COMPARATIVE MEASUREMENTS OF TIRE/PAVEMENT NOISE IN EUROPE AND THE UNITED STATES

Noise Intensity Testing in Europe (NITE) Study

State of California Department of Transportation

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16. ABSTRACT

Pavements in four European countries were measured for their tire noise performance in a manner identical to that done in the States of California and Arizona. This allowed the comparison of pavements that provided a range of noise performance from quiet to noisy and the examination of different pavements design approaches between Europe and the southwestern states. A total of sixty-eight pavements were measured in Europe for comparison to over two hundred pavements measured in California and Arizona. This comparison indicated that the range of pavement tire noise levels was similar between both regions with the quietest European pavements performing slightly better than the best in California or Arizona. Several constructions not generally in use in the U.S. were evaluated in Europe and found to perform well within their respective pavement category. These included double layer porous asphalt of fine aggregate size, porous Portland cement concrete, and exposed fine-aggregate Portland cement concrete. Pavements common to both Europe and California and Arizona produced similarly noise levels when pavement textures and aggregate sizes were considered. California and Arizona rubberized asphalt pavements, which were not encountered in Europe, displayed performance approaching that of the quieter doubled layer porous asphalt constructions.

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ABREVIATONS AND ACRONYMS

AASHTO	American Association of State Highway and Transportation Officials
ADOT	Arizona Department of Transportation
Agg	Aggregate
ARFC	Asphalt Rubber Friction Course
BASt	Bundesanstalt für Straßenwesen (Germany)
CA/AZ	California/Arizona
Caltrans	California Department of Transportation
CPX	Close Proximity (method)
dB	Decibels
dBA	Decibels, A-weighted
DC	Diamond Cross-Grooved
DGA	Dense Graded Asphalt
DLPA	Double Layer Porous Asphalt
DSK	Dünnschicht im Kalteinbau (Cold installation of a thin layer)
EA	Exposed Aggregate
Ex	Epoxy/Stone
FHWA	Federal Highway Administration
ISO	International Standardization Organization
(G)	Ground
LB	Longitudinal Broom
LCPC	Laboratoire Central des Ponts et Chaussées (France)
Long	Longitudinal
NCP	Nova Chip Pavement
NITE	Noise Intensity in Europe
OB	Oberflächenbehandlung (Surface dressing)
OGAC	Open Graded Asphalt Concrete
(P)	Porous
PA	Porous Asphalt
PCC	Portland Cement Concrete
P/G	Porous Ground
Pl	Polished
RAC	Rubberized Asphalt Concrete
RT	Random Transverse
SD	Surface Dressing
Shp	Sharp
SI	Sound Intensity
SilVia	Silenda Via (Sustainable Road Surfaces for Traffic Noise Control)
SMA	Stone Mastic (or Matrix) Asphalt
SPB	Statistical Passby (method)
Trans	Transverse
UK	United Kingdom
US	United States

DISCLOSURE SECTION

DISCLAIMER STATEMENT

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1.0 INTRODUCTION

This reports details the findings of tire/pavement noise measurements conducted on various pavements in four European countries on various in-service roadways and test tracks. The results are compared to similar data obtained in the states of California and Arizona. Initially, this report describes the measurement methodology used and the previous findings resulting from the California and Arizona testing. This is followed by a detailed description of the Noise Intensity Testing in Europe or "NITE" project. The results of the testing in Europe are then presented grouped by pavement type and for each tire type and test speed. The implications of the results are in terms of comparing measurements and pavement design approaches between Europe and California/Arizona and pavement. Finally, the findings of the study are finalized and recommendations for further investigation are made.

The concept of this study was developed as a consequence of two independent endeavors. The first was the development of the application of the sound intensity method of tire/pavement noise to quantifying the performance of highway pavements in-situ. This method only required the use of a fixture to hold the SI microphones and can be readily used on most vehicles. This highly portable technique can be used anywhere to obtain consistent results with only the need to transport test tires. The second motivator for the NITE project was the AASHTO/FHWA Quiet Pavement Scanning Tour conducted in May of 2004. Under this tour, a delegation from the United States (US) visited a number of European countries to discover and document the state-of-art practice in European technology for quiet pavement systems. The Europeans have been experimenting with quiet pavement design much longer than the US. Although this tour was successful in its qualitative assessment, because of measurement method and test tire differences between researchers in Europe and the US, there was no common scale to compare the performance of European pavements to those in the US. To fill this void, Caltrans and the FHWA funded a project to perform sound intensity measurements in Europe that could be compared directly to those in the California/Arizona (CA/AZ) database.

The objectives of the NITE were threefold. The first objective was to measure the quietest pavements in Europe. The second was to obtain the range of performance of the pavements typical of European roadways. The third was to relate quantitatively the results from Europe to those from California and Arizona. As identified by European researchers, members of the AASHTO/FHWA Scan team and the literature, known quieter pavements in Europe were measured and found to be only slightly (1 or 2 dB) quieter than the pavements in California and Arizona. The range of tire/pavement noise from noisiest to quietest pavements was also found to be similar although somewhat different design approaches were found between Europe and CA/AZ. Based on the findings of the project, a number of findings from the previous CA/AZ studies were confirmed. Also resulting from the NITE project, several pavement types not currently used in CA/AZ were identified for further research and development toward the goal of achieving lower tire/pavement noise levels.

2.0 SUMMARY OF PREVIOUS FINDINGS

In recent years, Caltrans has been quite active in the investigation of quieter pavements for purposes of noise abatement. To evaluate the performance of a quieter pavement over time, Caltrans initiated a long-term study of highway traffic noise on a section of Interstate I-80 near Davis, CA. This project began with the overlay of an older section of dense graded asphalt concrete (DGA) with an open graded asphalt concrete (OGAC) in 1998 (Ref. 1)[*]. Initially, reductions on this heavily traveled portion of highway were about 5 to 6 dB. Through 2005, the reduction has remained in the range of 4 to 5 dB. In 2002, Caltrans constructed research test sections on a portion of LA 138 in northern Los Angeles County to investigate the performance and longevity of five different asphalt overlays relative to a new DGA (Ref. 2, 3). Caltrans has also been monitoring the tire/pavement noise performance of pavement projects throughout California to gain a more thorough understanding quiet of pavement applications. Caltrans has cooperated with the Arizona Department of Transportation (ADOT) in mutual investigations of the application of quieter pavement. In 2002, Caltrans funded the development and application of tire/pavement noise sound intensity measurement technique to evaluating the in-situ performance of highway pavements (Ref. 3). Since that time, the sound intensity method has become an extremely useful tool in understanding the effects of pavement on tire/pavement noise generation.

2.1 Sound Intensity Method

Although traditional wayside techniques of documenting the effect of pavement on traffic noise had been successful in the past, Caltrans was interested in a technique to quantify tire/pavement noise source levels directly without the site restrictions imposed for wayside measurements. To achieve this objective, Caltrans funded the development of the on-board, sound intensity (SI) method for examining the role of pavement in the generation of noise for highways in the state. This method had been originally developed at General Motor for tire noise research work on test tracks (Ref. 4, 5). Like the Close Proximity (CPX) method (Ref. 6), this near-field approach has attributes that make it attractive for evaluating actual roadway surfaces. Both types of on-board approaches can isolate tire/pavement differences relative to sound propagation effects and uncertainties inherent with passby methods. They can also be used to evaluate a large number of roadway sections quickly and efficiently. Both methods isolate tire/pavement noise from other sources, however, for the SI method this is inherent in the measurement, while for the CPX method, it requires the use of specially built and qualified trailers or test vehicles.

For SI measurements, a probe consisting of two, closely spaced microphones are used. For the tire/pavement noise measurement, two locations of the intensity probe are needed, one opposite the leading edge and one opposite the trailing edge of the tire contact patch (Ref. 3). The probe positions are 75mm above the ground and 100mm out from the tire sidewall (Fig. 1). Since the measurements are made separately at the leading and trailing edges of the contact patch, a minimum of two passes is required over

[*] Referral to studies/documents are cited as “(Ref. X)” and referral to specific pavements are cited as “(reference no. YY)”

the test pavement. These are later averaged together on an energy basis to determine the reported sound intensity for a given tire or pavement. The effective frequency range of the measurements is from the 1/3 octave band centered at 500 hertz to the 5000 hertz band. A photograph of the SI fixture and probe installed on the right rear wheel of a test vehicle is provided in Fig. 2 with a windscreen placed over the microphones.

To apply the SI method to evaluating highway pavements, standard practices have been adopted. For purposes of rapid data collection, it was desired to use primarily one test speed as well as one single test tire. A primary test speed of 60 mph was chosen. This has proven to be successful in maintaining safe vehicle spacing, obtaining consistent data, and avoiding influencing the existing traffic flow. To capture the performance of pavements on lower speed roadways, a test speed of 35 mph is used. A Goodyear Aquatred 3 P205/70R15 was selected as the primary test tire. Similar to results reported in the literature, it has been found that this tire rank orders pavements consistently compared with other passenger car tire designs (Ref. 3). For research evaluations, a secondary test tire was chosen based on initial testing of a number of different tires. This was a Uniroyal Tiger Paw AWP also P205/70R15 in size. The tread designs of both test tires are shown in the photographs of Fig. 3. For sampling tire/pavement noise, a 5 second linear average of the data is typically used. Typically, two passes over the test pavement are made for each microphone location. These passes are generally within a few tenths of a decibel of each other.

As part of the development of the SI method, attention has been given to correlating SI levels to controlled passenger car passby tests with the same tires. To date, this has been done for 3 different tire sets, at 3 different speeds and on 12 different pavements, both AC and PCC. Comparison of the overall A-weighted SI and passby levels is given in Fig. 4 for wayside microphone positions both 7.5m and 15m from the centerline of vehicle travel. Considering the whole data set, the average deviation from a best fit, 1-to-1 relationship is 0.6 dB for the 7.5m data, and 0.7 dB for the 15m data. For light vehicles, changes in SI levels have also been found to track very well to changes measured by both SPB and time averaged, wayside measurements.

2.2 CA/AZ Tire/Pavement Noise SI Data Base

Beginning in 2002, the SI method has been used extensively throughout California to quantify the performance of different pavements for the tire/pavement noise generation performance. This has included samples of most types of pavement used by the State as well as textured PCC surfaces of bridge decks and elevated structures (Ref. 3, 7, 8). A large number pavement surfaces have also been measured in Arizona in cooperation with ADOT (Ref. 9, 10). This data provides good insight as to what the current levels are and if there are quieter alternatives already in use. The range in overall A-weighted level from this time period was found to be about 13 dB excluding bridge decks (Fig. 5). In California, Caltrans does not use transversely tined PCC for on-grade highways. As a result, the maximum levels approach 105 dBA providing a range of about 8 dB within the State. With the inclusion of Arizona transversely tined PCC, the range extends up to 109 dB. Bridge decks have been found to produce levels approaching 113 dBA for the aggressive transverse textures. The data of Fig. 5 can be viewed in three groups. First, about the lower 1/3 of the pavements are either open graded and/or rubberized asphalt. The middle 1/3 are mostly dense graded asphalt with some overlap of OGAC/RAC and quieter PCC surfaces. The upper 1/3 is dominated by PCC except for a "chip seal" surface that contained very large aggregate that produced a rough texture and generated high levels of lower frequency noise. The overall and 1/3 octave band levels and descriptions of the pavements referred to in this report from the CA/AZ database are provided in Appendix 1

The SI database has been used for several purposes. Overall, it defines the range of performance that can be expected for different pavements. Quieter pavements can be identified throughout the full range or within each category. It has been used examine pavement parameter differences and relate them to noise performance. It has also been used in the early decision making process for examining alternatives for noise abatement. With some idea of the type and condition of existing pavement on a highway, the data are used to roughly estimate what improvement might be expected by modifying an existing surface. Once a project is better defined, SI measurements can be made of the actual existing roadway surface to more accurately determine the expected improvement.

A CA/AZ database has also been started for a test speed of 35 mph. This speed was selected to better represent urban roadways for purposes of documenting tire/pavement noise. In addition to in-service roadways, two test tracks are included in this data set. The first is the ISO 10844 test track surface at the General Motors Desert Proving Ground. This surface is generally considered to be a slightly porous AC pavement. The second test track was the Caltrans surface at the California Highway Patrol Academy in Sacramento, CA. This surface is a very fine aggregate DGA pavement. The overall A-weighted levels for the five surfaces of the 35 mph database are presented in Fig. 6.

2.3 Findings Prior to the NITE Project

Although not a replacement for wayside traffic noise measurements, the SI method has proven to be a very useful tool in evaluating the influence of pavement on tire/pavement noise generation. Within Caltrans, it is quickly becoming the preferred, scientific tool for evaluating pavements and guiding quiet pavement applications with wayside measurements to follow where practical. From the studies performed to date, the following observations have been made:

1. Pavement can reduce tire/pavement noise up to 8 or 10 dB depending on the existing and final pavement
2. For at-grade highways, the total range in tire/pavement noise is about 13 dBA
3. Within each of the generic groupings of pavement (PCC, DGA, and OGAC/RAC), there remains a significant range in tire/pavement noise performance
4. Apparent surface roughness/texture controls the lower tire/pavement noise frequencies (below ~1000 hertz)
5. As a group, open graded and/or rubberized asphalt concrete show the best tire/pavement noise performance
6. Grinding PCC surfaces can be effective in reducing tire/pavement noise by reducing texture effect such as transverse tining and by reducing joint slap

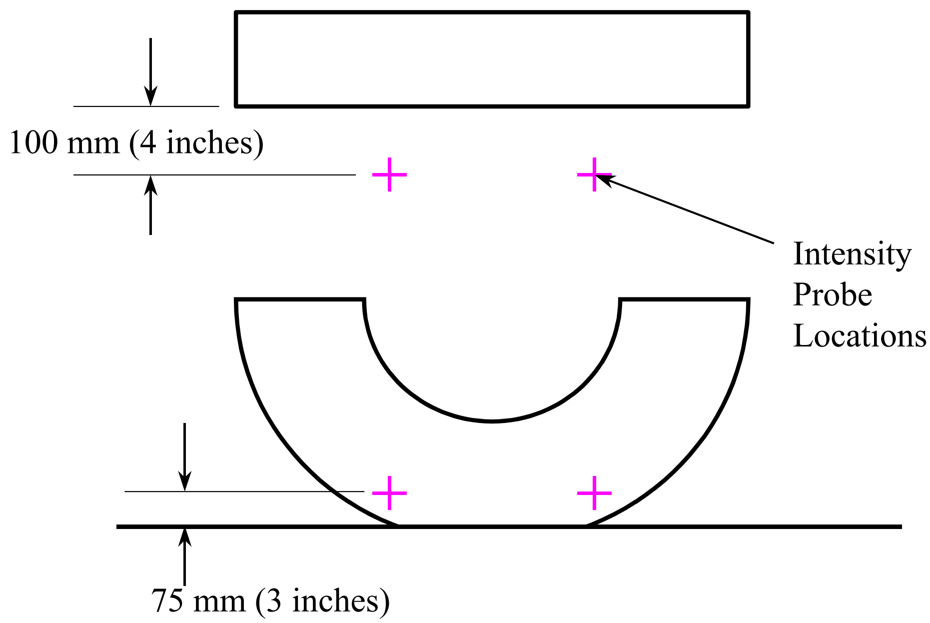

Figure 1: Relationship of sound intensity probe locations to a test tire

Figure 2: Photograph of the sound intensity measurement fixture installed on the right rear wheel of the test vehicle

Figure 3a: Photograph of test tire tread patterns - Goodyear Aquatred 3 P205/70R15

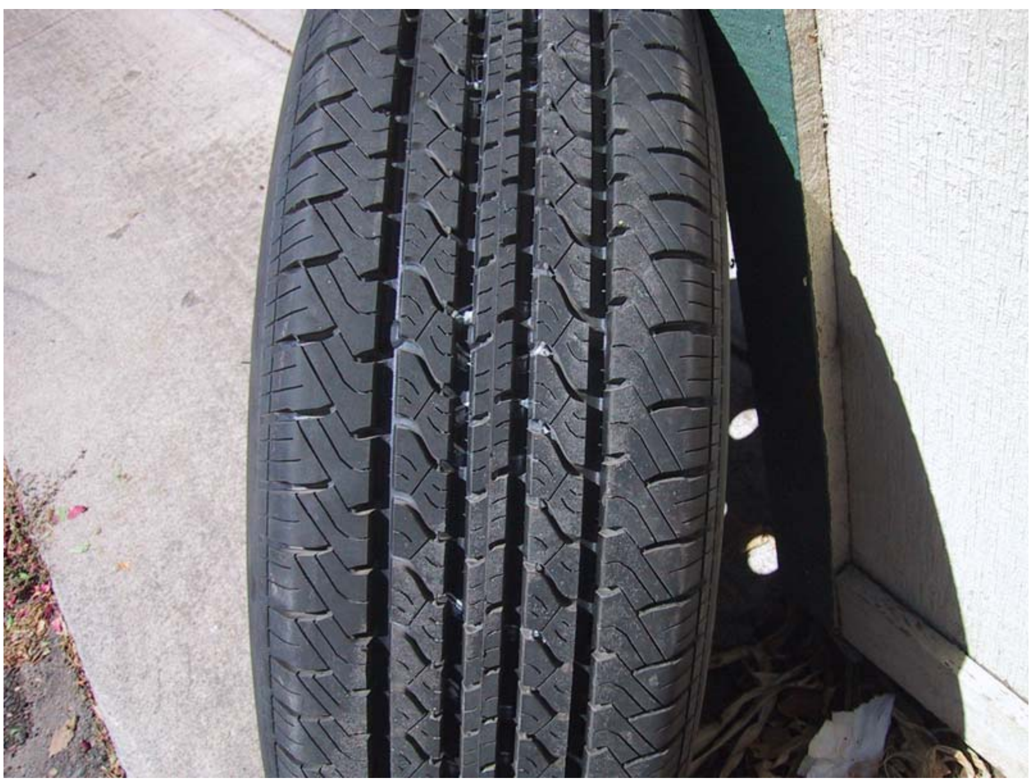

Figure 3b: Photograph of test tire tread patterns - Uniroyal Tiger Paw AWP P205/70R15

