group, had evaluated as of May 2008 nearly 1,500 concrete pavement textures in the United States and Europe (*8*) with the objective of finding ways to build quieter concrete pavements. Results of this effort, in terms of OBSI levels on four "families" of typical concrete pavements, are shown in Figure 1.

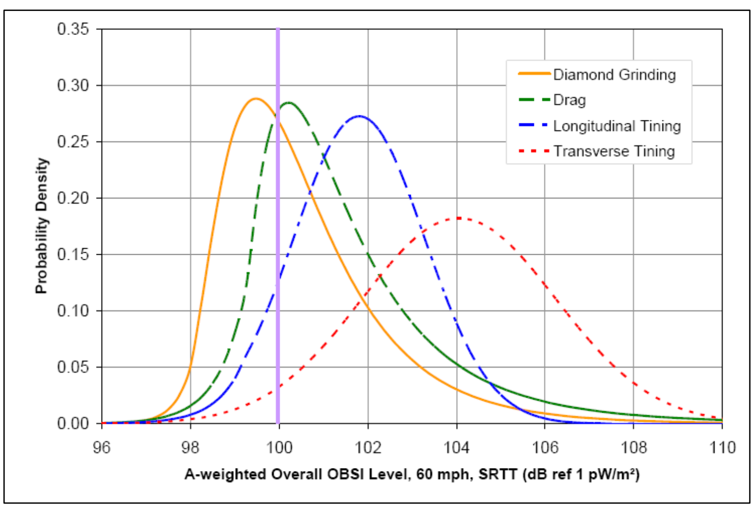


Figure 1. Distributions of OBSI noise levels for conventional concrete pavement textures as reported by the CP Tech Center (*8*).

UCPRC ASPHALT PAVEMENT MONITORING

A comprehensive experiment was started by the UCPRC as part of the Caltrans QPR program in 2005 that considers performance of four main asphalt surface types, and the effect of rainfall, traffic, mix parameters, surface properties, and age. The pavement types in the experiment are open-graded asphalt concrete (OGAC), rubberized open-graded asphalt concrete (RAC-O), rubberized gap-graded asphalt concrete (RAC-G) and dense-graded asphalt concrete (DGAC). In addition, special sections placed by various Caltrans pilot and research projects were also included in the field and laboratory plan for monitoring (*3*,*9*).

A 2008 report (2) summarizes the OBSI results as well as other performance aspects besides noise, such as permeability, ride quality, distress development, and friction. The report presents the 1st and 2nd years' data of field and laboratory measurements for the main factorial set of the four types of asphalt surface with ages at the start of the study in three age categories: less than 1 year; 1 to 4 years; and 4 to 8 years. The 2008 report also includes results for the Division of Environmental long-term noise monitoring sections of various ages at the start of the study. The data obtained during the 3rd year of testing are being analyzed and indicate, as can be expected, a yearly increase in OBSI levels for the nearly 70 sections being evaluated in the asphalt pavement QPR study.

Figure 2 presents the OBSI results on all sections as measured in 2006, 2007, and 2008, along with the average for all sections. A regression line was fitted to the data to predict the 2009 OBSI average. From the chart it is possible to conclude that some sections remain quiet, but others become louder. The sections in this plot could be interpreted as a trend for the entire population of asphalt pavements in California. In 2 years these pavements have become, on average, 1.3 dB(A) louder, changing from 100.8 to 102.1 dB(A).

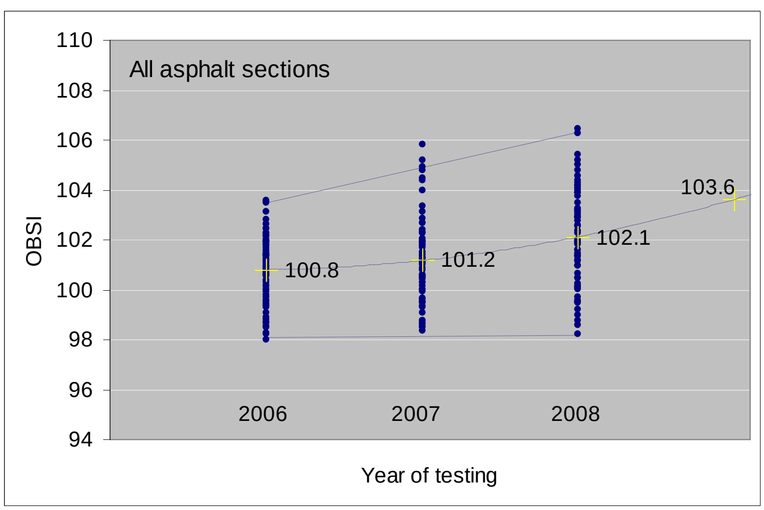


Figure 2. Trend for the average OBSI over 3 years for the set of asphalt pavement monitoring sections in California.

