Comparison of Surface Characteristics and Pavement/Tire Noise of Various Thin Asphalt Overlays

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ABSTRACT
Traffic noise has become a major concern in the last decade and many states have been looking for solutions to reduce noise levels. Reducing noise levels by proper selection of surface type may provide an alternative to sound walls. California Department of Transportation (Caltrans) has been using different open-graded mixes to reduce highway noise levels and to improve wet weather driving conditions. Before placing more open-graded mixes, there is a need to identify their noise reduction properties, durability, and safety, and to compare these with other asphaltic mixes. In 2005, Caltrans initiated a long-term program to investigate and monitor field performance of different open-graded mixes and other commonly used asphalt surface mixes. This paper summarizes part of the first-year measurements of relevant parameters from asphalt pavements with different surface mixes. It was found that open-graded mixes generally reduce the tire/pavement noise level, and the amount of reduction is correlated with air-void content and surface texture. However, the noise-reduction benefit may be lost with the increase of pavement age.
INTRODUCTION

Open-graded asphalt concrete (OGAC) mixes have been used in the United States for more than 50 years, primarily because they can reduce hydroplaning, water splash and spray, and therefore can reduce wet weather accident rates. Open-graded mixes have also been shown to reduce tire/pavement noise (1, 2, 3). In the last decade, open-graded mixes have been extensively used in California to obtain these benefits, while obtaining collateral benefit from their noise reducing properties. However, the performance of open-graded mixes, in terms of durability, safety, and ride quality, as well as their noise reducing properties compared to other mixes, is not well known. For open-graded mixes to be accepted as a noise mitigation tool there should be proof of adequate performance and of lower life cycle costs compared to competing alternatives.

The California Department of Transportation (Caltrans) spends around $350–$800 million annually on pavement rehabilitation and maintenance projects, of which approximately 15% is spent on open-graded asphalt projects (4). A comparative study of the performance of different open-graded mixes and other commonly used asphaltic surfaces would help to identify the best strategy to give best performance and to mitigate traffic noise and may result in very large cost savings.

The University of California Pavement Research Center (UCPRC) was asked by Caltrans to conduct research in the areas of acoustics, safety, durability, and ride quality for different types of open-graded and other asphalt mixes used in California. In this study, safety is evaluated in terms of skid resistance (friction) and permeability measured on pavement surfaces.

The preliminary findings presented here are part of a larger project that involves a greater number of pavement sections, from which field and laboratory data are still being collected. All of the pavement sections will be monitored over up to ten years. This paper presents first round correlations of tire noise levels with selected pavement characteristics. The analysis focuses on comparing the different pavement types over a number of measured parameters.

TEST SECTIONS

The work presented here covers six Caltrans pavement test sites containing various types of in-service asphalt concrete sections. These sites have been acoustically monitored by the Caltrans Division of Environmental Analysis. A total of 23 sections were identified from these sites. The six sites are identified in Table 1 by location, using county and highway number. Thicknesses and surface types are indicated (see nomenclature at the bottom of the table). Construction season, average annual daily traffic (AADT), and average annual daily truck traffic (AADTT) are also included to help characterize the sites.

The Yolo 80, SAC 5 and SM 280 sites are interstate highways while the other sites are state routes. What follows is a brief description of each site:

- The Yolo 80 test site is an OGAC overlay on top of DGAC with a nominal maximum aggregate size (NMAS) of 9.5 mm.
- The Sacramento 5 test site is a RAC-O overlay on jointed concrete pavement with a NMAS of 12.5 mm. Measurements were conducted on both directions.
- The Los Angeles 138 test site consists of five pavement types, as shown in Table 1. The BWC section is a gap graded hot-mix asphalt layer applied over a thick polymer modified asphalt emulsion membrane. The DGAC section acts as a control section for comparison purposes. All sections have NMAS of 12.5 mm. Measurements were conducted on both directions, except for the DGAC section, totaling nine sections.
The mixes at the Fresno 33 test site consist of three rubberized asphalt concrete (RAC) processes: RAC-G is wet process rubberized asphalt concrete; RUMAC-GG is dry process rubber modified asphalt concrete, and Type D MB (dense-graded) and Type G MB (gap graded) are terminal blend process asphalt rubber concrete. Two thicknesses, 45 mm and 90 mm, are included for each rubberized mix. A 90 mm conventional DGAC control section completes the series of nine sections. All the test sections have NMAS of 19 mm.