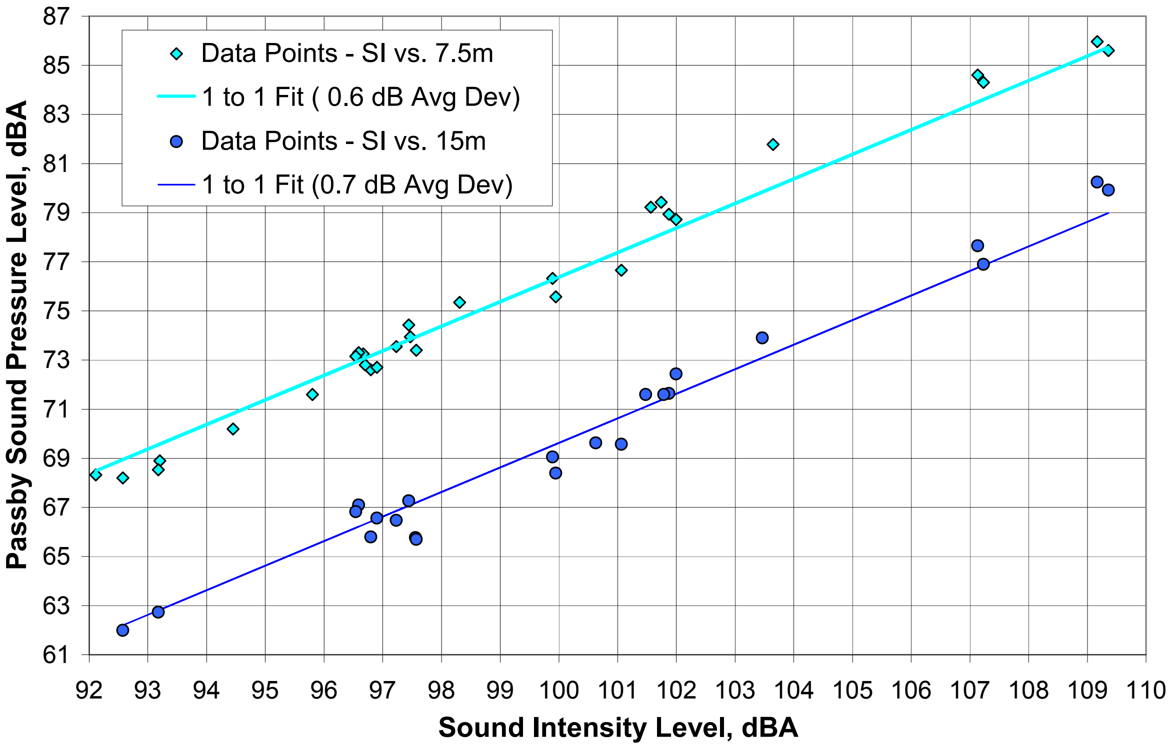

Figure 4: Relationship between sound intensity levels and cruise passby levels for test vehicle with varying tires, test pavements, and vehicle speeds

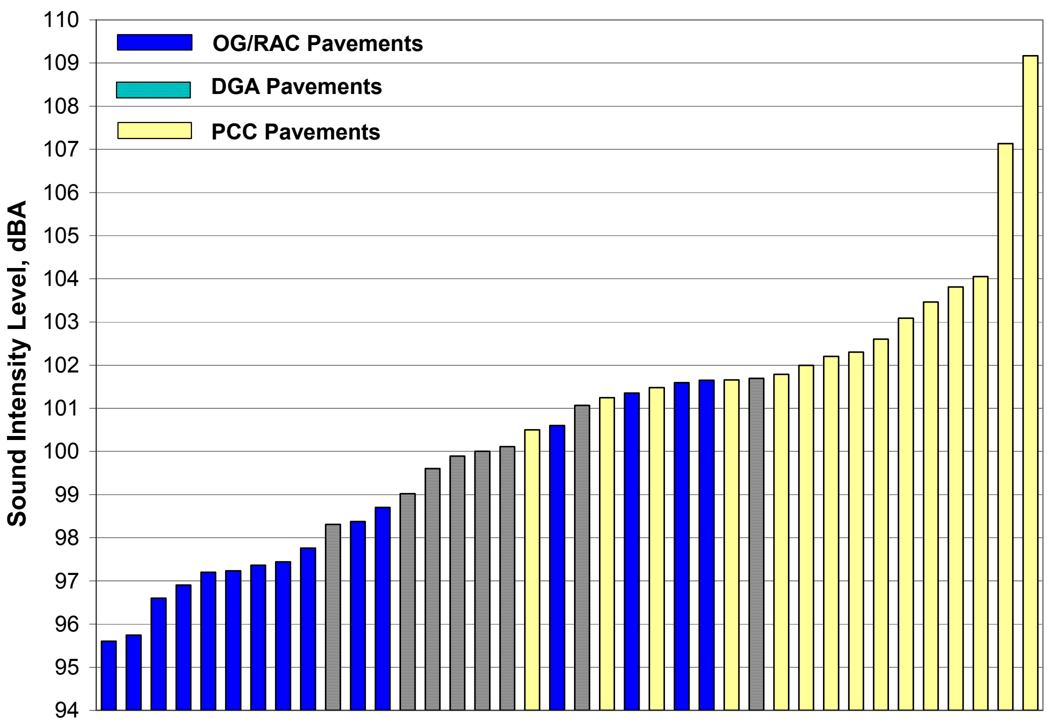

Figure 5: Tire/pavement noise for representative, at-grade highway surfaces from the California/Arizona sound intensity data base – Goodyear Aquatred 3 at 60 mph

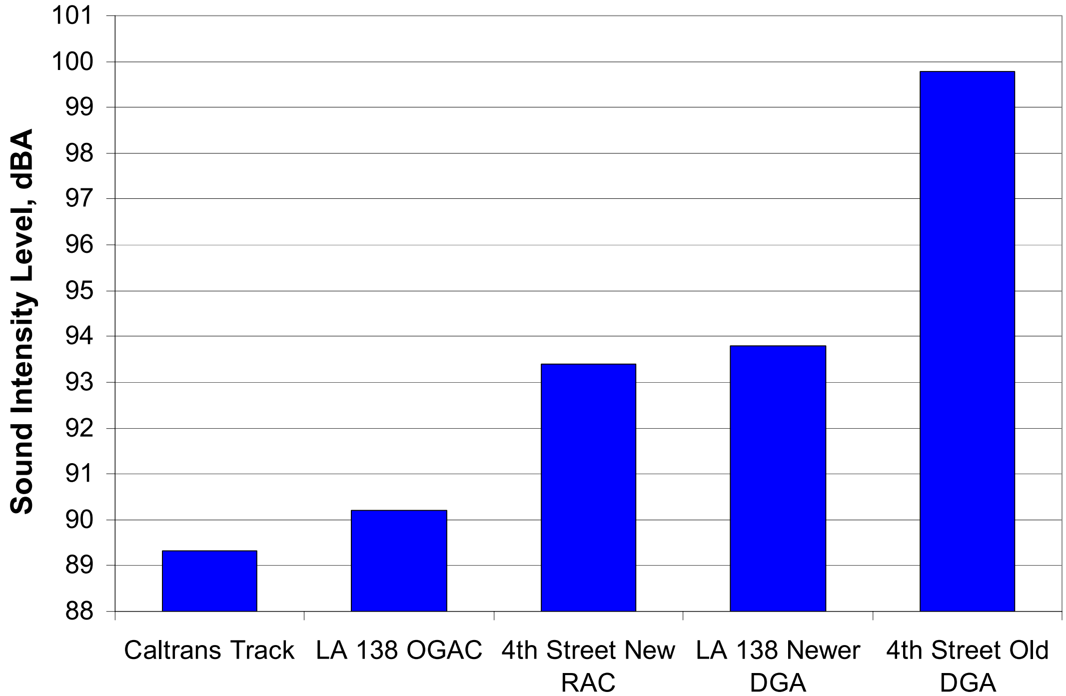

Figure 6: Tire/pavement noise for road surfaces from the California sound intensity data base including pre & post measurements for a pavement rehabilitation project on 4th Street in the City of San Rafael, CA – Goodyear Aquatred 3 at 35 mph

3.0 NITE PROJECT DESCRIPTION

The NITE project was conceived as a logical follow-up to compliment the AASHTO/FHWA Quiet Pavement Scanning Tour (Ref. 11). With the development of the SI technique and protocols used in California, it became apparent that there was an opportunity to obtain the first definitive database comparing the noise generated by European pavements to those in the US. With SI, this could be done practically and efficiently using the same tire and test equipment.

The objectives of the project in order of priority were to:

1. Measure the quietest pavements in use in Europe
2. Measure the range of pavements in current use
3. Relate the Caltrans SI measurements to the European CPX results

Because of the open-ended scope of the project, it was decided to limit the testing to three weeks. Follow-up testing could be initiated at a later time, once the results of the initial round of measurements were analyzed and reported. In the three-week period, it was clear that testing in all of the countries that were visited in the Scan as well as other countries that had been identified as having quieter pavement would not be possible. As a result, priority was placed on measuring the largest number of quieter pavements and obtaining data where CPX measurements had been performed by European investigators.

3.1 Project Approach

In principle, sound intensity measurements of European roadways could readily be accomplished, as the sound intensity fixture and measurement equipment are quite portable. However, to definitively tie the European data to the CA/AZ database, the same tire design as used in the US was required for the European testing. As the US test tire was not available in Europe, tires were shipped from the US. It was also necessary to identify a test vehicle that could accommodate the P205/15R tire size used in the CA/AZ data. With the assistance of General Motors, it was determined that the then newly introduced 2004 Chevrolet Malibu and 2004 Opel Vectra had common wheel designs and could accommodate the P205/70R15 tire size. This allowed direct comparison testing between the CA/AZ test tire and the test tire to be used in Europe prior to shipping the new test tires. To accomplish this, "back-to-back" sound intensity measurements were made on different pavements for the CA/AZ tire as mounted on the normal 1998 Subaru Legacy Outback test vehicle and the tire for the European testing as mounted on a rented Chevrolet Malibu. Consistent with other testing of this tire design when mounted on other vehicles and test trailers, the difference in tire/pavement noise between the two test tire/vehicles was found to be 0.1 to 0.8 dB for the 4 different surfaces. On average, difference was 0.5 dB with the new tire on the Malibu being lower in level.

For testing in Europe, an Opel Vectra was provided by General Motors. Opel headquarters is located in Rüsselsheim, Germany, near Frankfurt providing a central starting point for testing in surrounding countries. To assure matching rolling radius, 5 Goodyear Aquatred 3 tires were shipped to Opel. Four tires were used in driving the vehicle from one test location to another and a fifth was used exclusively for testing. In addition a single Uniroyal Tiger Paw AWP was shipped to be used in testing when feasible. With Opel's assistance the tires were installed on the test car and the SI fixture adapted to the car (Fig. 7). Before leaving the Rüsselsheim area, there was an opportunity to perform "shake-down" tests at the Opel Proving Ground at Dudenhofen, Germany. At this site, sound intensity and passby tests were conducted on an ISO 10844 test track surface used for vehicle passby noise development. For 35 mph cruise conditions, the relationship between sound intensity and passby levels was found to be identical to that demonstrated in the CA/AZ testing (Fig. 8). With this initial testing completed, the work progressed to measurement on actual roadways.

3.2 Test Sites

Some care was involved in the selection of potential test sites for the NITE project. Input was obtained from several sources including European researchers, the technical literature, and the observations of some of the members of the AASHTO/FHWA Scan team. In addition to the five official and one unofficial countries visited by the Scan team (France, the UK, the Netherlands, Denmark, Italy and Belgium) three additional countries were identified as having pavements which would be of interest to the NITE project. These were Germany, Austria, and Sweden. The countries and interests for testing in each are given in Table 1. Prior to the start of testing, the scope was limited to five countries which were in the closest geographic proximity and possessed some pavements that were known to be quieter and/or had been the subject of other research. These were the Netherlands, Germany, France, Belgium, and Denmark. Of these, only Denmark was missed due to weather and time constraints. The test sites included in the project are given in Table 2. In all, 68 pavements were measured. Of those, 61 were measured at 60 mph (97 km/h) with the Goodyear Aquatred 3, 34 at 35 mph with the Goodyear tire, and 32 at 60 mph with the Uniroyal tire. Some of the sites tested in Germany had been included in a CPX round robin study conducted in July of 2003 (Ref. 12) allowing some comparison to the NITE results.

3.3 Available Data

The complete list of test sites and pavements is given in Appendix 2. For each test surface, each test speed and each test tire, the sound intensity data was processed into individual A-weighted, 1/3 octave band levels from 500 to 5000 Hertz. The overall A-weighted levels corresponding to the sum of the energy these 1/3 octave band data were also calculated. In Appendix 3, the data for 127 combinations of surface, speed, and test tire are available. All pavements are documented in Appendix 3 with multiple photographs taken at the time of the testing with the exception of single section of roadway on A73 in the Netherlands. The pavements were also documented with information and specifications supplied by researchers in the countries where the tests were made. Portions of these data are supplied in the main body of this report as well as in the Appendices. For additional specific data, the author should be contacted.

Table 1: European countries of interest for tire/pavement noise testing

Country	Interest
Netherlands	Extensive use of quiet AC pavements including double layer, porous asphalt, some CPX results potentially available
France	Range of seven typical pavements including quieter pavements available at one location, previous test data available
Beligum	Seven different pavements including porous AC and PCC at one site on public roads, previous data available
Germany	Wide range of pavements available both on test tracks and public roads including porous AC and PCC, sites included in CPX round-robin testing
Denmark	New design thin, porous layer AC pavements
Italy	Porous AC pavements with resonators
United Kingdom	More than 12 proprietary pavement meeting UK noise requirements, quieter exposed aggregate PCC surfaces
Austria	Reported as having the quietest ground PCC in Europe
Sweden	New all rubber pavement surface experimental test section, other porous AC designs

Table 2: Locations of roadways and test tracks measured for tire/pavement noise in Europe

Country	Roadway	Location	Pavement
Netherlands	A15	Gorinchem	Double layer porous - multiple constructions
	A59	Stranddaarbuiten	Double layer porous - multiple constructions
	A326	Nijmegen	Double layer porous with fine aggregate
	A270	Eindhoven	PCC and epoxy overlay on PCC
	A73	Venry	Various AC & OCC surfaces
France	Track	Nantes	LCPC test track with 7 various pavements
Beligum	N255	Herne	Test surfaces with 6 various pavements
Germany	B56	Düren	Test surfaces with 10 various pavements
	Track	Dudenhofen	Opel ISO passby test track surface
	Track	Sperenberg	BASt-Müller-BBM test site with multiple types

Figure 7: Photograph of the sound intensity measurement fixture installed on the Opel Vectra test vehicle in Europe

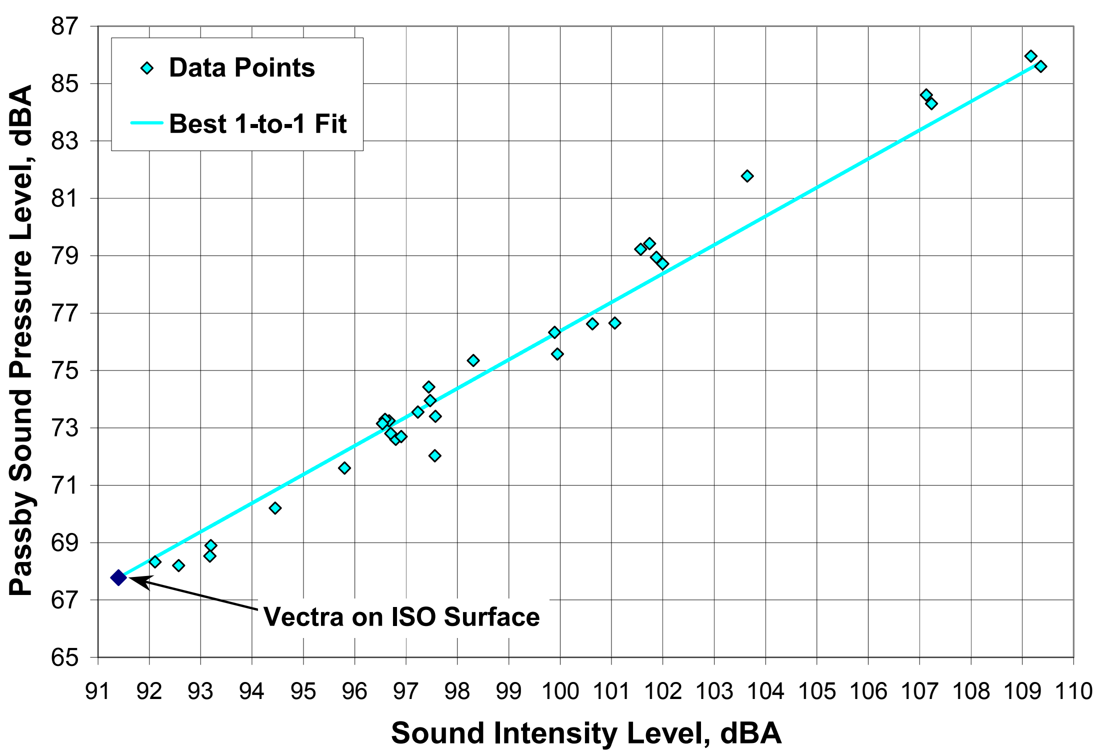

Figure 8: Sound intensity level and cruise passby level for the European Opel Vectra test vehicle and those of the US Subaru test vehicle (from Fig. 4)

4.0 RESULTS OF TESTING

Portions of overall results of the NITE testing are provided in Fig. 9 in a format analogous to the CA/AZ results of Fig. 5. Fig. 9 spans the loudest pavement measured with an overall A-weighted level of 107.6 dBA for a transversely tined PCC in the Netherlands to the quietest at 94.6 dBA, which was a double layer porous asphalt (DLPA) also in the Netherlands. This range is almost identical to the CA/AZ database (95.6 to 109.2 dBA) although the absolute levels are shifted slightly downward. It should be noted that no attempt was made to account of different test temperatures in either of these data sets. The measurements in Europe were completed in a relatively small temperature range spanning about 60° to 70° F (15° to 21° C). The CA/AZ data base span a generally wider range, from about 55° to 90° F (13° to 32° C) with some more extreme temperatures both lower and higher. Any effect of temperature on SI measurements has not been documented at this time and as a result no corrections were applied.

For NITE data shown in Fig. 9, in addition to DPLA, the designations for (single layer) porous asphalt (PA) and stone mastic (or matrix) asphalt (SMA) have been added. In California and Arizona SMA is not as common as it is some other states in the US. Although SMA is somewhat similar to DGA, it characterized by high stone-to-stone contact, a more viscous binder, and low air voids. Photographs visually comparing SMA and DGA are provided in Fig. 10.

In order to facilitate comparison between the European and CA/AZ databases, the results of both are displayed on the same graphs for different pavement groupings. In Fig. 11, data for DGA and SMA are presented. For this grouping, the range of levels for the European and CA/AZ surfaces is very similar. For the grouping of quieter pavements, porous AC, OGAC, and RAC, the European surfaces span a slightly larger range on both ends (Fig. 12). The quietest European surfaces are typically double layer porous AC and are about 1 to 2 dB quieter than the lowest CA/AZ surfaces. On the higher end, the noisier European surfaces are single layer porous with larger aggregate sizes. For the PCC surfaces, the higher levels in both Europe and CA/AZ are transversely tined with the highest being the random transverse tined studied in Arizona (Ref. 9) (Fig. 13). On the quieter end, one European PCC surface is remarkably lower than any of the others. This is a section of the B56 roadway near Düren, Germany. This was a porous, ground PCC surface. Excluding some of the exceptions noted, the apparent range of different pavement groupings was found to quite similar between the European countries and California and Arizona.