Figure 3 presents the data from Figure 1 in a disaggregated manner by pavement type and showing the age of the sections at the time of OBSI measurements. There are sections that were tested about 6 months after construction during the 1st year of the study, and there are sections that were almost 16 years old the last time they were tested. The average section age is

5.5 years. Linear trends have been fitted to the OBSI data of each pavement type. The results indicate that the quietest asphalt pavement surface mixes are the rubberized open graded, followed by conventional open graded, rubberized gap graded, and dense graded in that order. One interpretation from this plot is that no asphalt pavement that has been in place for more than 8 years is producing noise levels lower than 100 dB(A). Another representation of the data is shown in Figure 4 where all the OBSI results of each pavement surface mix type are grouped together and sorted in ascending order. An extra category, labeled as “other,” is included in Figure 4 and includes bonded wearing courses, experimental rubberized mixes, mixes with modified binders, and open-graded mixes with 19-mm (¾-in) aggregates.

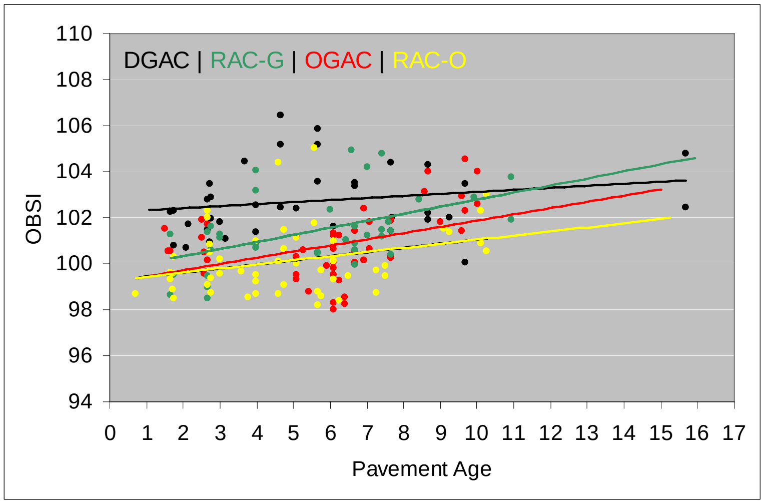


Figure 3. OBSI versus pavement age for four types of asphalt pavements.

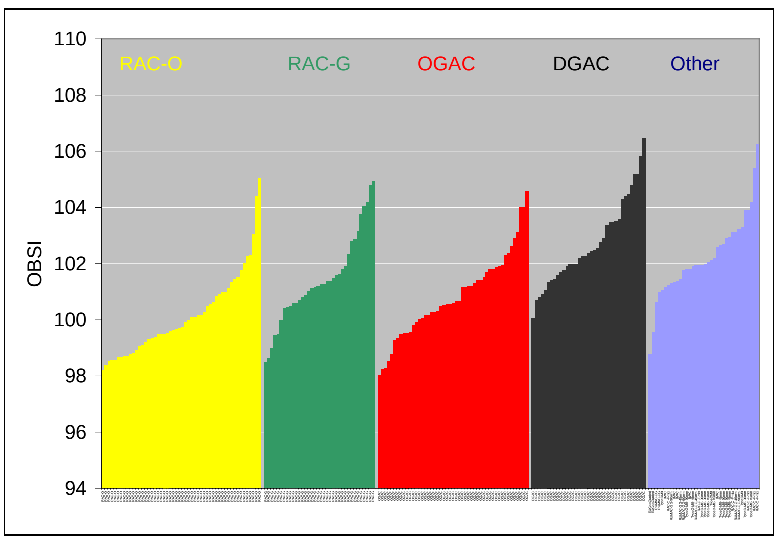


Figure 4. Comparison of OBSI levels for different types of California asphalt pavements.