The San Mateo 280 test site consists of only one section of RAC-O overlay of AC on top of jointed concrete, and it has a NMAS of 12.5 mm.

The Los Angeles 19 test site consists of one section of European Gap-graded asphalt concrete with a NMAS of 12.5 mm using a European specification.

### TABLE 1 Pavement Sections in Caltrans Environmental Noise Monitoring Sites

<table>
<thead>
<tr>
<th>Site Location</th>
<th>Surface Types</th>
<th>Construction Season</th>
<th>AADT</th>
<th>AADTT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yolo 80</td>
<td>30-mm OGAC</td>
<td>Summer 1998</td>
<td>134,000</td>
<td>8,991</td>
</tr>
<tr>
<td>Sacramento (SAC) 5</td>
<td>30-mm RAC-O</td>
<td>Summer 2004</td>
<td>122,000</td>
<td>16,116</td>
</tr>
<tr>
<td>Los Angeles (LA) 138</td>
<td>30-mm OGAC, 75-mm OGAC, 30-mm RAC-O, 30-mm BWC, 30-mm DGAC</td>
<td>Spring 2002</td>
<td>4,300</td>
<td>606</td>
</tr>
<tr>
<td>Fresno (FRE) 33</td>
<td>45-mm RAC-G, 90-mm RAC-G, 45-mm RUMAC-GG, 90-mm RUMAC-GG, 45-mm Type-G MB, 90-mm Type-G MB, 45-mm Type-D MB, 90-mm Type-D MB, 90-mm DGAC</td>
<td>Summer 2004</td>
<td>7,575</td>
<td>1,439</td>
</tr>
<tr>
<td>San Mateo (SM) 280</td>
<td>40-mm RAC-O</td>
<td>Fall 2002</td>
<td>110,000</td>
<td>2,552</td>
</tr>
<tr>
<td>Los Angeles (LA) 19</td>
<td>35-mm European (EU) Gap Graded Asphalt Concrete</td>
<td>May 2005</td>
<td>36,500</td>
<td>1,861</td>
</tr>
</tbody>
</table>

Notes: OGAC: Open-graded Asphalt Concrete  
RAC-O: Rubberized Open-graded Asphalt Concrete  
BWC: Bonded Wearing Course  
RAC-G: Rubberized Gap-graded Asphalt Concrete (wet process)  
RUMAC-GG: Rubber-modified Asphalt Concrete (dry process)  
Type-D MB: Dense-graded Rubberized Asphalt Concrete (terminal blend)  
Type-G MB: Gap-graded Rubberized Asphalt Concrete (terminal blend)  
DGAC: Dense-graded Asphalt Concrete

### METHODOLOGY

Data were collected on each of the 23 test sections during traffic closures, followed by additional measurements at normal highway speeds. The types of data and corresponding sampling/test methods during and after traffic closures are shown in Table 2.
TABLE 2 Field Data Collection Methods

<table>
<thead>
<tr>
<th>Type of Data</th>
<th>Specific Test/Sampling</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pavement cores</td>
<td>100 mm and 150 mm in diameter</td>
</tr>
<tr>
<td>Condition survey</td>
<td>Caltrans condition survey manual</td>
</tr>
<tr>
<td>Microtexture</td>
<td>British Pendulum, ASTM E303</td>
</tr>
<tr>
<td>Permeability</td>
<td>Falling Head Method</td>
</tr>
<tr>
<td>Tire/pavement noise</td>
<td>On-Board Sound Intensity (OBSI)</td>
</tr>
<tr>
<td>Roughness</td>
<td>IRI from laser profilometer, ASTM E1926</td>
</tr>
<tr>
<td>Macrotexture</td>
<td>Laser profilometer, ASTM E1845</td>
</tr>
</tbody>
</table>