4.1 Results by Specific Pavement Types

4.1.1 DGA Pavements

Six European pavements were measured that were determined to be in the general category of DGA. For some of these surfaces, aggregate sizes were available, however, some were only categorized visually. When the overall A-weighted sound intensity levels are compared rank ordered by level, the trend is that the level increases with increased aggregate size or visual surface roughness (Fig. 14). The visual comparative differences are indicated in Fig. 15 which shows photographs of a “fine” DGA (reference no. 10)[†] and a more coarse, 0/10 mm aggregate size DGA (reference no. 12) along with overall level as measured at the LCPC test track. One-third octave band spectra for the DGA surfaces are presented in Fig. 16. As

[†] For pavement references, see the Appendix 2 and 3.

expected, these data show somewhat larger differences between the pavements of different roughness in the lower frequencies, below 1600 Hz, than in the higher frequencies. The maximum low frequency differences range from about 8 to 10 dB, while the high frequencies are about 5 to 7 dB.

4.1.2 SMA Pavements

Seven European pavements of SMA construction were tested in the NITE Project. For these pavements, the range of aggregate size was documented. The overall levels are presented in Fig. 17 rank ordered by level and, as with the DGA, the trend is toward larger aggregate sizes producing higher noise levels. Individually, there are some exceptions to this tendency. What should be the finest aggregate gradation, 0/3 mm (reference no. 53) is virtually equal to the noise level of a pavement with a 0/5 mm gradation (reference no. 52). Also, there is almost a 2 dB difference in three pavements of the same 0/8 mm aggregate size (reference nos. 54, 56, and 41). Photographs of two of 0/8 mm SMA pavements (reference nos. 54 and 41) are shown in Fig. 18. Visually, these pavements appear to have similar aggregate size, however, the surface of pavement no. 54 appears to be different than no. 41. For no. 54, the texture of the surface appears to be below a relatively flat upper surface almost as if the surface had been rolled creating a negative texture condition. For pavement no. 41, individual stones rise out of the pavement creating a more positive texture. This difference in texture type may be contributing the noise level difference of these surfaces. From the 1/3 octave band data (Fig. 19), these two surfaces produce relatively similar spectra shape except that pavement no. 41 has more broad-band high frequency content above 800 Hz. From Fig. 19, it will also be noted that spectral shape of the finer pavements, 0/3 mm and 0/5mm (Reference no. 53 and 52), are somewhat different than the others with less low frequency content and a higher frequency, broad peak at 1600 and 2000 Hertz. Previous studies have concluded that the presence of higher frequency content is associated with details of the test tire tread design which become more pronounced on smoother surfaces (Ref. 7). It will also be noted that this higher frequency content occurs for the fine DGA in Fig. 16.

Other similarities occur between the SMA and DGA surfaces. Comparing Figs. 14 and 17, it is seen the range in level for measured surfaces is nearly identical with the exception of the coarse DGA. The quietest surfaces are in the range of 98 to 99 dBA and the noisiest, both near 103 dBA. Also the overall trend with aggregate size (or surface roughness) is quite similar. From Figs. 16 and 19, the characteristics of the spectra are similar.

4.1.3 Single-Layer Porous Asphalt

Six surfaces have been lumped into a category referred to a single layer porous. The actual state of these pavements was somewhat unclear due to the age of the pavements and suspected clogging of the pavement. Furthermore, these are not all considered to be “porous” in the sense of being a “drainage” pavement. Some are likely comparable to OGAC pavements which have some amount of openness near the surface, but are not actually permeable throughout their depth. When these surfaces are rank ordered (Fig. 20), any tendency with aggregate size or roughness appearance is not apparent as it was for the DGA & SMA surfaces. This can be illustrated by examples from the Sperenberg test track as shown in Fig. 21. For these surfaces, the ISO pavement with a range of aggregate sizes appears to be less rough than the 8/10 mm surface. However, as these surfaces experience no virtually no traffic, clogging of pores is not expected to be significant. As a result, the more coarse 8/10 mm porous pavement is about 3 dB quieter than the ISO surface, which is only "porous" near its surface. Because of the varying conditions of the single layer porous pavements, the spectra are more dissimilar to each other than what was seen for the DGA or SMA. For the PA surface, the range in level is large (8 to 15 dB) throughout the entire frequency range (Fig. 22). For the relatively smooth ISO surface, the elevated levels in the 1600 and 2000 1/3 octave bands are quite pronounced similar to the behavior noted for the smoother of the DGA and SMA surfaces (Sections 4.1.1 and 4.1.2).

4.1.4 Double-Layer Porous Asphalt

The DLPA pavements in Europe tend to be used to address two issues: 1.) water drainage for reduced splash; 2.) improved noise performance. A typical example of the build of DLPA pavements is shown in Fig. 23. These pavements include a thicker lower layer (~ 4.5cm) of large size aggregate and a thinner (~ 2.5cm), upper layer of fine aggregate. The upper layer is chosen to improve noise with the understanding that finer aggregate will produce lower the noise levels. The larger, uniform aggregate in the lower layer facilitates drainage through the pavement and eventually to the side of the roadway. With this design, clogging of the surface is not generally a problem for higher speed motorways.

Almost all of the DLPA pavements tested were in the Netherlands on 3 different motorways. On two of these, multiple sections of the same types of construction were available as built by different contractors. These pavements had top surfaces of either 4/8 mm chippings or 2/6 mm. One additional surface was tested at the Sperenberg test track. To present the data for the multiple "Zebra" sections from the Netherlands, sections of similar construction were averaged together for each motorway (levels for individual sections are given in the Appendices). For the A326 motorway, the west and eastbound data were averaged together also. These results are presented in Fig. 24. Unlike the other pavement types, there is only a small range in the measured levels. All of the DLPA surfaces were found to be in the quieter range of the pavements included in the study. As expected, there is a tendency for the finer aggregate surfaces to be lower in level than the coarser surfaces. It should be noted that all of the DLPA pavements in the Netherlands were of newer construction, 2 years or less, while the pavement at Sperenberg is not exposed to traffic. Photographs of the 2/6 mm and 4/8 mm DLPA surfaces are given in Fig. 25. Spectral differences between the DLPA pavement was relatively small except at 500 Hertz where they expanded to about 8 dB from the more typical 3 to 5 dB (Fig. 26)

4.1.5 PCC Pavements

Although PCC pavements were not a significant focus of study, a total of 13 sections of PCC were tested at 97 km/h. Surprisingly, with the inclusion of porous PCC surfaces, these data (Fig. 27) displayed a much greater range in level than was anticipated based on CA/AZ data. Excluding the porous PCC, the range was consistent with the CA/AZ data running from slightly greater than 101 dBA (reference no. 5) for fine and finely textured surfaces to over 107 dBA for transversely textured PCC (reference no. 33 & 34).

Similar to the porous AC surfaces, the porous PCC's display a wide range of performance (~ 7 dB). The highest level was measured on a section of older pavement on the N255 in Belgium (reference no. 3), which is potentially degraded with clogging. The lowest level was measured on a section of ground porous PCC on the B56 roadway near Düren, Germany (reference no. 42). The third porous PCC surface (reference no. 7) produced an overall in between these other two. This surface was measured on the test track at LCPC and was visually rougher than the ground section near Düren (Fig. 28). The 1/3 octave band spectra are useful for further understanding the performance of the ground and unground porous PCC (Fig. 29). For frequencies of 1000 Hertz and greater, the levels for the surfaces (no. 42 & 7) are virtually identical. Below 1000 Hertz, the unground surface produces considerably more noise as would be expected from its roughness. This leads to the conclusion that the effect of the porosity is similar in both pavements, but that the grinding reduces the lower frequency content further by providing a smoother surface and lower overall A-weighted level. For the ground, porous PCC, the spectral shape and levels are quite similar to those of single and double layer porous AC (Fig. 30).

In the Netherlands, testing was conducted on two adjacent sections of PCC on A270. The original surface contained transverse texturing and although not visually very pronounced (Fig. 31), produced levels slightly over 107 dBA, which is consistent with that measured on California bridge decks and PCC highways in Arizona. To reduce noise, the adjacent section was coated with an epoxy and fine stone layer (Fig. 32). This coating reduced the tire/pavement noise by about 3 dB to just over 104 dBA. This amount of reduction is in the range of that measured in California for grinding of transversely tined PCC bridge decks. Depending on the initial surface, grinding produced reductions from just over 3 dB to more than 10 dB with the post grind levels being in the range of 101 to 104 dBA (Ref. 3, 8). The ground PCC at the Düren test section (reference #46) also performed in this range of ground PCC surfaces with a measured level of about 103 dBA. The epoxy/stone surface spectra was found be similar to the other PCC surfaces if the porous and transversely texture pavements are excluded (Fig. 29).

At the Sperenberg test track, additional PCC surfaces were tested, but only at 35 mph due to their short length. Of special interest were two additional porous surfaces and a “polished” PCC surface (reference no. 64) both plain and with crosshatched grooves (reference no. 65). The polished surface did possess some texturing, however, it was in the longitudinal direction (Fig. 33). The grooves of the crosshatched surface were at 45 degrees to the direction of travel with grooves spaced 1 cm apart and a depth of 0.4 cm (Fig. 33). The overall level for these surfaces are presented in Fig. 34 along with 35 mph data from PCC surfaces at LCPC and on N255. For these data, low noise levels were measured for the porous PCC surfaces. In comparison to a double layer porous AC pavement measured at 35 mph also at the Sperenberg test track (reference no. 49), the level of one of the PCC surface is equal to the AC (reference no. 66), while the other (reference no. 67) is within 1dB. The polished PCC is slightly lightly higher in level (~ 1dB) and the cross-hatching produced slightly less than a 2 dB increase over the baseline polish surface. In comparing the spectra for smooth and crosshatched surfaces (Fig. 35), some of the “peaks” and “valleys” in the spectrum of the smooth pavement are filled-in for the cross-hatched pavement along with the level being generally higher. For the smooth surface, the spectrum is likely influenced primarily by the details of the tread pattern, while the grooves in the cross-hatched surface introduce an additional pavement forcing function that overrides the tread characteristic.

One-third octave band spectra for the porous PCC and AC pavements measured at Sperenberg are presented in Fig. 36 for a test speed of 35 mph. As was the case for some of the other porous PCC surfaces measured at 60 mph, the spectra for the AC and PCC surfaces are quite similar. These data, taken together with the 60 mph results, suggest that porosity is more of a controlling factor for determining tire/pavement noise than is binder type given similar aggregate size.

4.1.6 Other Sperenberg Pavements

In addition to the pavements discussed above, three other surface types were measured at Sperenberg. These included DSK, surface dressings (SD), and Novachip. For comparison two surface dressing pavements measured at LCPC are included here. The DSK and SD surfaces performed within the range noted for the SMA and DGA pavements (Fig. 37). For the SD surfaces, the noise level increased fairly consistently with increasing aggregate size similar to the SMA surfaces. The same trend was also seen for the DSK surfaces. The Novachip surface produced lower levels than any of the SMA or DGA surfaces (Figs. 14 and 17) by about 1 dB even though the aggregate size was larger than some of the SMA/DGA pavements. It should also be noted that this Novachip surface produced lower levels than most of single layer porous AC pavements (Fig. 20) and approaches that of the double layer porous AC (Fig. 24). One additional surface (reference no. 57) consisted of 0/8mm SMA with an epoxy coating. Although this surface retained some of its ultra smoothness due to the coating, cracks in the coating produced somewhat ambiguous results. The noise levels for this surface were as high as almost all other normal exposed aggregate surfaces. Spectra for these other surfaces at Sperenberg and the two from LCPC are shown in Fig. 38.

4.2 Results for Secondary Test Tire

To this point, tire/pavement noise sound intensity levels have only included the results of the Goodyear Aquatred 3 test tire for a test speed of 60 mph. As mentioned previously, results for a Uniroyal Tiger Paw tire were also available for 32 pavements at the 60 mph test speed. In previous testing in California, the Uniroyal tire is known to produce lower tire/pavement noise levels than the Aquatred 3 as well as three other tire designs (Fig. 39). It was also found that, accept on a very fine aggregate DGA, the noise level for all tires were relatively similar to each other. On the fine DGA surface (Caltrans test track), differences in the individual tire noise spectra were more pronounced compared to more typical highway surfaces such as coarser DGA on LA 138 (Fig. 40). As a result, a larger range in overall noise level for the tires is apparent. However, even with the fine DGA, the pavements were approximately equally in rank ordered by the different tires. Because of the somewhat unique performance of the Uniroyal tire, it was deemed that it would be a reasonable alternate tire to compliment the pavement results obtained from the primary Aquatred 3 test tire.

The overall A-weighted sound intensity levels for the Uniroyal tire measured on European surfaces are presented in Fig. 41 along with the corresponding Aquatred 3 results. With three exceptions, the pavement rank ordering that is produced by the Aquatred is virtually identical to that of the Uniroyal to within less than ½ dB. The three cases in which the rank ordering was different by about 1 dB included two porous pavements and one very fine aggregate surface (reference no. 58). Another comparison of the results for the two tires is given in Fig. 42, which plots the Aquatred 3 overall levels versus the Uniroyal. In this presentation of the data, a consistent, 1-to-1 relationship is seen which has constant offset between the tires of 1.6 dB and an average deviation of 0.6 dB. Similar to the California data, for more coarse surfaces with aggregate sizes up to 10mm, the spectral differences between tires were found to be fairly consistent (Fig. 43). For finer aggregate surfaces (up to 6mm), more specific frequency content differences were found (Fig. 44) consistent with the tread related differences noted for Fig. 38. Although these somewhat subtle differences in tire noise generation for the two tires on different pavements are of interest, the results for the Uniroyal are supportive of the findings discussed for the Aquatred 3 tire.

4.3 Results for 35 mph

Sound intensity was measured on a total of 34 surfaces at a test speed of 35 mph. These surfaces were located at the Sperenberg and LCPC test tracks and on the N255 roadway in Belgium. At the Sperenberg site, four PCC pavements were only measured at 35 mph because of their short length. At all other pavements where 35 mph data were obtained, corresponding results for the Goodyear Aquatred are available at 60 mph.

4.3.1 Comparison to 60 mph

The data for 35 mph can be used to assess the degree to which the results from one speed can be used to predict the pavement performance at another. In Fig. 45, the overall A-weighted sound intensity levels for both speeds are charted as rank ordered by the 60 mph results. In this comparison, the rank ordering for the speeds is somewhat consistent, however, variations of 1 to 2 dB are seen. To quantify this more, the data are cross-plotted in Fig. 46. The average difference between the speeds is 7.6 dB and individual data points deviate from a 1-to-1 fit of the data by an average of 0.9 dB. A linear regression of these data indicates a less than 1-to-1 slope, but with an r^2 value of 0.9. This indicates that while the data are strongly related, predicting from one to the other would typically be within about ±1 dB.

4.3.2 Performance of the ISO 10844 Pavement

The ISO 10844 surface is widely used for light vehicle exterior noise compliance testing under the ISO 362 passby noise test procedure and for exterior noise compliance testing of tires according to EU directive 13325). In this low speed, full-throttle acceleration procedure, the contribution of tire noise ranges between about 20 and 40% of the total noise emission (Ref. 13, 14). This standard is currently being revised to include a low speed cruise mode in addition to a more moderate acceleration condition making the contribution of tire/pavement noise even greater. As a result, it is of interest to determine how the tire noise production of the ISO surface compares to that generally found on other pavements, particularly those used on public roadways. Within the combined NITE and CA/AZ 35 mph database, results for three ISO 10844 surfaces are available. These include a surface at Sperenberg (reference #51), the surface at the Opel Proving Ground (reference #68), and the passby test site at the General Motors Desert Proving in Mesa, Arizona. For this purpose, the overall levels for the combined 35 mph database are given in Fig. 47a with the data for the three ISO surfaces indicated. From this presentation, the ISO pavement produce noise levels toward the lower end of all pavements measured. For two of the ISO surfaces, Sperenberg and Mesa, data are also available for 60 mph and also indicate that the ISO surface is on the lower end of the measured pavements.

One of the issues of concern for an ideal test surface is how the noise produced on it relates to the noise generated on pavements typically from on actual roadways. For the 35 mph case (Fig. 47a), the ISO surfaces fall in the range of some of the quieter, smaller size aggregate SMA surfaces and porous PCC surfaces and at the lower end of the DGA surfaces. For 60 mph (Fig. 47b), the ISO surfaces fall above all of the DLPA surfaces of Europe as well as the ground porous PCC. For the CA/AZ surfaces, ISO surfaces are generally higher in level than the OGAC and RAC pavements. The ISO surfaces are lower than any DGA or PCC pavements in both the

NITE and CA/AZ data sets. Taken altogether, ISO surfaces are typical of the quieter pavement surfaces that are not specifically “quiet design” pavements. They are also on the higher end of pavements that are designed intentionally to be quieter. As a test surface, this is a reasonable break point for separating vehicle issues from pavement issues with the understanding that higher noise emission levels may occur in the community due to the pavement creating higher tire/pavement noise independent of vehicle (Ref. 15).