UCPRC PCC PAVEMENTS EVALUATION

A Caltrans QPR study being performed by the UCPRC since August 2008 is evaluating noise levels on concrete pavement. As in the case for the asphalt pavements, Caltrans requested an initial 2-year study, but this may be extended depending on the results. So far, 120 pavement sections and 24 concrete bridges have been tested, but the data analysis has only begun. The reason to include bridge decks is that California bridge decks very often have transversely tined surface textures, and are a source of public concern due to higher noise levels. Most pavements in California have been built with longitudinal tining. Besides longitudinal tining, other concrete pavement surface textures evaluated in this study include burlap drag, diamond grooving, and diamond grinding. Transversely tined concrete pavements are not included in this study because transverse tining of concrete pavements was discontinued by Caltrans after a study conducted in 1972-1976 (*11*) that specified that pavements should be given an initial texturing with burlap drag and a final texturing with a "spring steel tine device" to produce longitudinal grooves parallel to the center line. Among other reasons given for discontinuing transverse tining of concrete pavements is that "*A greater tire noise is generated by transversely tined concrete pavement and there is belief among some highway engineers that wear rates are also higher*" (*11*).

Table 1 presents the number of sections of each texture type in the study. All these sections were tested between September 2008 and early January 2009, at sites spanning 17 California counties.

Table 1
Texture Types and Number of Sections for Pavements and Bridges in The UCPRC PCC Study

Element	Texture	Sites	Sections	Total
Pavements	Burlap drag	15	43	120
	Diamond grind	15	30	
	Longitudinal tine	8	28	
	Diamond groove	6	18	
	Longitudinal broom	1	1	
Bridges	Transverse tine	5	8	24
	Transverse broom	3	5	
	Diamond grind	2	4	
	Polyester	4	4	
	Longitudinal broom	2	2	
	Longitudinal tine	2	1	

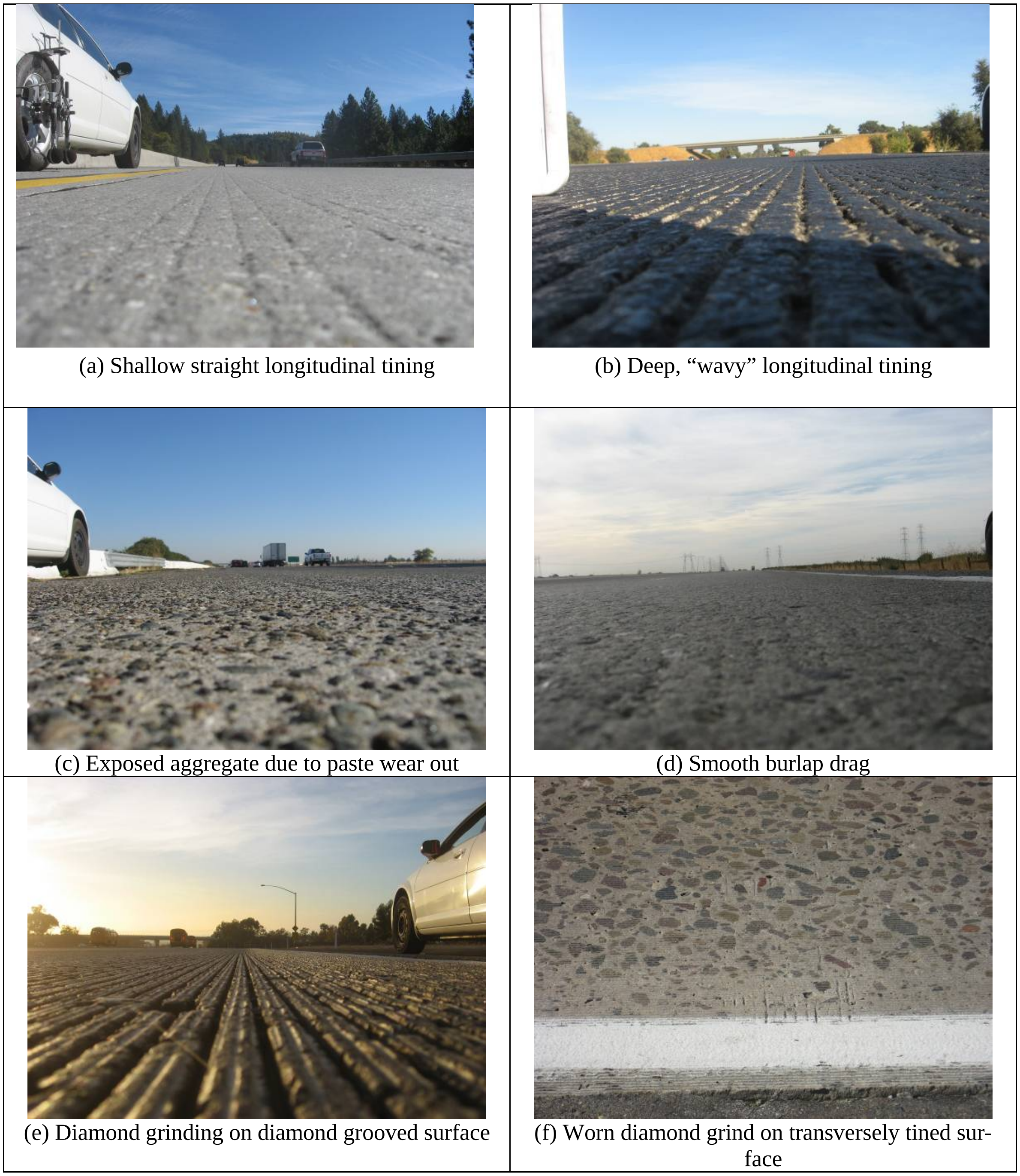
Methodology for Concrete Pavement Testing