Twelve cores were taken from each section, four of which are 100 mm in diameter and the rest are 150 mm. Six of the twelve cores were taken from the right wheelpath and the other six were taken from the non-trafficked area in-between the wheelpaths. Each section was 150 m long, and the cores were collected at 25-m intervals. A condition survey was conducted over the length of the section, recording type, severity, and extent of the distresses using the Caltrans current condition survey method (5). Permeability was measured next to each core, using a falling head permeameter developed by the National Center for Asphalt Technology (NCAT). Friction measurements were also conducted next to each core using the British Pendulum Tester following ASTM E303. By measuring next to each core, twelve permeability and friction measurements were obtained at each section.

Pavement/tire noise, roughness, and macrotexture measurements were obtained at highway speeds at the exact same section where the cores were taken. Traffic noise can be measured near the source by On-Board Sound Intensity or Close Proximity Methods, or way-side by Pass-By Method. The On-Board Sound Intensity (OBSI) method was used to measure the tire/pavement noise. OBSI is a two channel measurement procedure to evaluate sound intensity levels near the tire/pavement interface (6). The sound intensity probe consists of two 25 mm microphones spaced 16 mm apart and preamplifiers in a side-by-side configuration. A foam windscreen is placed over the microphones to reduce the wind noise. The probe is positioned 100 mm away from the plane of the tire sidewall and 75 mm above the pavement surface, mounted to the rear tire on the passenger side of a car. Signals from the microphones are input to a two channel real time analyzer. Measurements are taken at 97 km/h (60 mph), at two intensity probe locations, one at the leading edge and the other at the trailing edge of the tire/pavement contact patch. Three replicate measurements are collected at each probe location. Air and pavement temperatures are collected during OBSI measurements as well as during friction measurements. Roughness is measured with an inertial laser profiler mounted on the same passenger car used for the sound intensity measurements. It is reported as International Roughness Index (IRI) on each wheelpath. Macrotexture was also measured with the profilometer using a high frequency sampling laser on the right wheelpath, and it is reported in terms of Mean Profile Depth (MPD) and Root Mean Square (RMS) of profile deviations.
Aggregate gradation and air-void content of the mix were measured from cores collected at each section. Aggregate gradations were obtained by sieve analysis according to ASTM C136 and ASTM C117 using aggregates obtained from cores after burning off the binders with the ignition oven. Aggregates on the cut face of the cores were removed prior to determination of maximum density and the ignition oven. Air-void contents were calculated using the bulk specific gravity and the theoretical maximum specific gravity. Bulk specific gravity of the cores was measured using the Corelok method, while the theoretical maximum specific gravity was determined in accordance with ASTM D 2041.

RESULTS

The ranges of sound intensity level, air-void content, permeability, microtexture, macrotexture, and roughness were analyzed and compared for all OGAC, RAC-O, RAC-G, RUMAC-GG, Type G MB, Type D MB, EU Gap-graded, and DGAC sections. Descriptive statistics for different parameters as well as the number of sections, n, in each category are presented in Table 3 and Table 4.

According to the table, open-graded mixes (OGAC and RAC-O) have lower sound intensity levels than other mixes. The Yolo 80 section has the highest sound intensity level and drives up the average of the OGAC mixes. RAC-O mixes have the highest air-void content and permeability followed by OGAC mixes. Among all the Caltrans gap graded mixes (RAC-G, RUMAC-GG, Type G MB, and BWC), the RAC-G mixes have the highest air-void content and permeability followed by RUMAC-GG mixes. Rubberized asphalt mixes by the terminal blend process (Type G MB and Type D MB) and DGAC mixes have the lowest permeability, close to zero. In addition, Type G MB mix has the lowest air-void content among all the mixes. DGAC mixes have the highest BPN values while Type G MB mixes have the lowest. Mean profile depth (MPD) changes significantly according to the pavement type. The open-graded mixes (OGAC and RAC-O) have the highest MPD values while the Type G MB mixes have the lowest. IRI values for the test sections are close to each other, ranging between 0.7 and 1.7 m/km. Among all the mixes, Type G MB mixes have the lowest IRI values. Because these are thin overlays, the IRI would be significantly influenced by the underlying pavement.