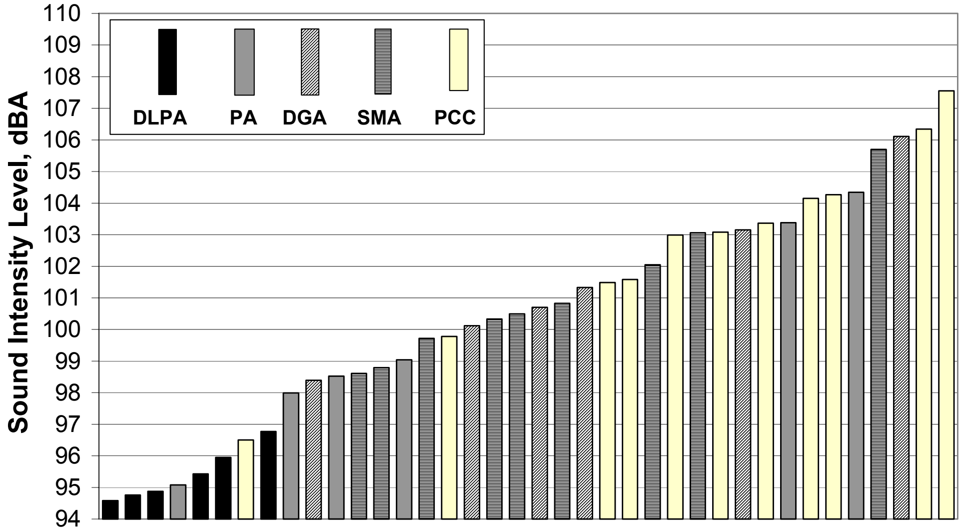

Figure 9: Tire/pavement noise for representative, at-grade highway surfaces from the European NITE sound intensity data base – Goodyear Aquatred 3 at 60 mph

Figure 10a: Photograph of typical pavement surfaces – SMA

Figure 10b: Photograph of typical pavement surfaces – DGA

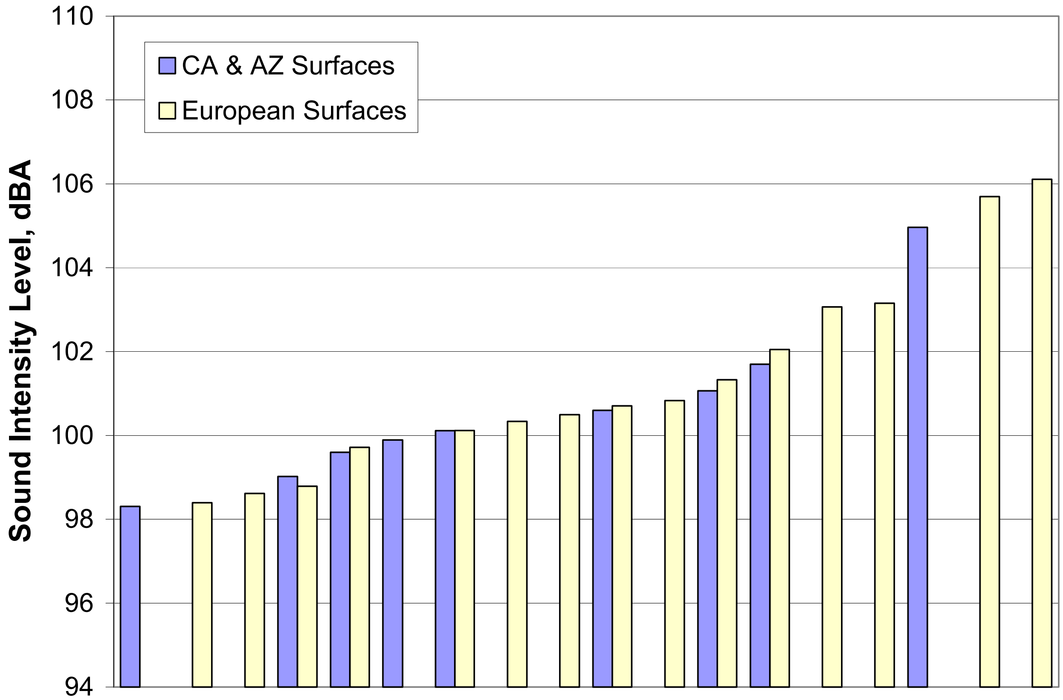

Figure 11: Sound intensity levels for DGA and SMA pavements from the European and CA/AZ data bases – Goodyear Aquatred 3 at 60 mph

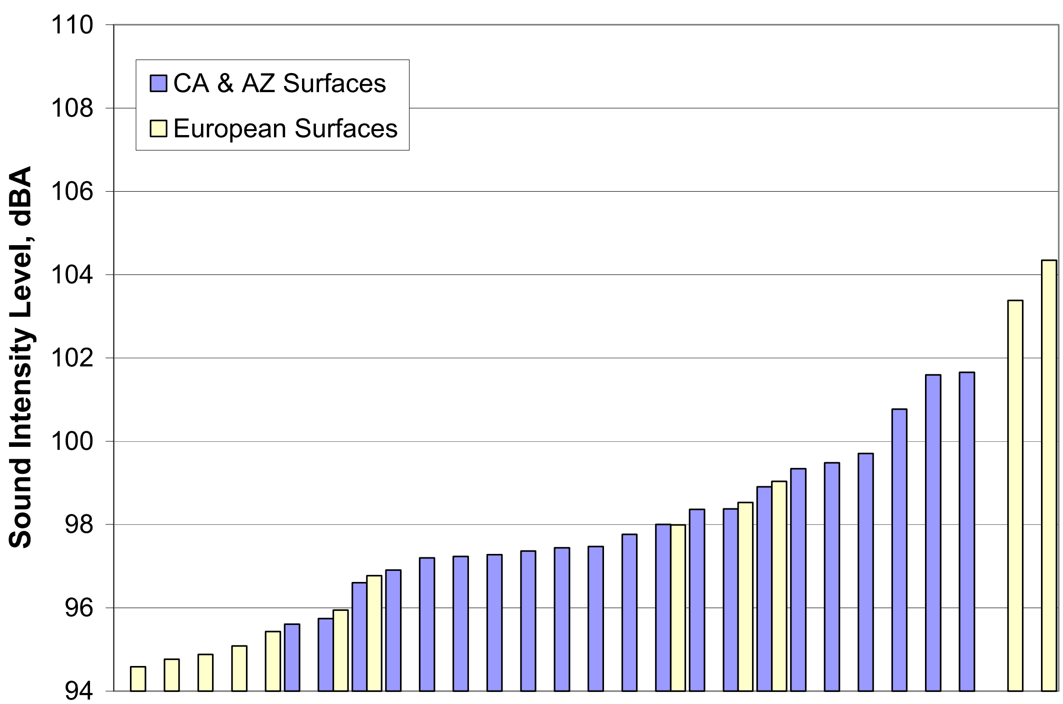

Figure 12: Sound intensity levels for single and double layer porous AC from Europe and OGAC and RAC pavements from CA/AZ – Goodyear Aquatred 3 at 60 mph

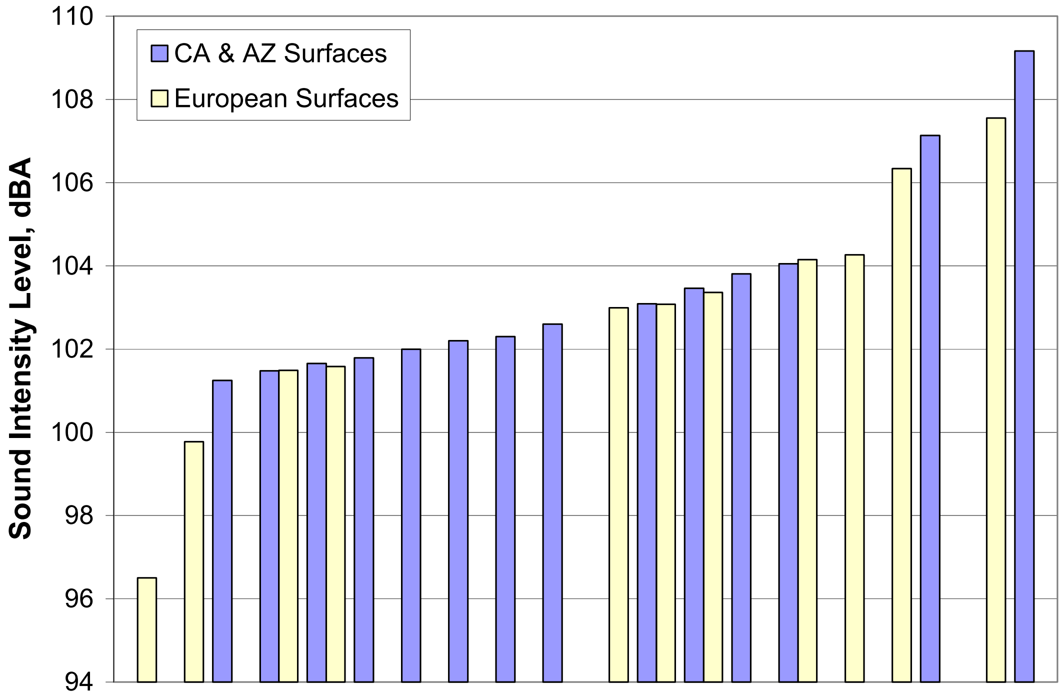

Figure 13: Sound intensity levels for PCC pavements from the European and CA/AZ data bases – Goodyear Aquatred 3 at 60 mph

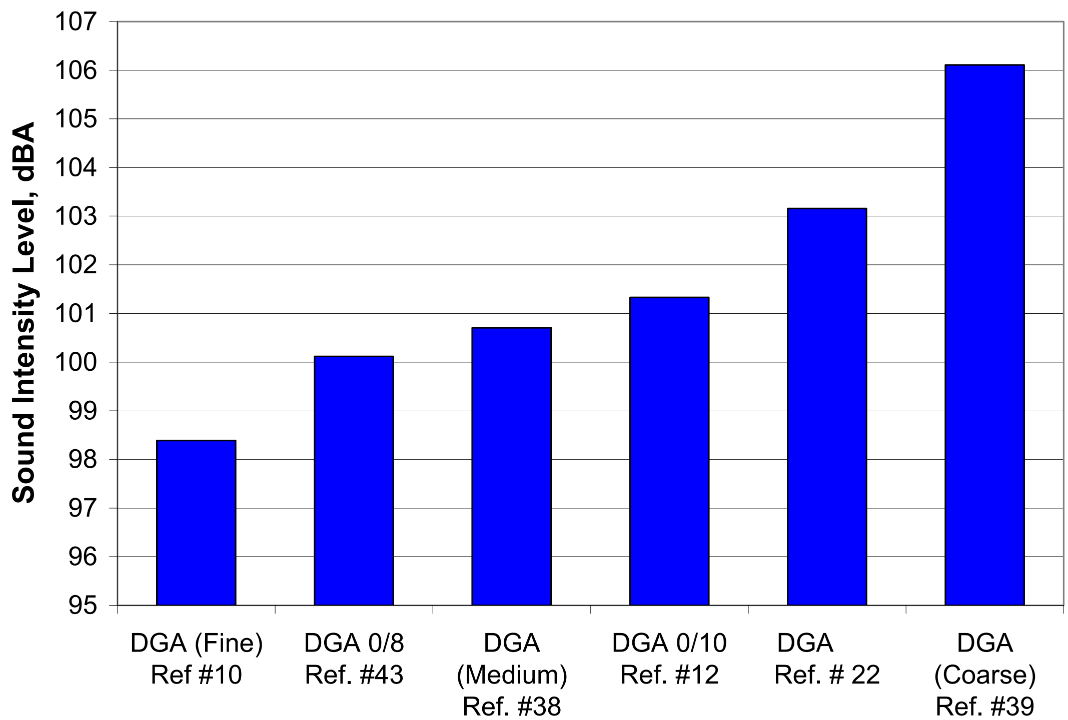

Figure 14: Range of noise performance of DGA pavements of varying aggregate size and apparent roughness – European data for Goodyear Aquatred 3 at 60 mph

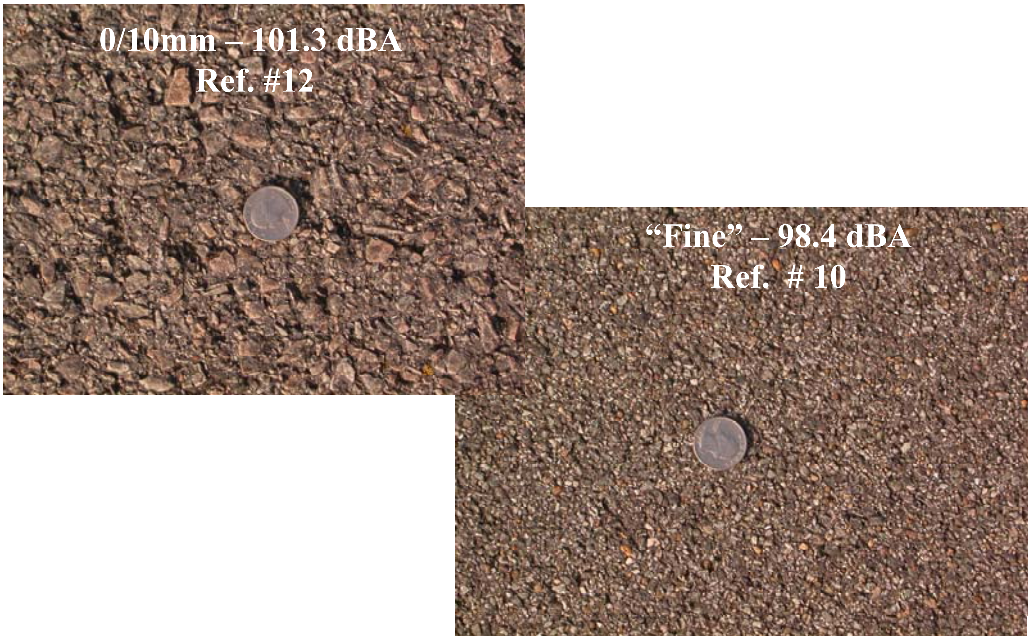

Figure 15: Photographs of two DGA surfaces containing larger scale (a.) and finer scale (b.) aggregate and apparent surface roughness

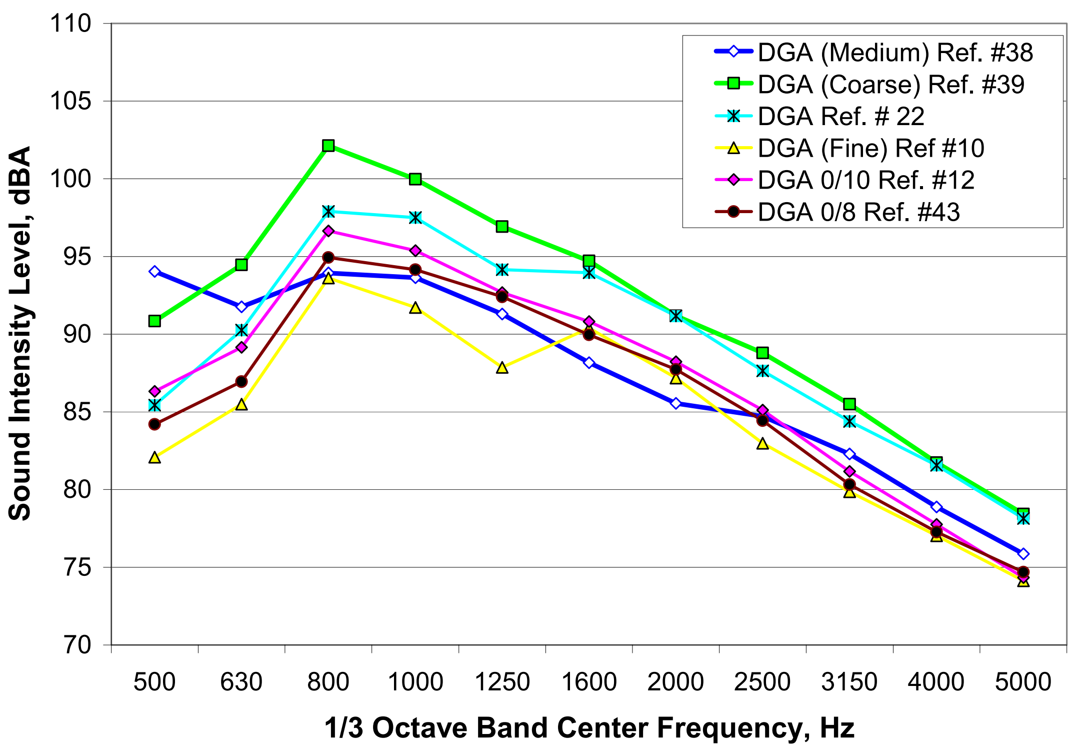

Figure 16: One-third octave band sound intensity levels for European DGA surfaces of varying aggregate size and apparent surface roughness

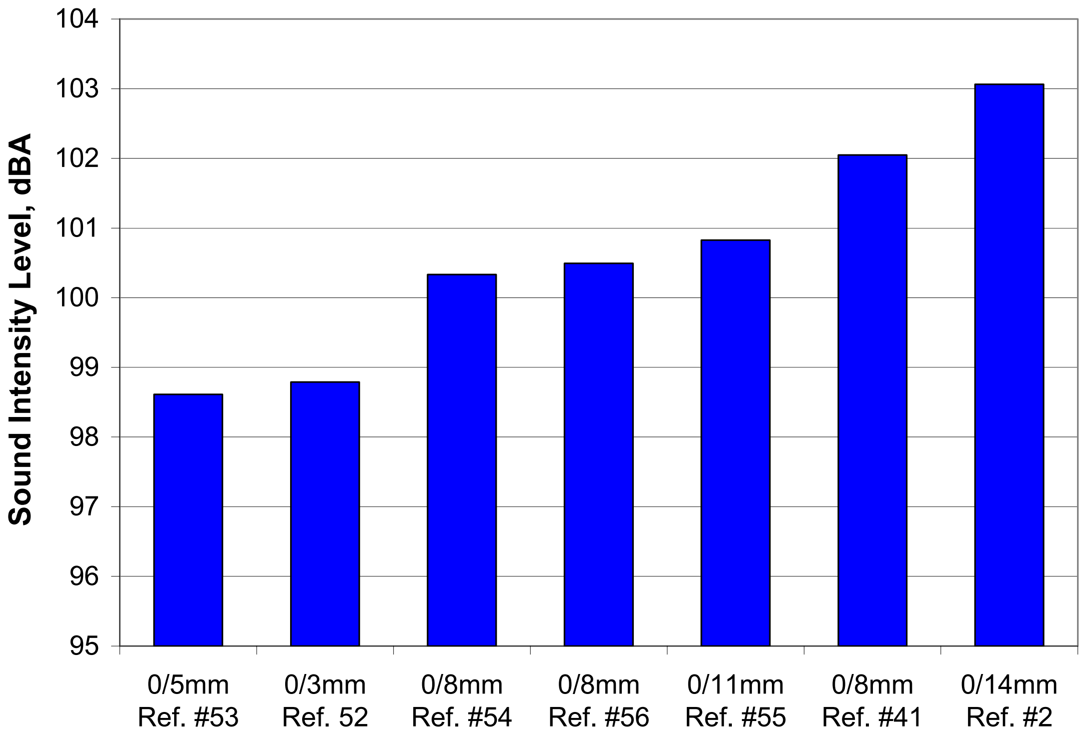

Figure 17: Range of noise performance of SMA pavements of varying aggregate size and apparent roughness – Goodyear Aquatred 3 at 60 mph

Figure 18: Photographs of two SMA surfaces containing narrower (a.) and wider (b.) ranges aggregate size resulting in different apparent surface roughness