In designing the UCPRC field experiment to test tire–pavement noise on concrete pavements, it was necessary to preserve the same testing protocol used on the asphalt pavements in order to have comparable results. It was also necessary to introduce additional testing to satisfy the special needs of jointed pavements. To preserve the testing method, three runs of 5 seconds at 60 mph with the SRTT tire were made on each section (440 ft sections). Optical triggering was used to ensure that the exact same stretch of road was measured in each of the three runs, and to also ensure that the same section will be tested in subsequent years. Since texturing of fresh concrete pavement is affected by concrete slab placement conditions, it is very possible that texture depth may vary within a few hundred feet. Accordingly, it was decided that three consecutive 5-second sections at 60 mi/h (96 km/h) (1,320 ft [402 m] long) should be tested. A speed correction factor was applied because keeping speed constant in live traffic for such a long stretch is often very difficult to do. The speed correction factor being used for now is +/- 0.3 dB(A) per mile change in testing speed (*14*). The effect of joints and cracks on tire–pavement noise is being explored because the joint slap noise acts together with the effect of texture (*15*). To investigate the joint slap effect, the longitudinal profiles were collected at 1-in. (25-mm) intervals, which allows for joint identification, along with joint faulting (using inertial profilometer). Average joint width is also being documented. Tire–pavement noise levels are measured at 15-milisecond intervals using the OBSI equipment to try to relate noise to joint width and faulting.

Texture Types and Variations

One observation that is worth noting is the wide range of textures encountered in the field in California. The longitudinal tining specification resulted in a variety of textures, ranging from straight lines to very "wavy" lines, with groove depth that varies between deep and shallow. The tining specification only mentions the type of instrument to apply the texture, but the results are highly variable. An analytical complication comes from the fact that pavements are "re-textured", as in the case of diamond grinding on top of original tined or burlap dragged surfaces that have exposed aggregates due to wearing out of the concrete mortar. Some examples of textures are shown in Figure 5.

Given the fact that nominal texture types show a great deal of overlap in terms of noise levels (a noise level cannot be associated unequivocally to a texture), it is evident that more effort should be placed on engineering characterization of pavement textures that would eventually allow for prediction of OBSI levels.



(a) Shallow straight longitudinal tining

(b) Deep, “wavy” longitudinal tining

(c) Exposed aggregate due to paste wear out

(d) Smooth burlap drag

(e) Diamond grinding on diamond grooved surface

(f) Worn diamond grind on transversely tined surface

Figure 5. Different texture types included in the study.

Short Interval Noise Data

The 15-millisecond noise data collected at 60 mi/h (96 km/h) means that each data point represents the noise level over a distance of approximately 16 in. (406 mm) (not even a full tire rotation). Although this type of information may not correlate well with the 5-sec typical interval used for OBSI, it at least allows identification of changes in texture types, and combined with the profile data at 1-in. (25-mm) interval, allows for an estimation of the effect of joint slapping on the overall noise. Figure 6 shows an example of 15-ms noise data (blue series) and the correspondence to faulted joints on the pavement elevation profile (pink series). Data from other sections seem to indicate a strong effect from not only faulted joints but also from joints that are wide open. These preliminary data seem to confirm laboratory findings that joint slap creates a transient noise event which can be 4-6 dB(A) louder than tire–pavement noise produced by the pavement texture alone (*15*).