### Table 3 Descriptive Statistics for Sound Intensity, Air-Void Content, and Permeability

<table>
<thead>
<tr>
<th>Surface Type</th>
<th>n</th>
<th>Sound-Intensity Level</th>
<th>Air-Void content</th>
<th>Permeability</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>dB(A)</td>
<td>(%)</td>
<td>(10^-2 cm/sec)</td>
</tr>
<tr>
<td>BWC</td>
<td>2</td>
<td>103.8 103.8 103.8</td>
<td>5.0 3.8 6.3</td>
<td>0.015 &lt;0.001 0.031</td>
</tr>
<tr>
<td>DGAC</td>
<td>2</td>
<td>103.9 103.8 104.0</td>
<td>6.5 6.4 6.5</td>
<td>&lt;0.001 &lt;0.001 &lt;0.001</td>
</tr>
<tr>
<td>EU-GG</td>
<td>1</td>
<td>101.9 101.9 101.9</td>
<td>11.8 11.8 11.8</td>
<td>3.200 3.200 3.200</td>
</tr>
<tr>
<td>OGAC</td>
<td>5</td>
<td>102.1 102.2 103.2</td>
<td>8.4 8.2 8.6</td>
<td>2.070 0.190 0.340</td>
</tr>
<tr>
<td>RAC-G</td>
<td>2</td>
<td>103.2 103.1 103.2</td>
<td>14.4 9.1 19.4</td>
<td>6.800 0.250 17.1</td>
</tr>
<tr>
<td>RAC-O</td>
<td>5</td>
<td>101.8 100.9 102.5</td>
<td>2 5.7 4.6 6.9</td>
<td>0.010 &lt;0.001 0.02</td>
</tr>
<tr>
<td>RUMAC-GG</td>
<td>2</td>
<td>103.8 103.7 103.9</td>
<td>4.2 3.7 4.7</td>
<td>&lt;0.001 &lt;0.001 &lt;0.001</td>
</tr>
<tr>
<td>Type-D-MB</td>
<td>2</td>
<td>104.6 104.4 104.7</td>
<td>3.5 3.3 3.7</td>
<td>&lt;0.001 &lt;0.001 &lt;0.001</td>
</tr>
<tr>
<td>Type-G-MB</td>
<td>2</td>
<td>104.4 104.3 104.4</td>
<td>6.5 6.4 6.5</td>
<td>0.015 &lt;0.001 0.031</td>
</tr>
</tbody>
</table>
Ongel, Kohler, Lu, and Harvey

### TABLE 4 Descriptive Statistics for Friction, Macrotexture, and Roughness

<table>
<thead>
<tr>
<th>Surface Type</th>
<th>British Pendulum Number (BPN)</th>
<th>Macrotexture (MPD) (microns)</th>
<th>IRI (m/Km)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n</td>
<td>Mean</td>
<td>Min</td>
</tr>
<tr>
<td>BWC</td>
<td>2</td>
<td>61</td>
<td>61</td>
</tr>
<tr>
<td>DGAC</td>
<td>2</td>
<td>63</td>
<td>60</td>
</tr>
<tr>
<td>EU-GG</td>
<td>1</td>
<td>59</td>
<td>59</td>
</tr>
<tr>
<td>OGAC</td>
<td>4</td>
<td>61</td>
<td>51</td>
</tr>
<tr>
<td>RAC-G</td>
<td>2</td>
<td>55</td>
<td>51</td>
</tr>
<tr>
<td>RAC-O</td>
<td>5</td>
<td>57</td>
<td>53</td>
</tr>
<tr>
<td>RUMAC-GG</td>
<td>2</td>
<td>54</td>
<td>53</td>
</tr>
<tr>
<td>Type-D-MB</td>
<td>2</td>
<td>57</td>
<td>55</td>
</tr>
<tr>
<td>Type-G-MB</td>
<td>2</td>
<td>52</td>
<td>51</td>
</tr>
</tbody>
</table>