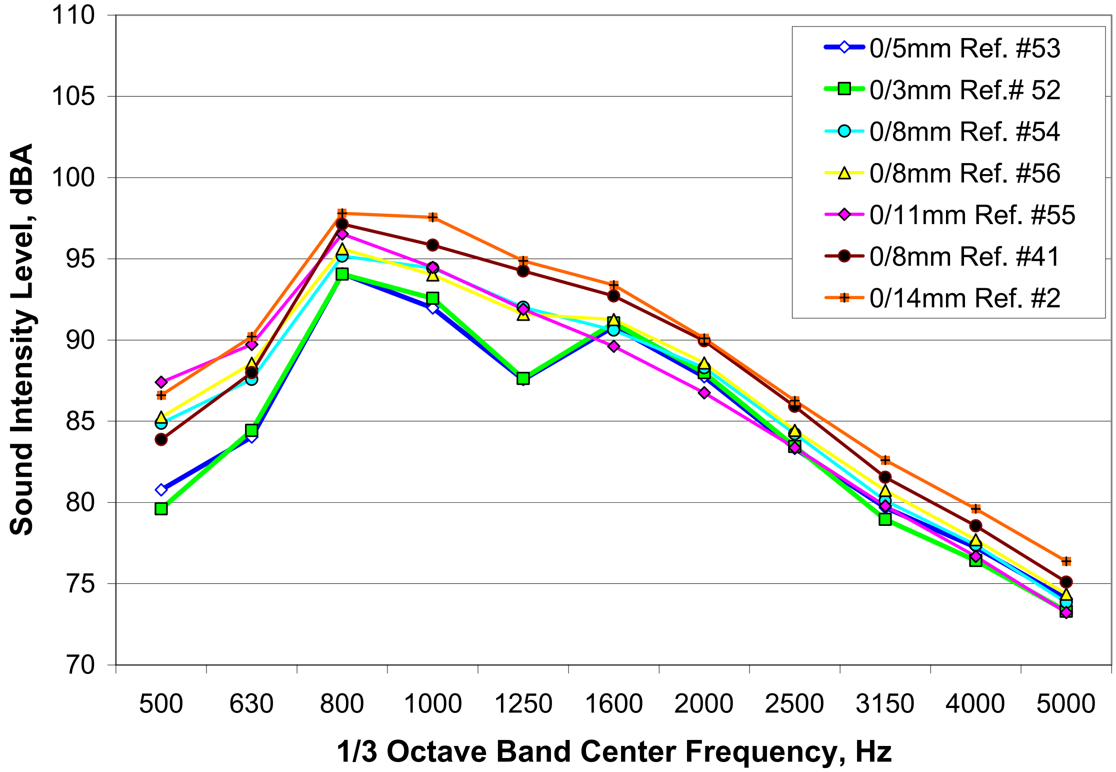

Figure 19: One-third octave band sound intensity levels for European SMA surfaces of varying aggregate size and apparent surface roughness

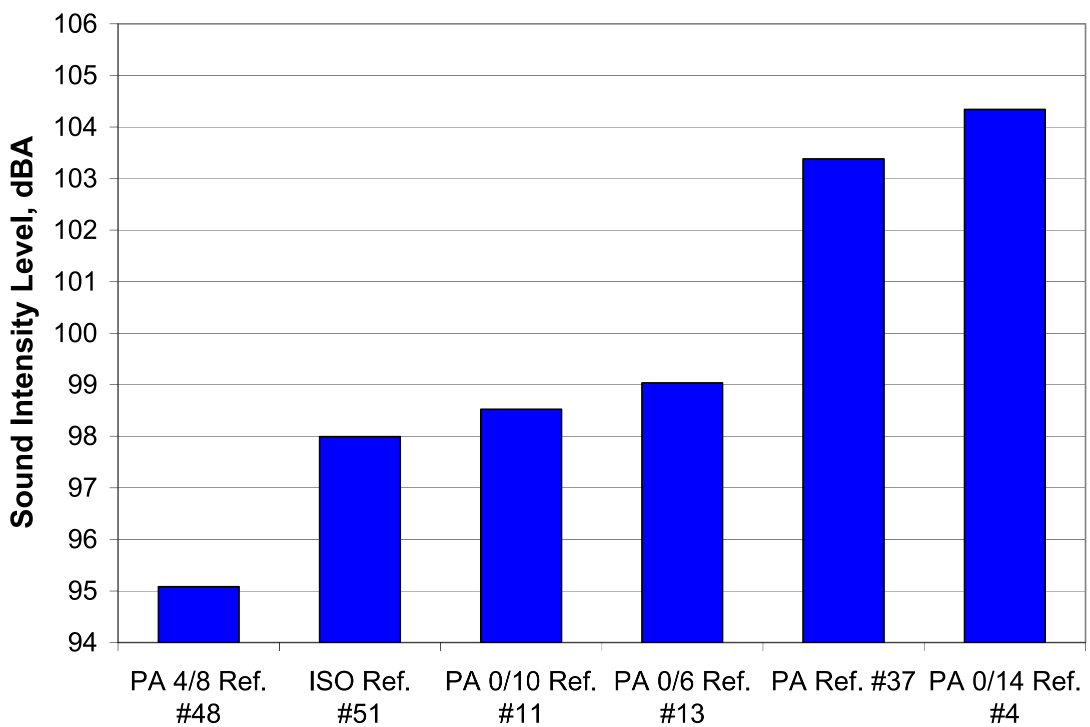

Figure 20: Range of noise performance of single layer, porous AC pavements of varying aggregate size and apparent roughness – Goodyear Aquatred 3 at 60 mph

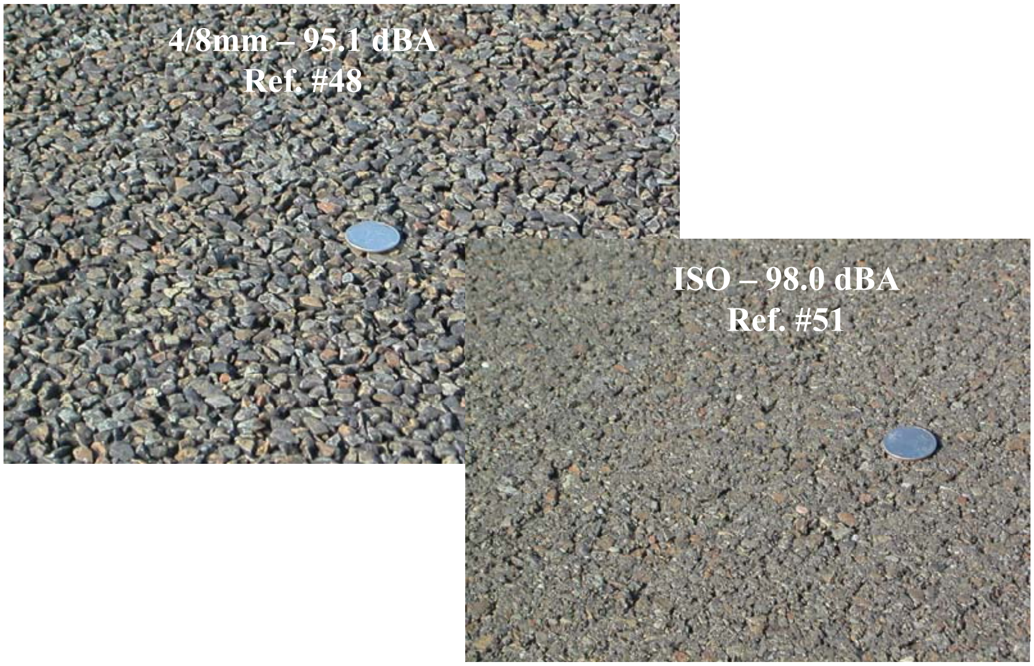

Figure 21: Photographs of two PA surfaces containing larger scale (a.) and finer scale (b.) aggregate and apparent surface roughness

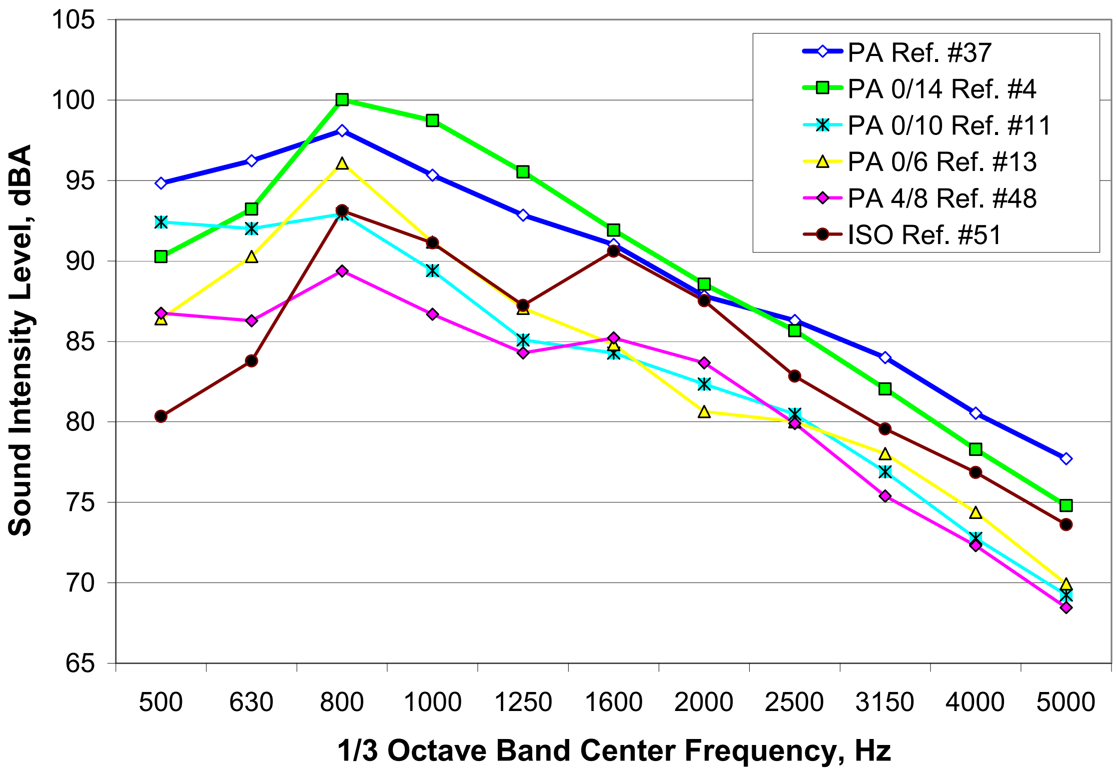

Figure 22: One-third octave band sound intensity levels for European PA surfaces of varying aggregate size

Figure 23: Photograph of typical double layer porous asphalt construction in the Netherlands

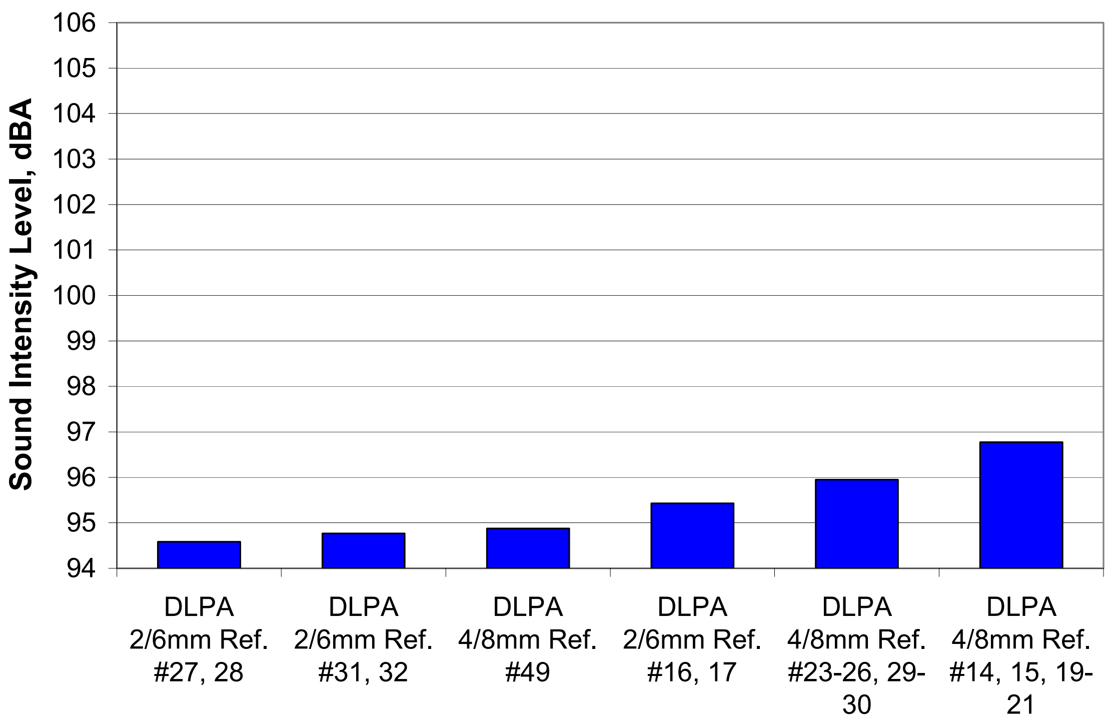

Figure 24: Range of noise performance of double layer, porous AC pavements of varying top layer aggregate size – Goodyear Aquatred 3 at 60 mph

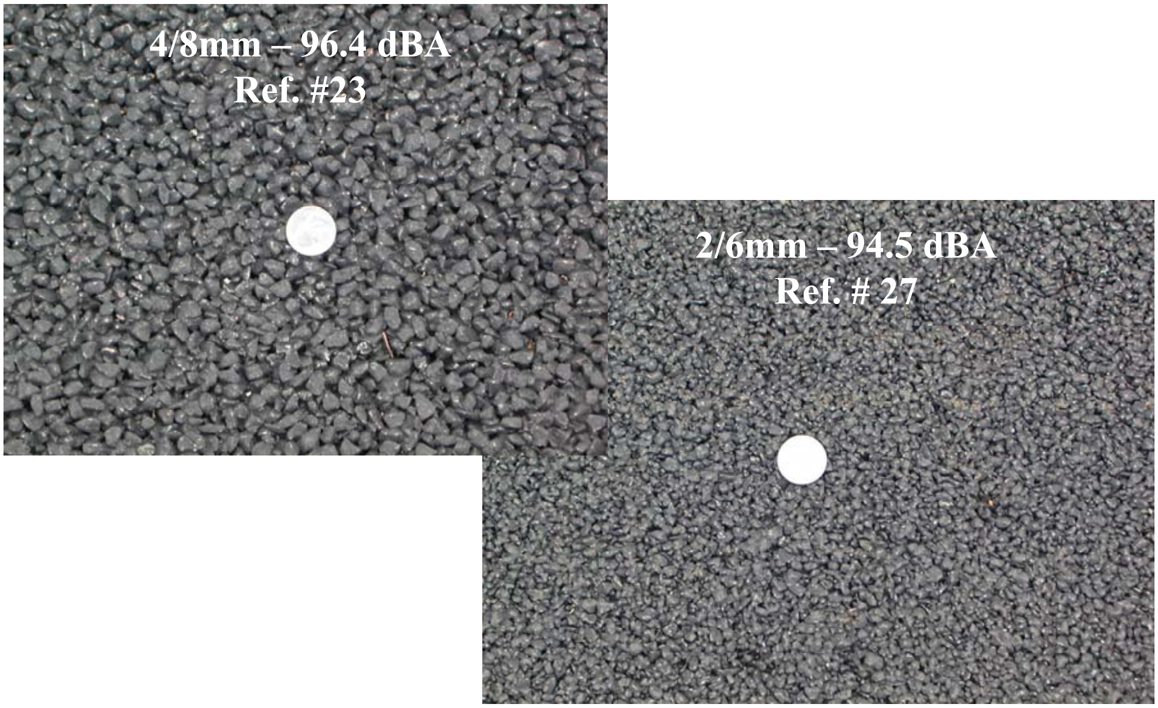

Figure 25: Photographs of two DLPA surfaces containing larger scale (a.) and finer scale (b.) aggregate and apparent surface roughness

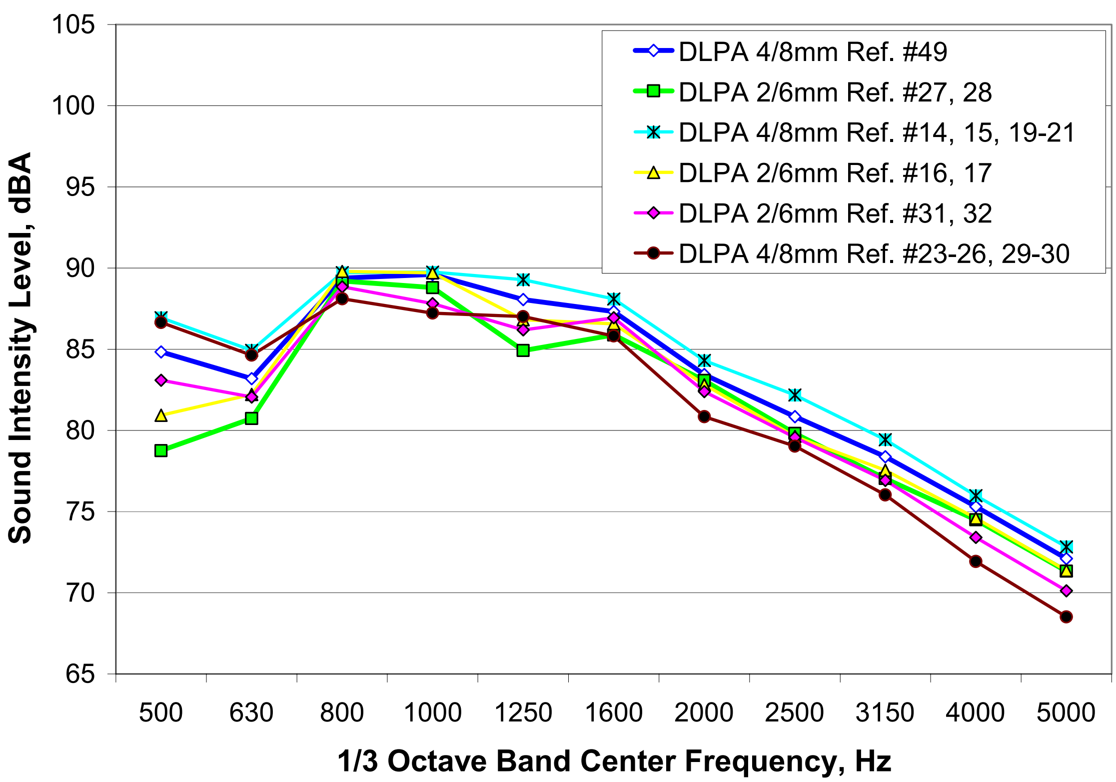

Figure 26: One-third octave band sound intensity levels for European DLPA surfaces of varying top layer aggregate size

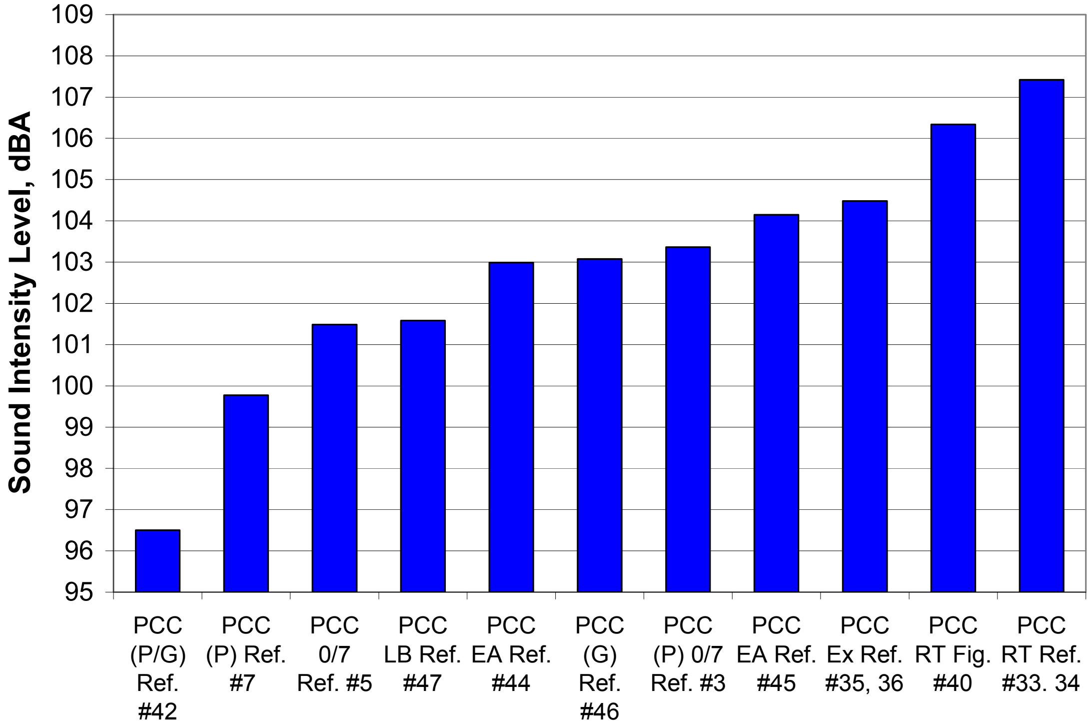

Figure 27: Range of noise performance of PCC pavements of varying construction and surface characteristics – Goodyear Aquatred 3 at 60 mph