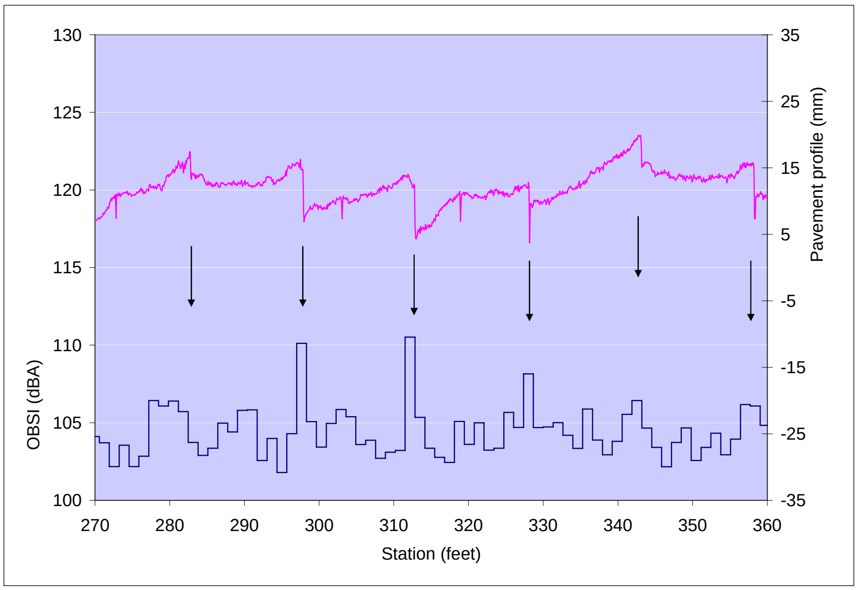


Figure 6. Noise level spikes and correspondence to joint faulting.

Surface Texture Effect

So far, with only a fraction of the data analyzed, some effect from surface texture starts to appear. Figure 7 shows that diamond-ground surfaces can be the quietest, followed by the diamond grooved. No clear conclusions can be made yet regarding longitudinal tining and burlap drag. It must be noted that transverse tining is not part of the set of textures on pavements, but it is being included in the bridge decks portion of the study. The average OBSI level of the 73 pavement sections included in Figure 8 is 104.3 dB(A); the lowest is 101.2 dB(A) and the highest is 107.0 dB(A). The lowest OBSI level was measured on a diamond-ground pavement, while the highest values were measured on a burlap drag surface whose surface is worn out leaving exposed large aggregate (see Figure 5c), and on a diamond-ground surface with a base texture (original texture) of transverse tining (see Figure 5f). Although the lowest values are not as low as those reported in Figure 1, the range of OBSI levels measured in this study are comparable to the values reported in the literature.

A small study on texture will be conducted using detailed texture profiles on a limited number of sections, to complement the results obtained with the high-speed texture laser. The detailed texture data has been obtained using a device with a single laser that scans an area of 3 by 4 in. (76 by 102 mm). The device and an example of the results for a diamond-grooved surface on California State Route 58 in the Mojave desert are shown in Figure 8.

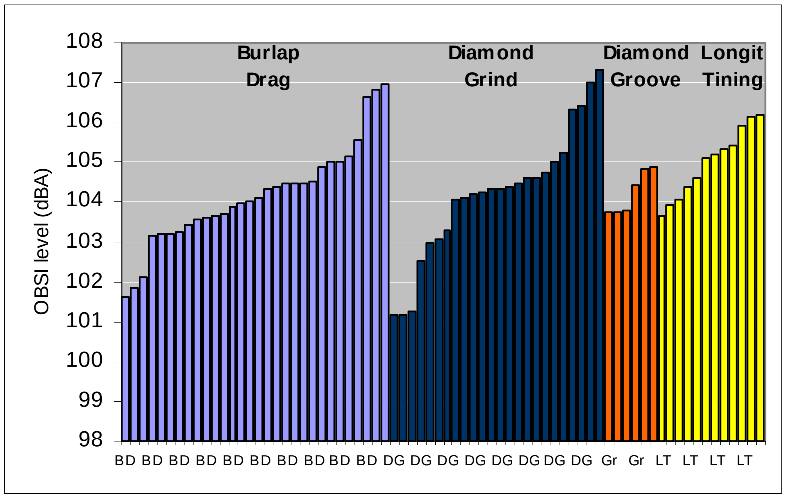


Figure 7. Tire pavement noise for some of the concrete pavements with different textures from California QPR study.