Figure 1a shows the A-weighted sound intensity levels for each test section in ascending order. A-weighted sound intensity is a measure that roughly corresponds to the response of the human ear to sound. In the figure, test sections are named with the county, route, thickness, pavement type, and direction information. Pavements are categorized as OGAC, RAC-O, Gap Graded AC (that includes RAC-G, RUMAC-GG, Type G MB, and EU GG), DGAC, and Type D MB, and different pavement types are shown with different patterns. Figure 1b shows the overall A-weighted sound intensity levels by pavement type as boxplots, with the mean values shown next to each box. According to Figure 1a, Yolo 80 presents the highest sound intensity levels. This is possibly due to the old age of the pavement, over which mix aging and surface distresses have occurred. Sections with the same type but thicker surface layers have lower sound intensity levels than the thinner ones. However, this is a weak trend in a small set of data. According to Figure 1b, Type D MB mixes have the highest average sound intensity levels followed by Type G MB mixes. According to a comparison of LA 138 sections, it can be concluded that open-graded mixes may lower the noise levels by 4 dB(A) under the same traffic and climatic conditions. Comparison of all the sections suggests that a maximum of 4.5 dB(A) reduction may be obtained using open-graded mixes. Since as a general rule of thumb, human ears can differentiate between two levels of similar sounds that are at least 3 dB(A) different in level (7), the noise abatement by the open-graded mixes is quite significant.

Figure 2a shows the mean profile depth (MPD) for each test section and Figure 2b shows the MPDs for different pavement types as boxplots. SM 280 RAC-O section has the highest MPD while the FRE 33 Type G MB sections have the lowest. It can be seen from the boxplots that open-graded mixes, rubberized and non-rubberized, can have considerably larger macrotexture than dense and gap graded mixes, even though they typically use smaller nominal maximum aggregate sizes.

Figure 3 shows the permeability results for each test section on a logarithmic scale. At the FRE 33 site, Type D MB, Type G MB, and DGAC sections and the BWC WB section at LA 138 have permeability values very close to zero. The RAC-O mixes at SM 280 and SAC 5 RAC-O mixes have the highest permeability results while the DGAC, BWC Type D MB, and Type G MB mixes have the lowest.
FIGURE 1 A-weighted sound intensity levels (a) all sections ranked and (b) grouped by pavement type.
FIGURE 2 MPD for test sections: (a) all sections ranked and (b) grouped by pavement type.
Figure 4 shows the air-void content results. According to the plots, Type D MB and Type G MB mixes have the lowest air-void contents while open-graded mixes have the highest. The air-void contents of the open-graded mixes range between 8% and 20%. Caltrans specifies 18% air-void content for the design of open-graded mixes, both for rubberized (RAC-O) and traditional OGAC; however, only SAC 5 and Yolo 80 sections have air-void contents close to the specifications. The lower air-void contents of the open-graded mixes may be due to clogging and densification under traffic, or finer than specified aggregate gradations, which are currently being analyzed.