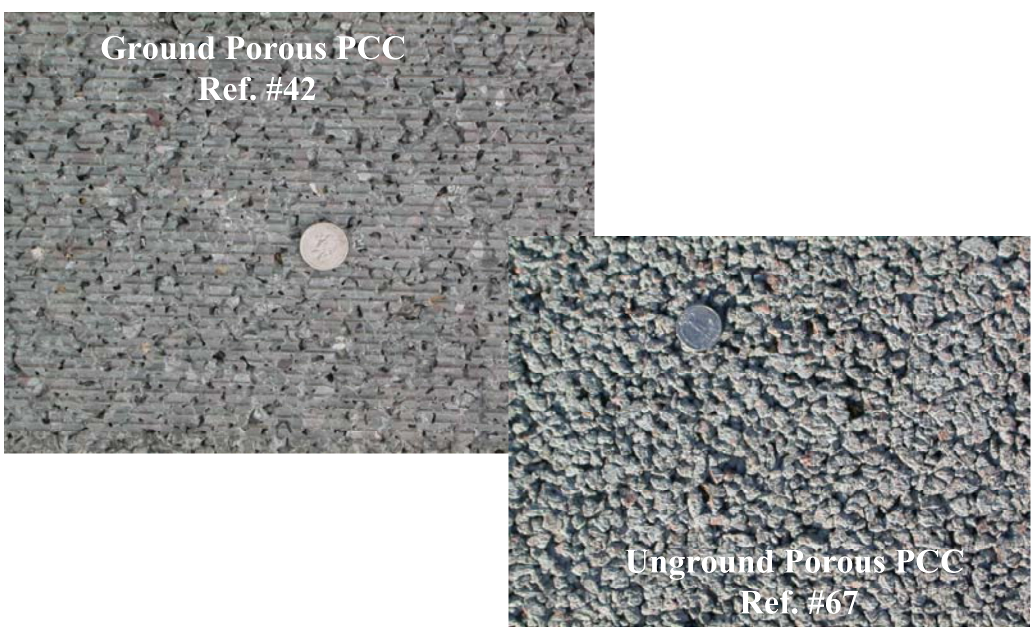

Figure 28: Photographs of two porous PCC pavements ground (a.) and not ground (b.)

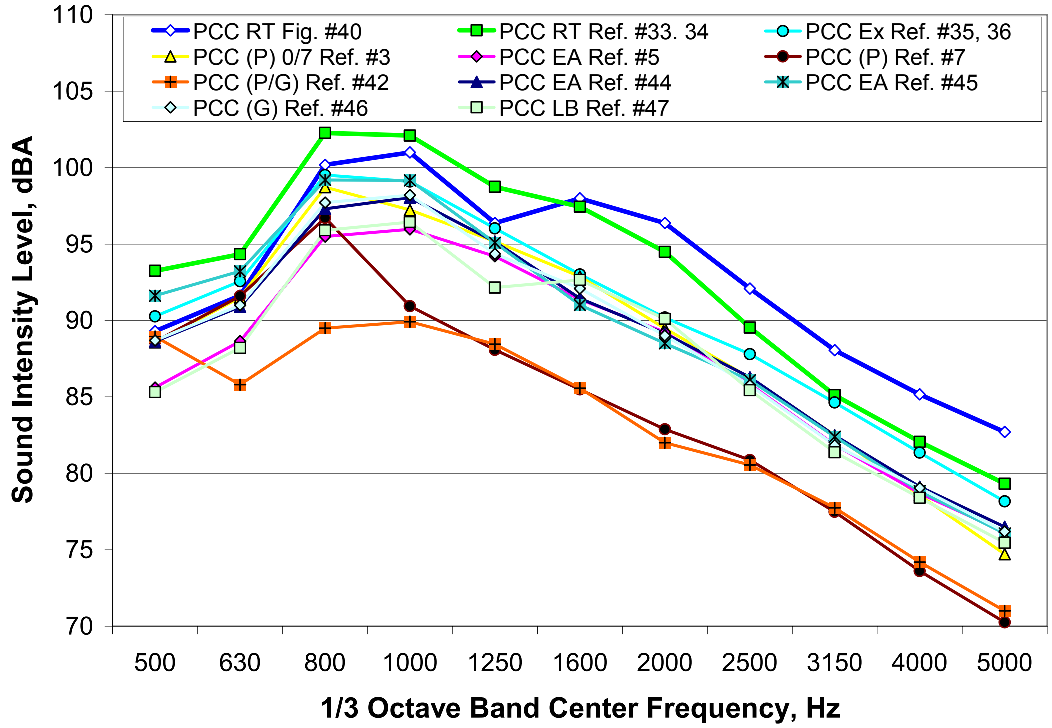

Figure 29: One-third octave band sound intensity levels for PCC pavements of varying construction and surface characteristics

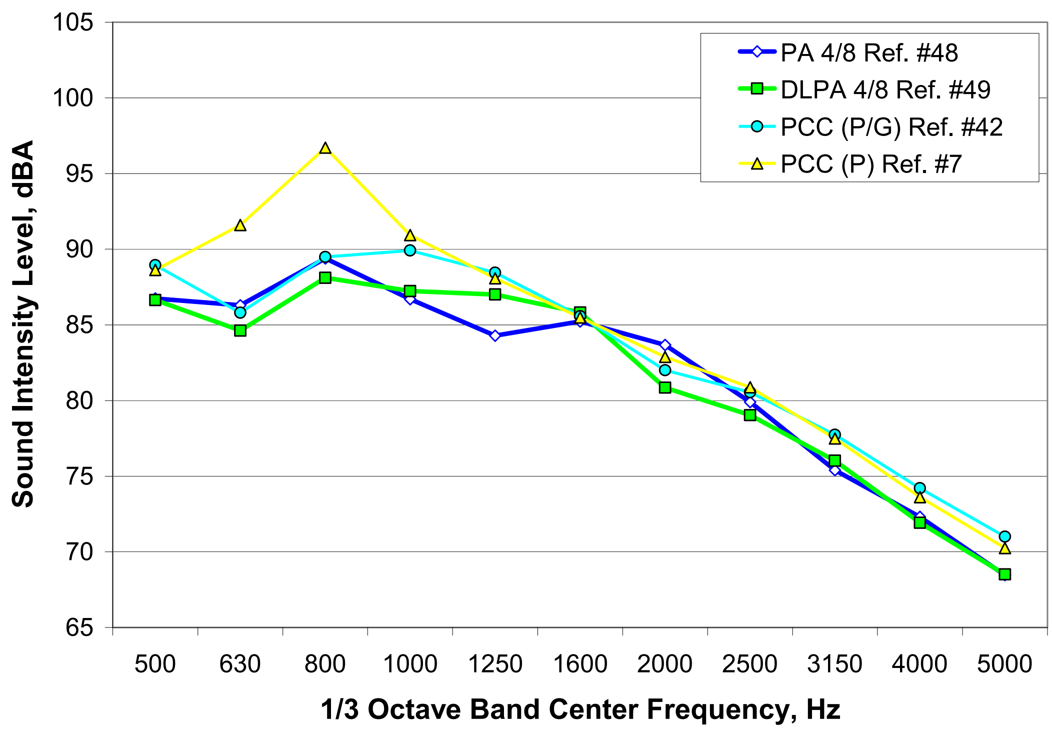

Figure 30: One-third octave band sound intensity levels for porous AC and porous PCC pavements

Figure 31: Photograph randomly textured PCC in the Netherlands on the A270 roadway (reference no. 33)

Figure 32: Photographs of epoxy and stone layer as applied to randomly textured PCC in the Netherlands on the A270 Roadway (reference no. 36)

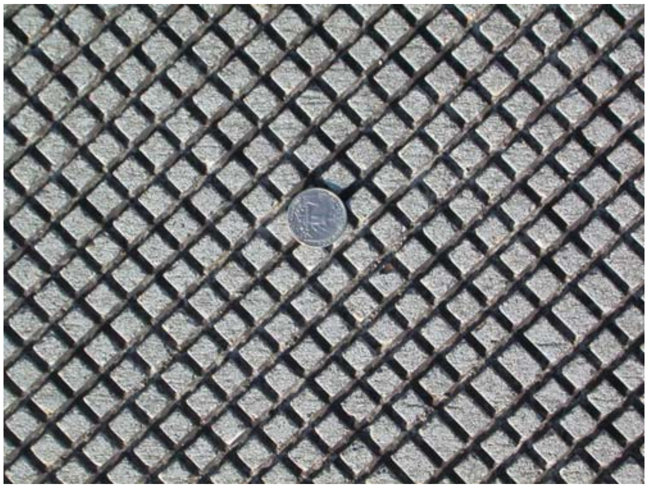 

Figure 33: Photographs of cross-hatched grooved (reference no. 65) and smooth Pl (reference no. 64) PCC surfaces at the Sperenberg test track

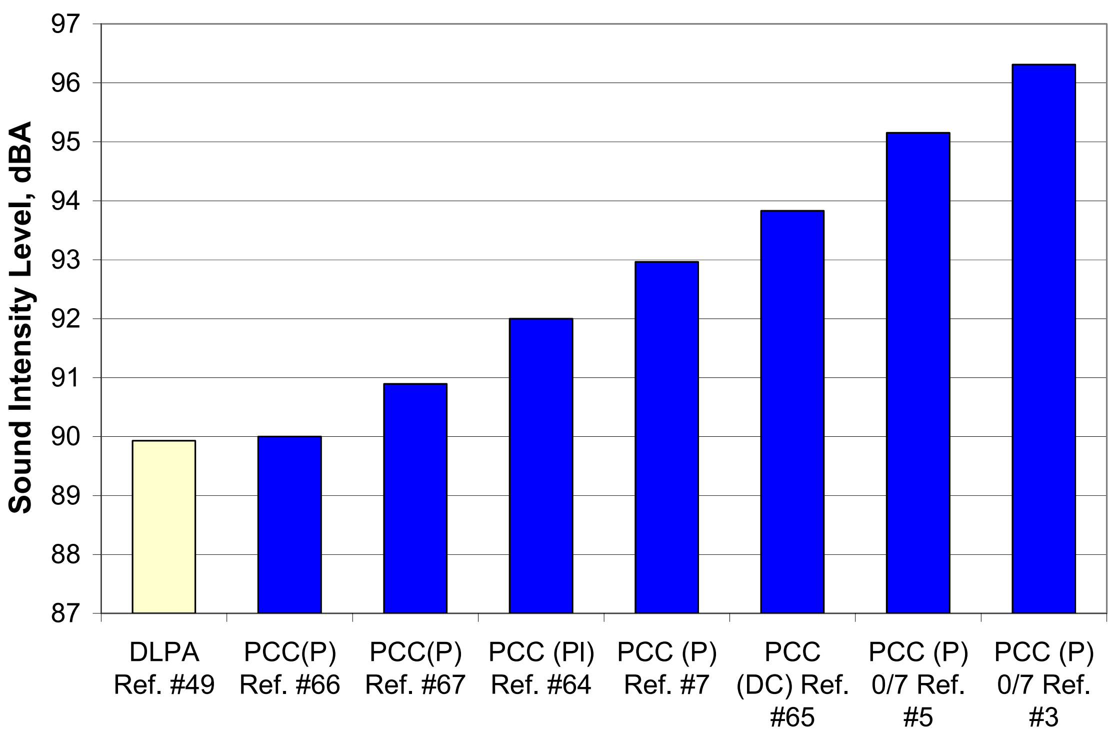

Figure 34: Range of noise performance of PCC pavements of varying construction and surface characteristics compared to DLPA – Goodyear Aquatred 3 at 35 mph

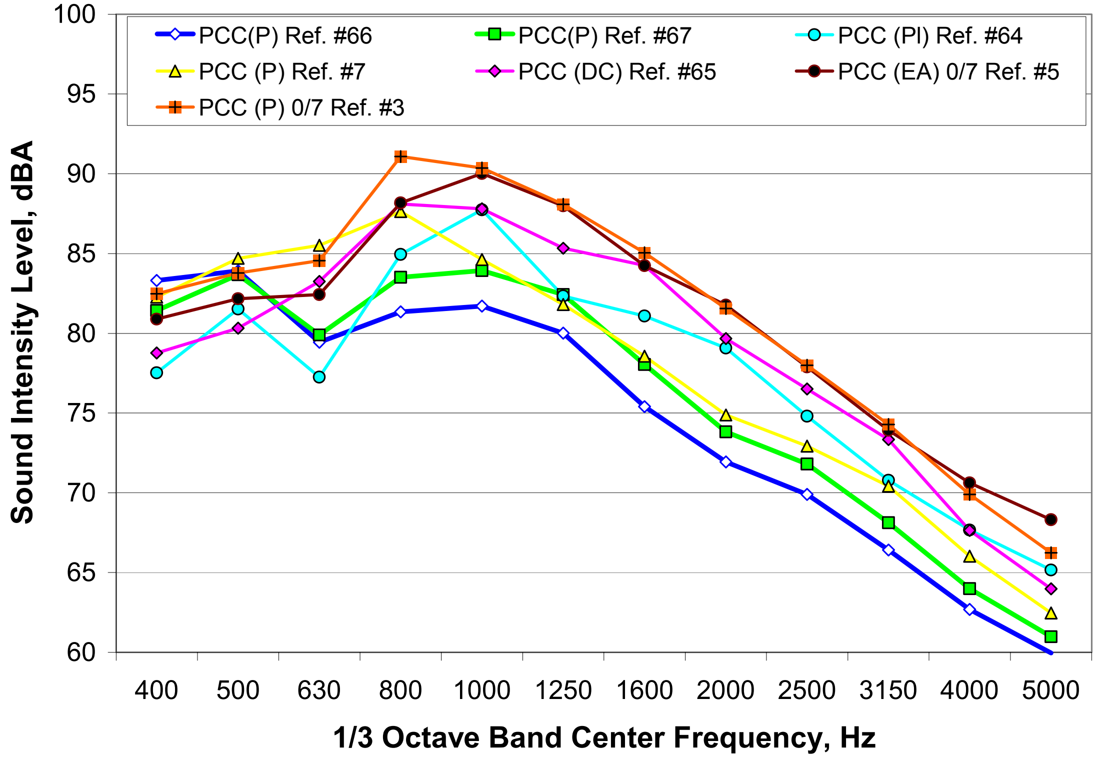

Figure 35: One-third octave band sound intensity levels for PCC pavements of varying construction and surface characteristics - Aquatred 3 at 35 mph

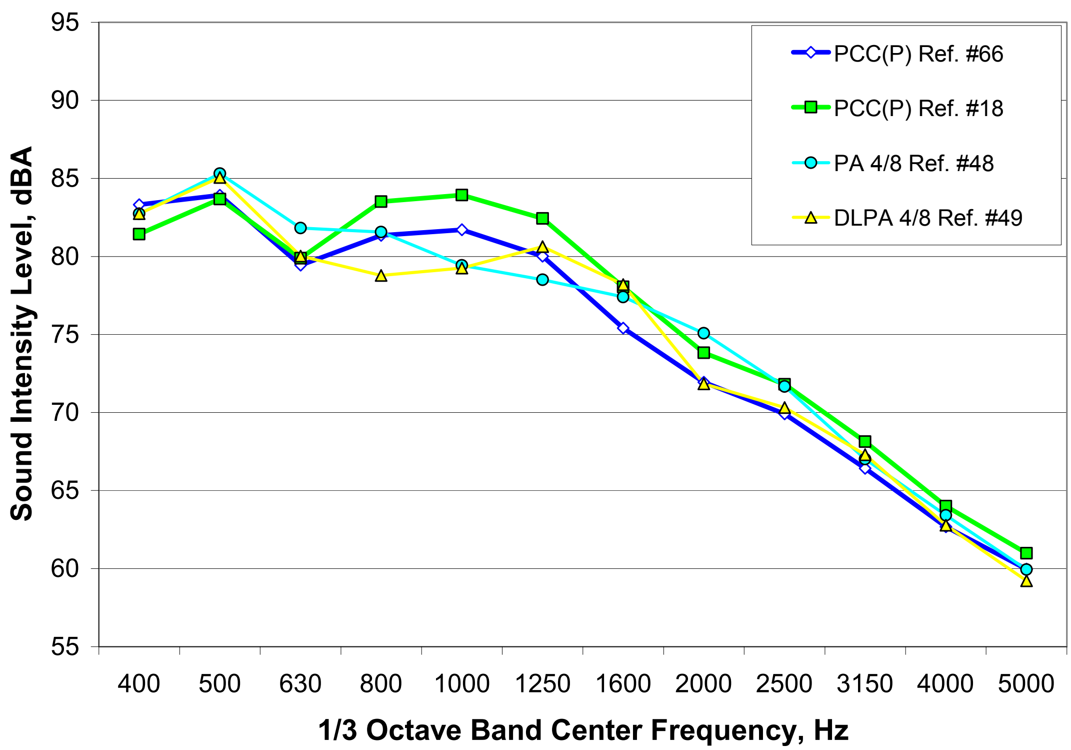

Figure 36: One-third octave band sound intensity levels for porous PA and PCC pavements - Goodyear Aquatred 3 at 35 mph