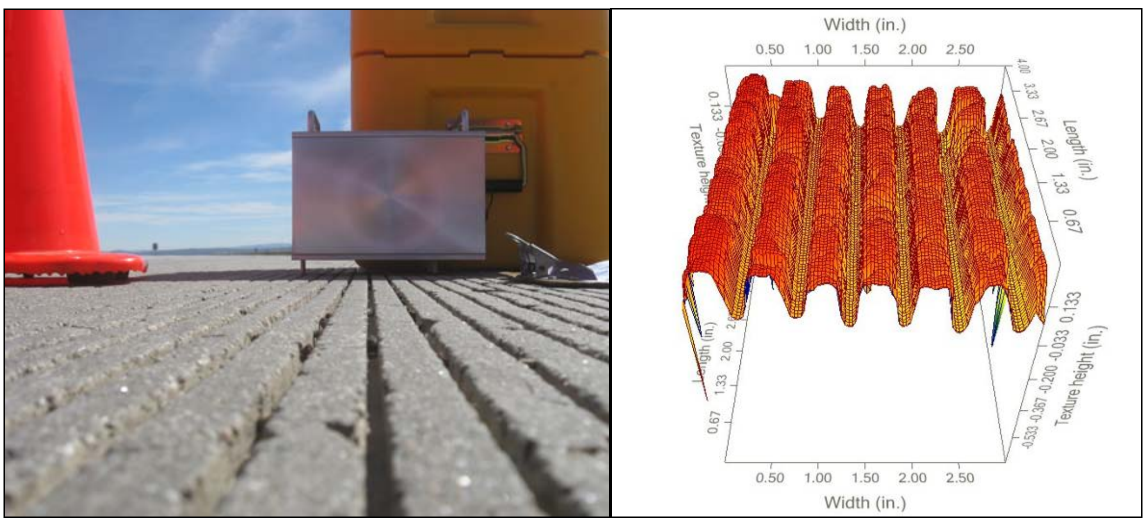


Figure 8. Laser scanner and results of texture elevation on a diamond-grooved pavement surface.

COMPARISON BETWEEN ASPHALT AND EXISTING PCC NOISE DATA

The results from early OBSI measurements in Arizona and California (*12*) indicated that longitudinally tined concrete pavements may not be all that different in terms of tire–pavement noise levels compared to asphalt pavements over the entire service life of the pavement structure. The issue of acoustic durability of different types of pavements, surface textures, and treatments is an important objective of the California QPR Program. It basically aims at comparing the rate of tire–pavement noise change with age for concrete pavements versus those of asphalt pavements. A study in the early 1990s by the Washington Department of Transportation (*13*) indicated that asphalt pavements start out quieter than Portland cement concrete pavements, but the noise level increases with age to the extent that after about 6 to 8 years the noise levels from asphalt pavements become greater than those of concrete pavements.

The concrete pavement noise data collected by the CP Tech Center (Figure 1) and the asphalt pavement noise data collected by the UCPRC are shown in Figure 9 in the form of cumulative distributions for the four major pavement types on each study. The quietest concrete pavements are the diamond-ground surfaces, while the quietest asphalt pavements are the rubberized open graded mixes. OBSI levels of about 100 dB(A) can be expected for the 50th percentile of the sections with each one of these two types of quiet pavements. The lower 10th percentiles are between about 98 and 101 dB(A) for all four types of both concrete and asphalt pavement, while the 90th percentiles are between about 103 and 106 dB(A) for concrete and 102 and 105 dB(A) for asphalt. The upper 90th percentiles for the quietest asphalt (RAC-O) and concrete (diamond-grind) surfaces are 103 and 102 dB(A), respectively.