Figure 5a shows the BPN results (friction) for all the test sections. The LA 138 OGAC and DGAC sections have the highest friction values while the Yolo 80 section has the lowest. Figure 5b shows BPNs for different pavement types as a boxplot along with mean values for sections less than 5 years old (excludes the Yolo 80 section). According to figure, DGAC and OGAC mixes have the highest BPNs while the gap graded mixes have the lowest. Figure 6 shows BPNs for mixes with different gradations and binder types that are less than 5 years old as boxplots. Rubberized dense-graded mixes are the Type D MB mixes, non-rubberized dense-graded mixes are the DGAC mixes; rubberized gap graded mixes include RAC-G, Type G MB, and RUMAC GG while non-rubberized gap graded mixes are the BWC and EU Gap Graded mixes; rubberized open-graded mixes are the RAC-O mixes and non-rubberized open-graded mixes are the OGAC mixes. It can be seen that the rubberized mixes have lower friction values.
than the non-rubberized ones. Inclusion of rubber in the mix seems to reduce the skid resistance. Gap graded mixes, as a mix category, have lower friction values because all gap graded sections except the LA 19 EU section include rubber in the binder.
FIGURE 4 Air-void contents for the test sections (a) all sections ranked, (b) grouped by pavement type.
FIGURE 5  Comparison of BPNs (a) with all sections ranked and (b) grouped by pavement type for sections that are less than five years old.
British Pendulum Numbers (BPN)

<table>
<thead>
<tr>
<th>Type of Mix</th>
<th>BPN</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rubberized</td>
<td>65.0</td>
</tr>
<tr>
<td>Non-rubberized</td>
<td>57.0</td>
</tr>
<tr>
<td>Dense Graded Mixes</td>
<td>60.0</td>
</tr>
<tr>
<td>Gap Graded Mixes</td>
<td>53.0</td>
</tr>
<tr>
<td>Open graded Mixes</td>
<td>57.0</td>
</tr>
</tbody>
</table>

**FIGURE 6** Comparison of BPNs for conventional and rubberized asphalt mixes that are less than 5 years old.

Figure 7 shows the comparison of IRI values for all the test sections. The Federal Highway Administration (FHWA) classifies pavements with IRI up to 1.5 m/km as good, and with IRI between 1.5 and 2.68 m/km as acceptable (8). According to these criteria, all test sections were in good condition at the time of the measurements, except for the SAC 5 Southbound (SB) section that was acceptable.

**FIGURE 7** Comparison of IRI values for the test sections.
Pavement Condition
The LA 138 and FRE 33 sites contain various pavement types subjected to same traffic and weather conditions, which allows in each case for a direct comparison of materials. In general, LA 138 pavement sections were in good condition. They were all constructed at the same time in April, 2002 after earlier placement of a thin DGAC layer on top of cracked asphalt pavement. All of the LA 138 open-graded mixes show some raveling and have polished aggregates. Additionally, 75 mm OGAC and 30 mm RAC-O sections show low transverse cracks. The BWC section shows the greatest signs of distresses with medium severity transverse cracks while the control DGAC section was in the best condition with only one transverse crack.

At FRE 33, the RAC-G and RUMAC-GG sections presented low and medium severity transverse cracking, except for the 90mm RUMAC-GG that showed no distresses. Additionally, the 90 mm RAC-G shows raveling while the 45 mm RAC-G section shows longitudinal cracks. The four MB sections (Type G MB and Type D MB) suffer from bleeding which extends through the length of the wheelpaths. The control section DGAC shows no distresses.

The SAC 5 RAC-O sections, which were placed directly over PCC slabs, suffer from reflection cracks of transverse joints. The southbound (SB) direction shows less cracking compared to the northbound (NB) direction.

LA 19 and SM 280 sections show no distresses while the Yolo 80 shows raveling.

Based on the condition survey results, raveling is the most common distress of open-graded mixes which agrees with the earlier findings of Huber (9), while bleeding is the common distress for MB mixes. Reflection cracking is observed when open-graded mix is placed right on the top of PCC layers.

Relationship Between Tire/Pavement Noise and Pavement Parameters
The sound intensity measurements from three passes at each pavement section showed good repeatability. The difference among results from multiple runs is generally smaller than 1 dB(A), with a 0.4 dB(A) average difference and a 0.3 dB(A) standard deviation of the difference. The average of three measurements, therefore, was used for analysis.