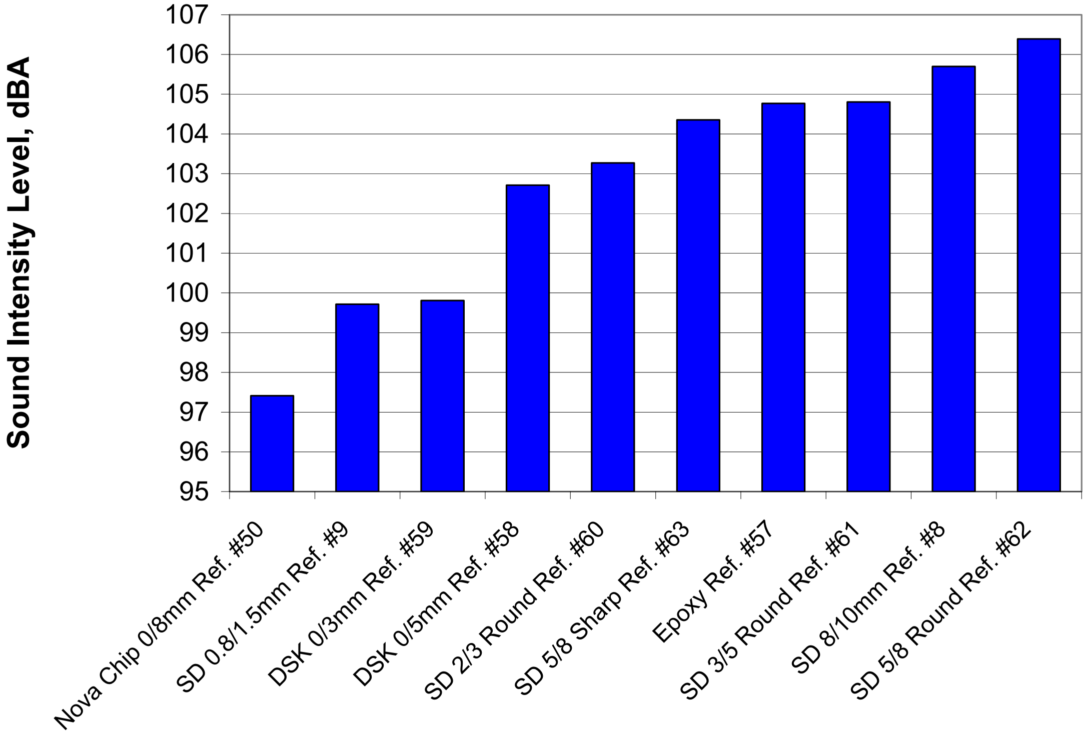

Figure 37: Range of noise performance for pavements of varying construction at the Sperenberg test track with surface dressing surfaces from LCPC – Goodyear Aquatred 3 at 60 mph

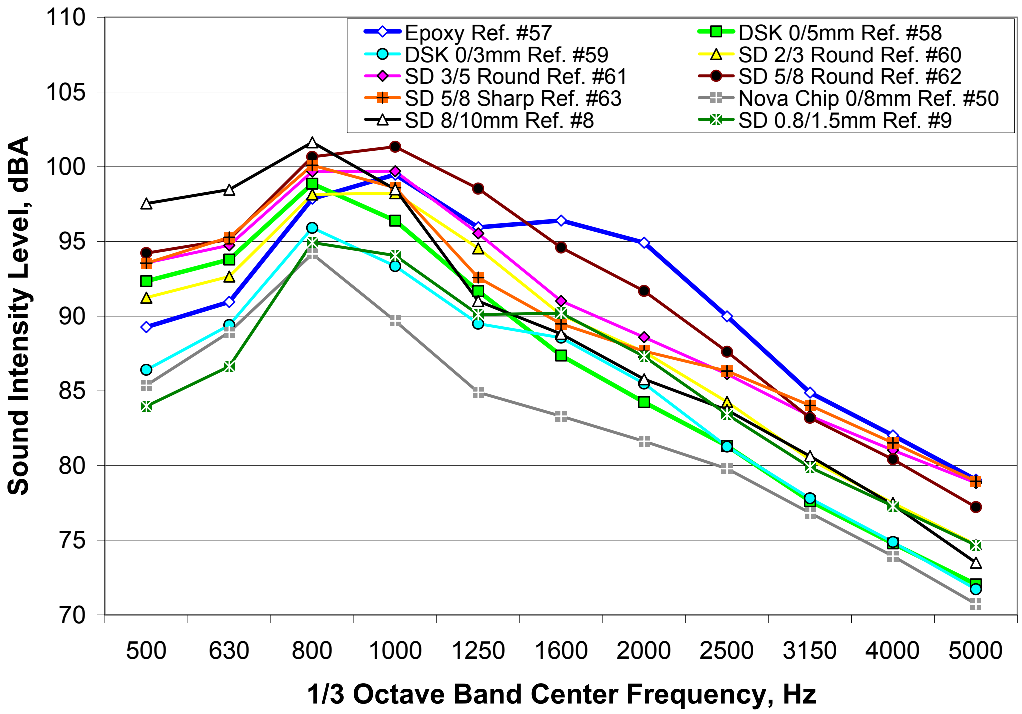

Figure 38: One-third octave band sound intensity levels for pavements of varying construction at the Sperenberg test track with surface dressing surface from LCPC – Goodyear Aquatred 3 at 60 mph

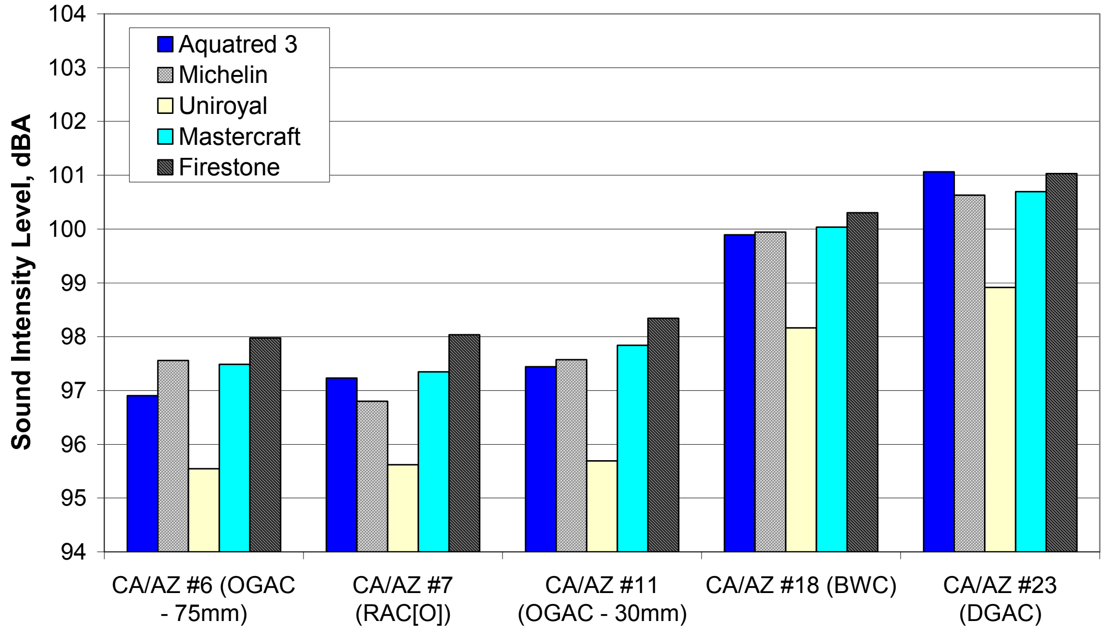

Figure 39: Tire/pavement noise for different test tires on different pavements at the Caltrans LA 138 pavement research site at 60 mph

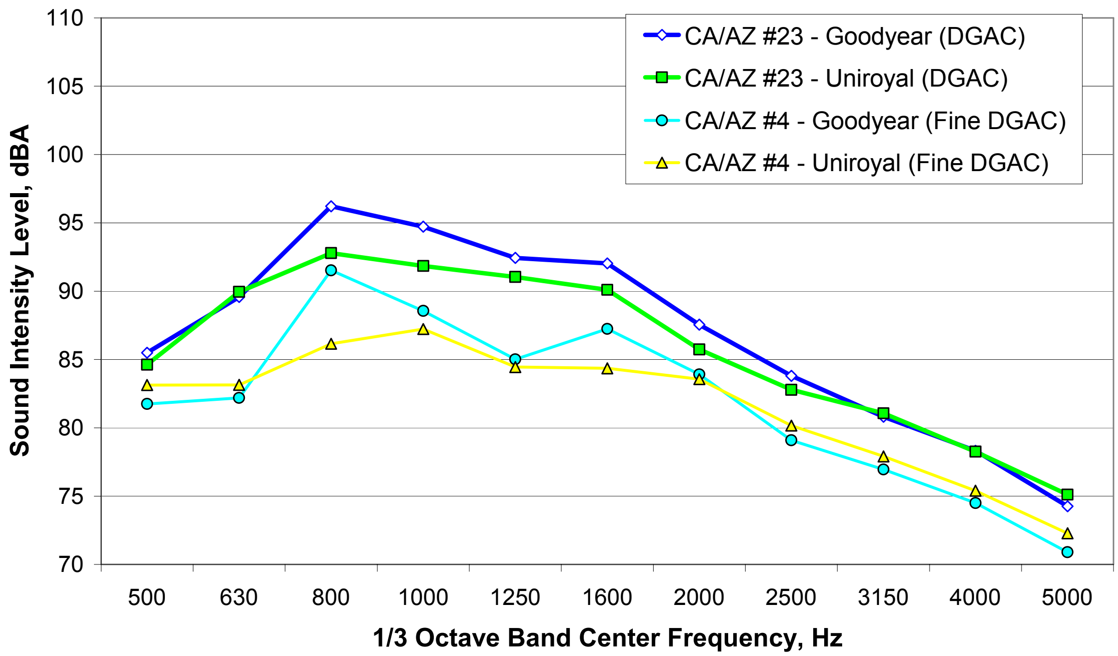

Figure 40: One-third octave band sound intensity levels for two test tires on two US DGA pavements of varying apparent roughness – 60 mph

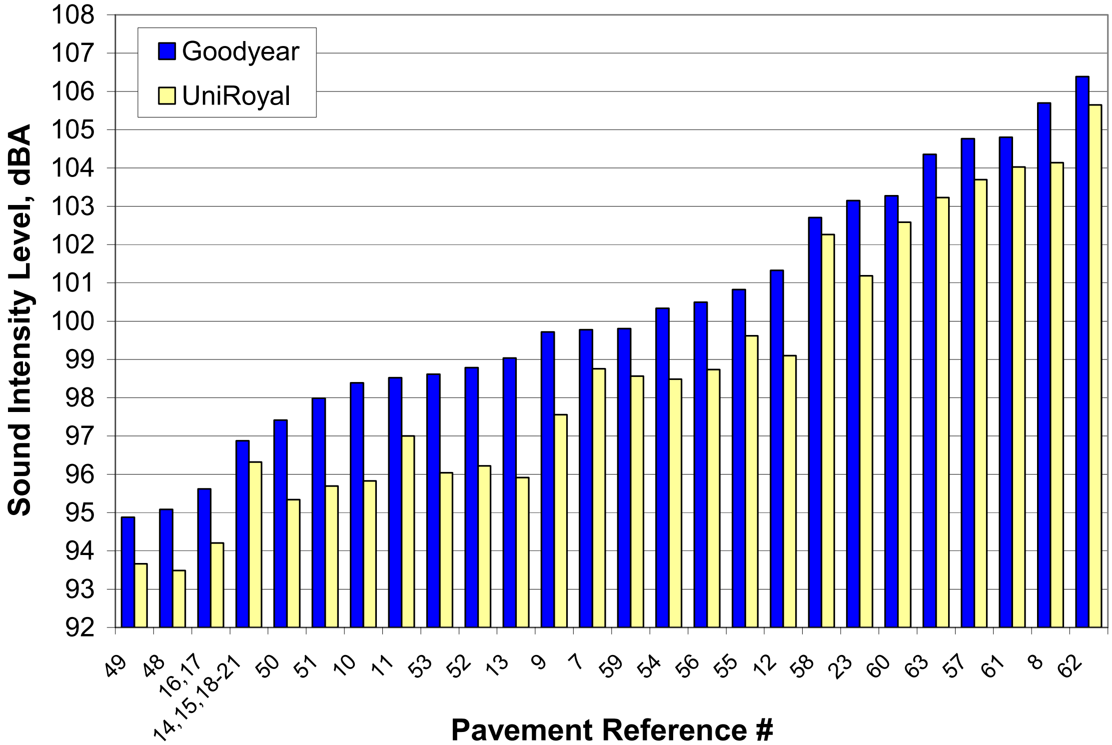

Figure 41: Overall A-weighted sound intensity levels of the Goodyear and Uniroyal test tires on different European pavements – 60 mph

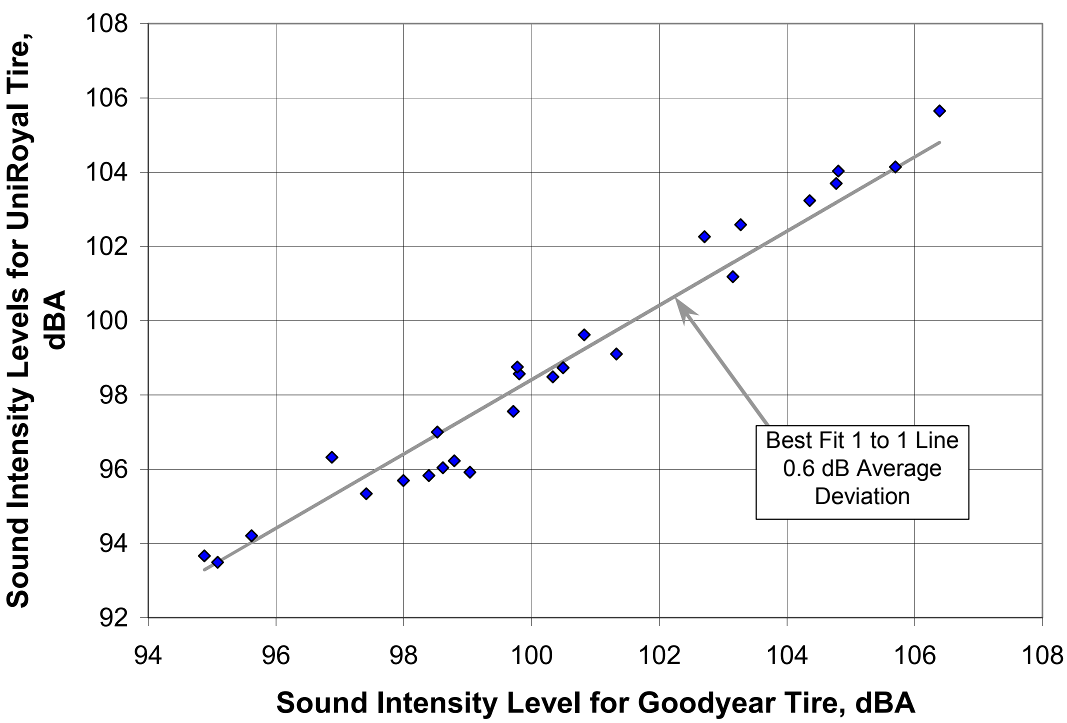

Figure 42: Relationship between overall A-weighted sound intensity levels for the Goodyear and Uniroyal test tires – 60 mph

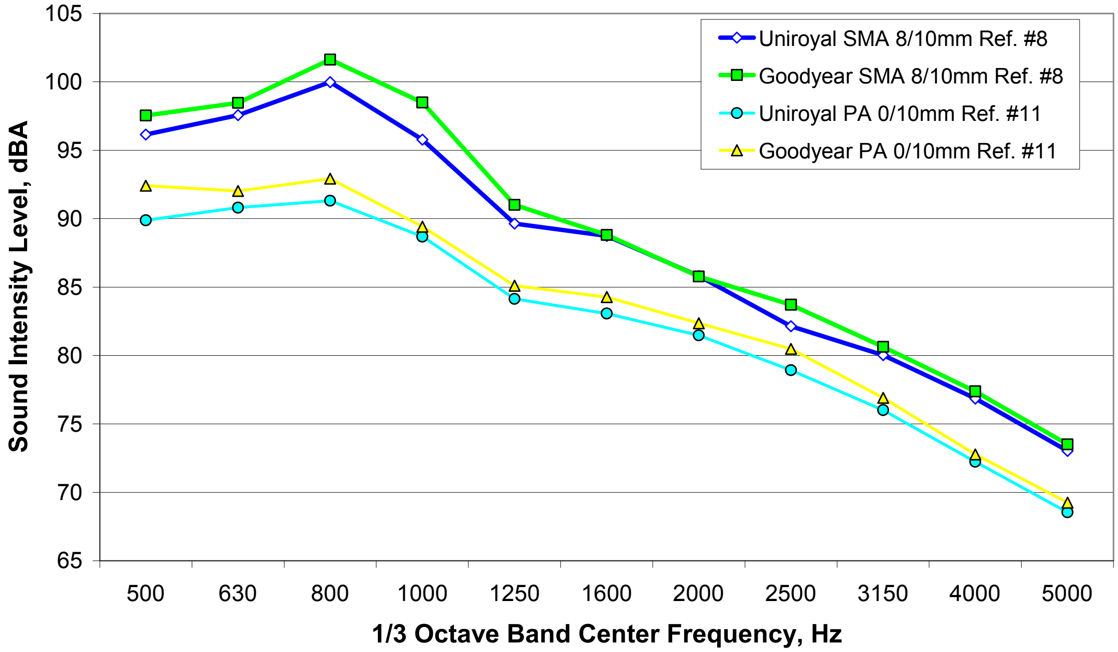

Figure 43: One-third octave band sound intensity levels for Goodyear and Uniroyal test tires on a SMA and a PA pavement – 60 mph

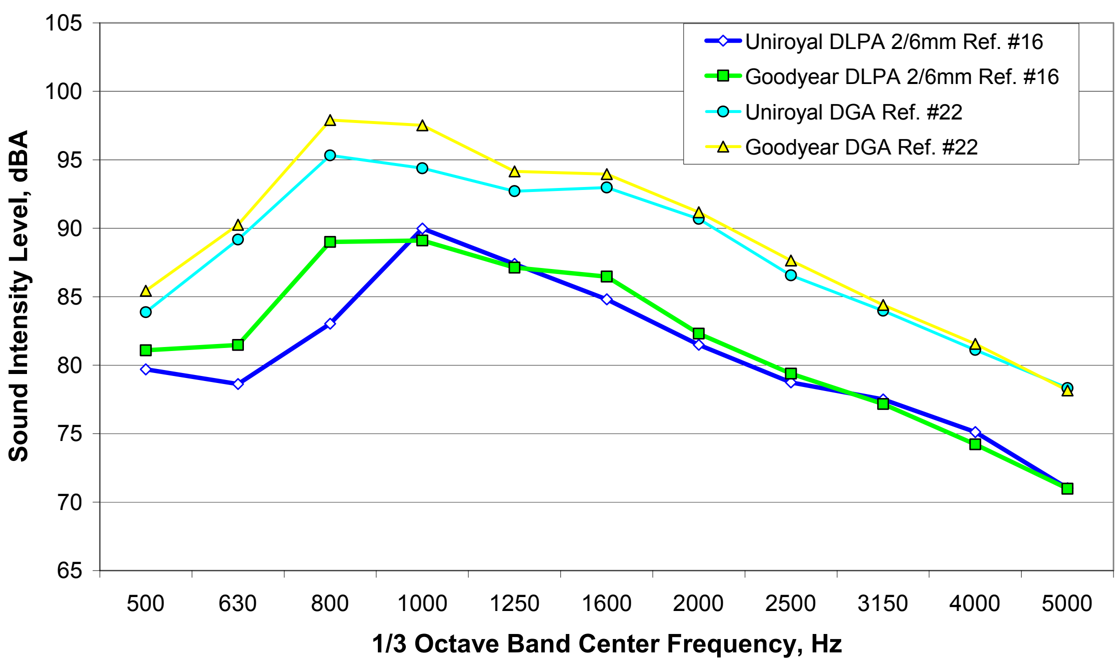

Figure 44: One-third octave band sound intensity levels for Goodyear and Uniroyal test tires on a DLPA and a DGA pavement – 60 mph