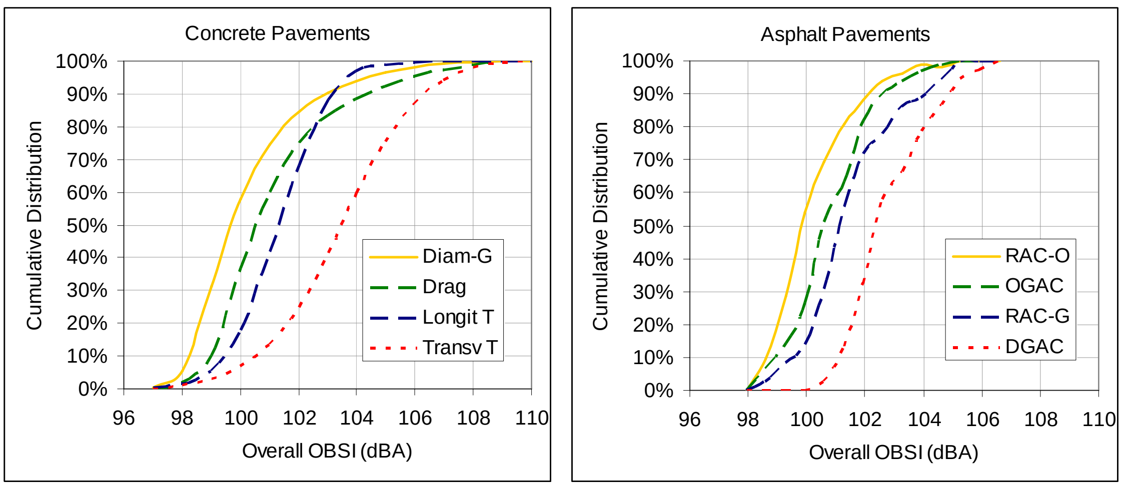


Figure 9. Cumulative distributions of OBSI levels for concrete pavements (CP Tech Center data) and asphalt pavements (UCPRC data).

Some caution should be exercised with the information shown in Figure 9 for several reasons. First, the asphalt pavement data comes only from California sections, whereas the concrete pavement data comes from a nationwide database. Second, the OBSI levels have been collected using the draft AASHTO Standard for OBSI, which has been evolving during the time of collection. As of January 2009, there is not yet an official provisional protocol. This may cause slight differences in the way the data are collected, which has to do with acoustic data-processing, microphone arrangements, and other parameters affecting OBSI results that are still topics of research. It should also be noted that the reference test tire has also been changed and this impacts OBSI noise levels, although transformation functions have been developed so long-term comparisons can still be made.

A study conducted in May 2008 (*10*) compared the results of the OBSI equipment operated by four organizations. Measurements were taken at the same time and on the same pavement sections in Mesa, Arizona. It was found that all the OBSI devices produced results within 1.0 dB(A). However, the OBSI equipment used by the UCPRC to collect data from the asphalt sections produced slightly higher OBSI measurements, while the OBSI device used by the CP Tech Center for the concrete sections produced slightly lower values compared to the average of the four devices; but all results were within 1.0 dB(A).

CONCLUSIONS

The following conclusions can be drawn at this point from this ongoing research study:

- The OBSI levels measured so far on California concrete pavements are within the ranges reported in the literature, and the results confirm that diamond-ground surfaces are the quietest, although not as quiet as reported by other researchers.

- As indicated in reference (*8*), it is important that the highway community establish rational goals for tire–pavement noise. Based on the work conducted to date at the CP Tech Center and at the UCPRC, a noise level of 100.0 dB(A) measured at 60 mi/h (96 km/h) using the OBSI method appears to be a target that both asphalt and concrete pavements can achieve for some time after initial construction.

- The UCPRC study on noise monitoring of asphalt pavement shows that after 2 years, the average noise from about 70 sections has increased from 100.8 dB(A) to 102.1 dB(A). This is an increase of 1.3 dB(A) over a 2-year period. It must be noted that many RAC-O sections that are less than 8 years old are still between 98 and 100 dB(A).

- In general, none of the asphalt sections in the UCPRC study after 8 years in service offers OBSI levels lower than 100 dB(A).

- Preliminary analyses on the joint slap noise on concrete pavement seem to confirm previous finding that reported effects on the overall noise. This opens the possibility to reduce concrete pavement noise not only through surface texture enhancements, but also by improving joint construction techniques such as narrower joints or avoidance of protruding or highly depressed joint sealant.

- Further analysis on the data being collected will answer questions about durability of acoustic properties of different types of concrete pavements. For that purpose accurate information on year of construction for each pavement sections is being compiled, but it is safe to say that most of the sections are more than 10 years old.

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The contents of this paper reflect the views of the authors, who are responsible for the facts and accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the State of California or the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

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