In order to understand the tire/pavement noise levels by pavement type, the overall A-weighted sound intensity levels were correlated with the other measured pavement parameters: air-void content, permeability, MPD, RMS, BPN, IRI, NMAS, thickness and age. Pearson correlation coefficients and p-values were obtained. Significance level of 0.05 was used in the analysis. In the correlation analysis, the Yolo 80 section was excluded because it is much older (8 years old) than the rest of the test sections. The right wheelpath values of permeability, air void, roughness and friction measurements were used in the correlations.
FIGURE 8 A-weighted sound intensity levels versus air-void content, MPD, and RMS.
According to the analysis, overall sound intensity level is correlated with the product of air-void content and layer thickness, which is consistent with the findings in the literature (7). However, little correlation was found directly between the sound intensity and thickness. Thickness may help only when the air void content is large so further investigation of thickness effects on the noise reduction are needed. The overall sound intensity level is also correlated with macrotexture values (MPD and RMS). Both variables are negatively correlated with the sound intensity levels, meaning that the increase in the product of air void content and thickness or macrotexture may reduce the sound intensity level. The relationship between sound intensity levels and the product of air-void content and layer thickness is shown in Figure 8a. The coefficient of determination is 0.45 ($R^2$) which is shown next to the regression line. Figure 8b and Figure 8c show the correlation of sound intensity with MPD and RMS, respectively. A linear trend was fitted to the data and the coefficient of determination is 0.60 and 0.69 for MPD and RMS respectively.

Analysis of correlations among pavement parameters revealed that air-void content is positively correlated with permeability. In addition, MPD and RMS are highly correlated and both of them are correlated with air-void content and permeability. Since macrotexture (MPD and RMS) and air-void content are correlated, their effects on the noise intensity levels, therefore, are not distinguishable at this point in the analysis. A comprehensive regression analysis that explicitly considers the correlations between different parameters (predictors) will be conducted to quantify the effects of pavement characteristics on noise level once a larger data set is obtained. Another analysis that will be conducted later is the correlation of sound intensity levels at different frequencies with the various measured pavement parameters. For now only the overall sound intensity level is being used, but it is possible that several pavement parameters may have distinct effects on the tire/pavement noise level at different sound frequencies.

**SUMMARY AND CONCLUSIONS**

Twenty-three test sections with different asphaltic surfaces were analyzed with respect to their noise level, air-void content, permeability, texture, friction, roughness, and condition. The pavement types evaluated include rubberized and non-rubberized open-graded, gap graded, and dense-graded mixes. Pavement sections were ranked by the different pavement parameters. Pavement characteristics were categorized by mix type. Additionally, measured pavement surface characteristics were correlated with the sound intensity levels. Although the size of the sample data is relatively small in terms of number of pavement sections, the following conclusions could be drawn from the analysis of the sections included in this part of the investigation:

1. Sound intensity measurements indicate that open-graded mixes may reduce the tire/pavement noise up to 4.5 dB(A), compared with other asphaltic mixes. Open-graded mixes typically have higher air-void contents, permeability, and surface macrotexture (MPD) than gap or dense-graded mixes.

2. The sections with the same materials and under the same traffic and weather but with thicker layers seem to have lower noise levels. A moderate correlation was found between noise level and the product of surface layer thickness and air-void content. Increasing either the thickness or the air-void content may reduce the tire/pavement noise, but further investigation is needed.
3. Rubberized mixes provide less friction than non-rubberized mixes. The reason is not clear and more research is needed.

4. Open-graded mixes seem to be prone to raveling while MB mixes show bleeding probably due to the suspected higher binder content and the low air void content. Reflection cracking is more likely to occur when an open-graded mix is placed directly on top of PCC.

5. Air-void content is positively correlated with permeability. MPD and RMS are highly correlated and both of them are positively correlated with air-void content and permeability.

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REFERENCES