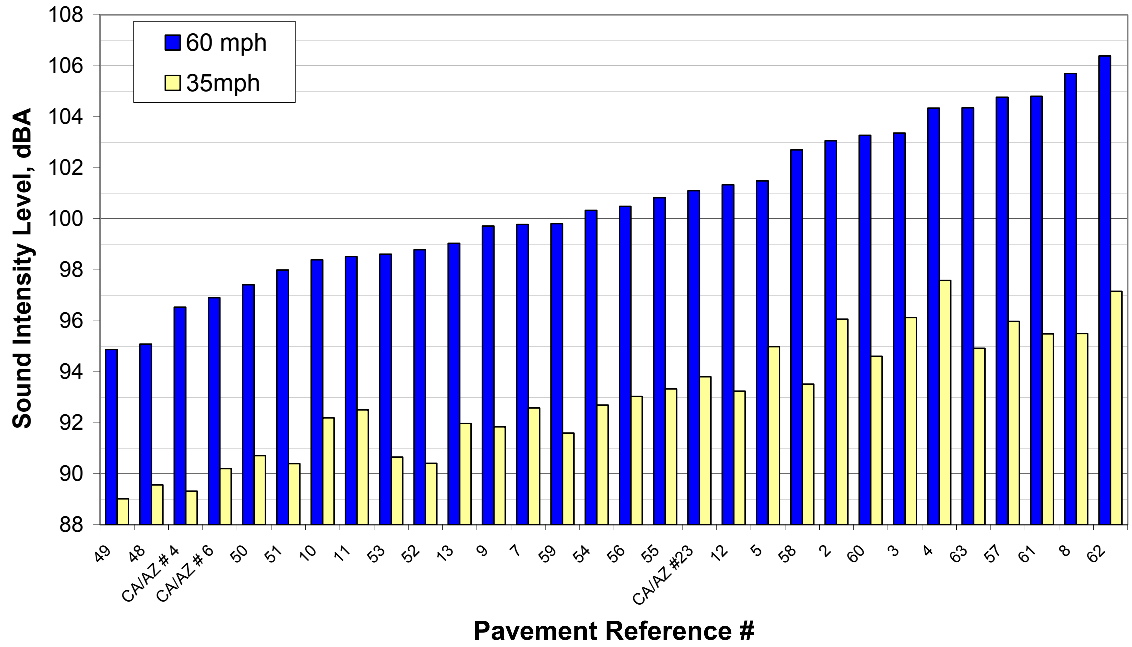

Figure 45: Overall A-weighted sound intensity levels for 60 mph and 35 mph on different pavements – Goodyear Aquatred 3

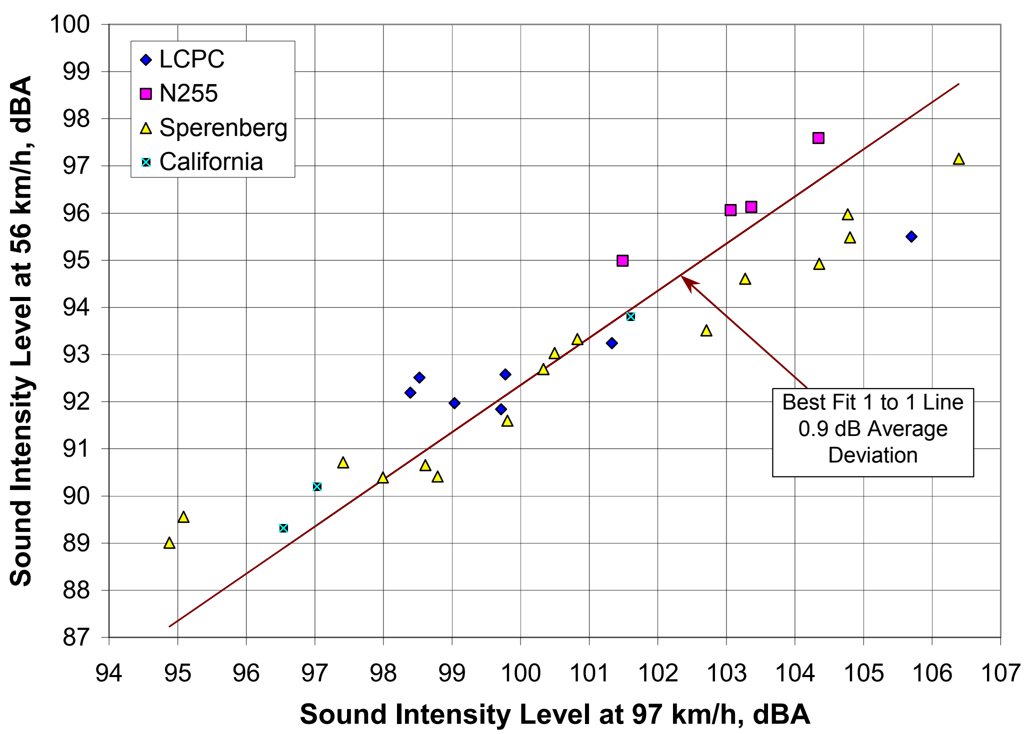

Figure 46: Relationship between overall A-weighted sound intensity levels for 60 mph and 35 mph – Goodyear Aquatred 3

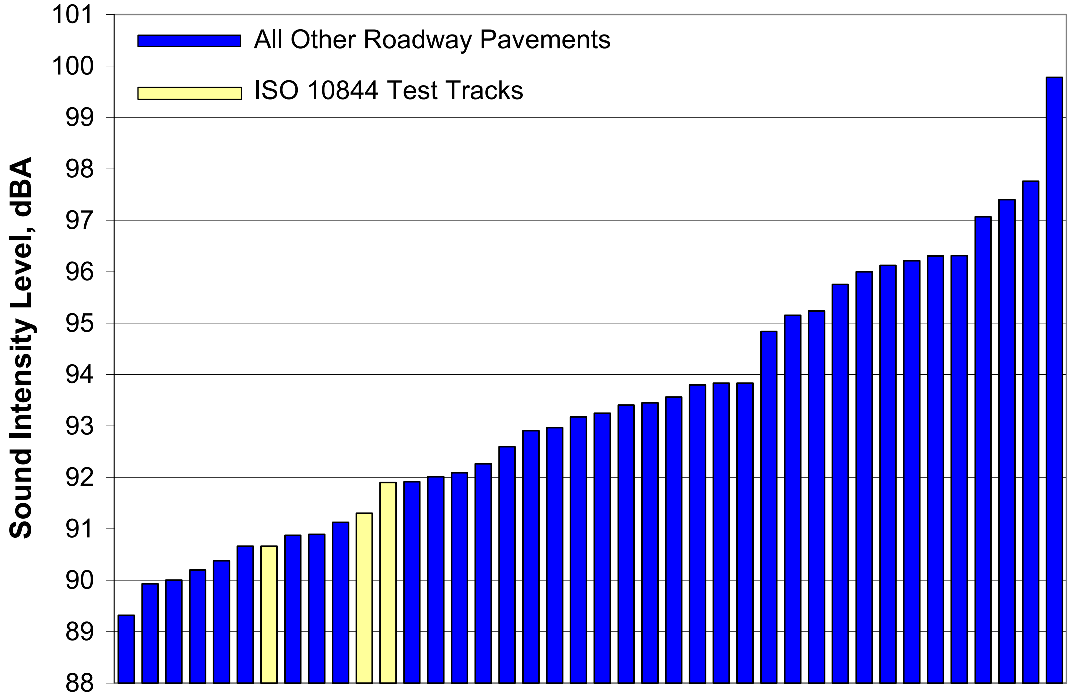

Figure 47a: Overall A-weighted sound intensity levels representing the NITE and CA/AZ databases and the ISO 10844 test surfaces – Goodyear Aquatred 3 at 35 mph

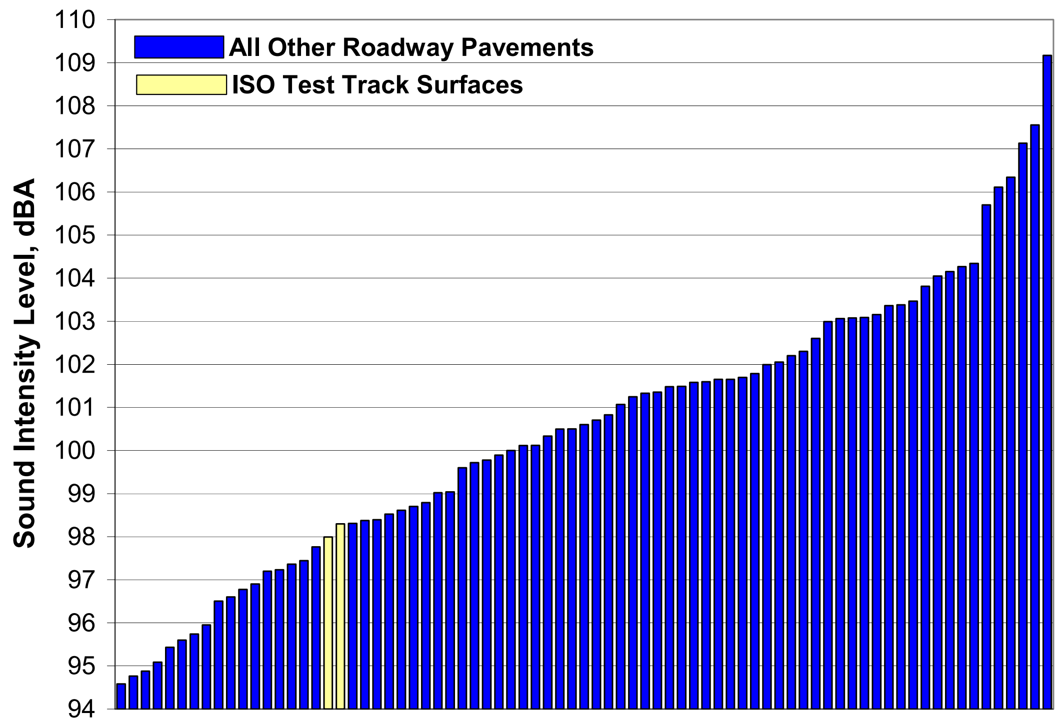

Figure 47b: Overall A-weighted sound intensity levels representing the NITE and CA/AZ databases and the ISO 10844 test surfaces – Goodyear Aquatred 3 at 60 mph

5.0 IMPLICATIONS OF NITE RESULTS FOR CALIFORNIA AND THE US

There are two broad areas where the findings of this study have implications for California and other agencies in the US. The first is the quantitative comparison of pavement performance and research findings between Europe and the US. The second is the relative performance of pavement as it relates to design parameters.

5.1 Comparison of European and California/Arizona Pavement Measurements

One of main purposes of the NITE project was to determine if the pavement technology in Europe produced quieter pavements. Historically, this has been difficult to determine due to different test techniques, test tires, different vehicle characteristics and different pavement baselines. Large reductions for quiet pavements relative to some baseline pavements have been reported in the literature from Europe, however, it has not been known if similar reductions could or were being made in the US. With the NITE database, it is possible to begin to address this issue. Comparing Figs. 5 and 9, the range and level of tire/pavement noise appears to be quite similar. The issue of relative improvements can be examined more closely by comparing the range of some commonly occurring pavements to quiet pavements for Europe and the US. Because the lowest levels were measured in the Netherlands, these data were chosen for these comparisons. In Fig. 48, several DGA and PCC pavements, which were found on motorways in the Netherlands, are plotted with two different DLPA pavements. From these data, a possible improvement in level with the DLPA could be around 10 dB. In Arizona, the bulk of the PCC is uniform transverse tined, although there is a limited amount of longitudinal and random transverse tined PCC. Relative to Arizona Asphalt Rubber Friction Course (ARFC) overlays that have been recently applied in the Arizona Quiet Pavement Pilot Project, reductions on the order of 10 dB are typical as illustrated in Fig. 49. In California, however, the range of possible improvement is smaller primarily due to the absence of the use of transverse tining for on-grade PCC surfaces (Fig. 50). Without the transverse tining, PCC surfaces are typically 2 dB to 5 dB lower than Arizona. In comparison to the Netherlands, the higher levels in California are 2 to 4 dB lower. As a result, even if the quieter DLPA were implemented in California, the improvement may be less than that which might be expected in the Netherlands or Arizona. These data emphasize that the benefits of a quiet pavement will be a function of both the performance of the quiet pavement and the pavement that it replaces. It also emphasizes that care must be taken in assuming that the reductions found in one state or country will be realized in another.

Two of the test sites included in the NITE project were also included in a round-robin test of measurement devices for the “Sustainable Road Surfaces for Traffic Noise Control” (SilVia) project (Ref. 12). In this testing, researchers from five organizations in Europe participated in CPX noise measurements of surfaces at Sperenberg and Düren, Germany. One of those participants, M+P of the Netherlands, has provided their data for comparison to that of the NITE project. This included a total of twenty-two different pavements. In comparing the two data sets, it should be realized the SilVia tests were conducted at 80 km/h (50 mph) while the NITE testing was conducted at 97 km/h (60 mph). Further, the test tires were not common. The CPX measurements were made with those tires specified in the draft standard, while the NITE measurements were made with the Goodyear Aquatred 3 at both sites and the Uniroyal Tiger Paw at the Sperenberg track only. Data for both of these cases are presented in Figs. 51 and 52.

In each, the data are fitted with a "1-to-1" line as well as a linear regression. For both tires, the linear regression yields a slope that is less than 1and "r^2" values near 0.9. For the Goodyear tire, the average deviation from the regression line is 0.6 dB while the standard deviation is 0.8 dB. For the Uniroyal tire, the values are 0.8 and 1.1 dB, respectively. In the SilVia data, the standard deviation among the five different participants was 0.8 dB at 80 km/h.

Even with the differences in test speed and tires, the deviations found in the CPX to sound intensity comparison were remarkably similar to the CPX deviations noted between participants. More direct comparison between the techniques using the same tires and test speed are expected to yield more of a 1-to-1 relationship similar to that measured using the ADOT CPX trailer (Fig. 53) (Ref.16). In this case, the CPX and sound intensity data were measured simultaneously for the same tires on a number of different pavements operating at 60 mph (97 km/h). Regressing these data produced an almost 1-to-1 relationship with a standard deviation of 0.6 dB.

5.2 Comparison of European and California/Arizona Pavement Designs

For the more conventional pavements, DGA, SMA, and non-porous PCC, the range of performance of pavement types were quite similar between the US and Europe (Figs. 11 & 13). From a gross design perspective, the controlling factors for noise appear to be consistent. For SMA and DGA designs, aggregate size and surface roughness appear to be the most dominate factors and quieter and noisier samples of each are found in both places. In the NITE study, PCC surfaces were studied in less detail, but transversely tined PCC was also found to be higher and similar in level in Europe and the US. For the quietest surfaces, those in Europe were found to be slightly quieter than those of CA/AZ with an offset of about 1 dB (Fig. 54). To examine the differences and similarities between Europe and the US in more detail, it is convenient to consider AC and PCC pavement groupings separately using the existing CA/AZ database as a starting point.

5.2.1 Asphaltic Concrete Pavements

A further breakdown of the database illustrated in Fig. 5 indicates that AC pavements can be grouped into those with rubber content, those of open graded design, and those of dense graded design. As illustrated in Fig. 55, these groupings show that the pavements with rubber content are typically and more consistently lower in level than the other two. The OGAC designs tend to span almost the full range of AC pavements, although some approach the performance of those with rubber content. And finally, the DGA pavements are generally higher in level although they do overlap with specific pavements in each of the other two categories. It should be noted that these represent pavements of different age and no attempt to account for those differences has been made in these data.

An analogous grouping of the AC pavements measured in Europe can also be made. In this case, the groupings include double layer porous AC, (single layer) porous AC, and DGA and SMA as a single grouping due to their similarity in performance and parameter dependencies. In this case, as a group, the DLPA pavements perform better and more consistently than either of the other two groupings (Fig. 56). Similar to the OGAC grouping for the CA/AZ data, the PA grouping tends to span the entire range of performance, likely influenced by the size of the aggregate and the condition of the pavement relative to its porosity. Similar to the DGA in CA/AZ, the DGA/SMA category tends to be higher in level and overlap with at least the PA category. It should be cautioned when considering these groupings that the DLPA pavements all are only a few years old or less or are in non-trafficked test tracks.

In considering the AC pavements, some contrast between those in Europe and those in California and Arizona should be noted. In Europe, the quieter pavements are often "drainage" pavements, intentionally constructed to be water (and air) permeable. These porous pavements are effective in reducing the tire noise source strength and should provide sound absorption characteristics that should positively effect sound propagation away from a vehicle. Although porous pavements are often intended to reduce splash and spray, by using smaller size aggregate on the top of a dual layer porous, they can also achieve the lowest tire/pavement noise levels measured to date. In contrast, for the CA/AZ surfaces, high permeability is not necessarily achieved with the open graded designs and pavements with rubber content. Further, there has been no indication of improved sound absorption of these surfaces relative to others. However, from the groupings of Fig. 54, it is apparent that rubber content can provide quieter pavements, approaching the performance of the European DLPA pavements. At this time, although rubber content has been found to have a positive effect on noise performance, its role is not fully understood.

Another difference between the quieter AC pavements in Europe and California and Arizona is that European porous pavements tend to be thicker, 40 to as much as 120mm. For the quieter CA/AZ rubberized pavements, the overlays are typically thinner, 25 to 30mm, but achieve very close to same performance of the thicker permeable European surfaces. From the LA 138 results (Fig. 39, CA/AZ #6 & #11), nearly doubling the thickness of the OGAC layer only produced a ½ dB or less improvement in noise performance. A final difference between the quieter European pavements and the quieter CA/AZ pavements is aggregate size. The European pavements have maximum aggregate sizes of 6 to 8mm. Aggregates in the CA/AZ pavements range from 9.5mm to 19mm. The relationships between permeability, porosity, pavement thickness, aggregate size, and rubber content are clearly an area for further research. However, the findings to date suggest that, directionally, better tire/pavement noise performance can be obtained by achieving a high degree of pavement porosity, by added rubber content, and by using smaller aggregate sizes.

5.2.2 Portland Cement Concrete Pavements

To consider PCC surfaces in more detail, results from the CA/AZ data base were grouped in the categories of ground, longitudinal tined, uniform transversely tined, and random transversely textured. These data formed fairly consistent groups with the ground surfaces being the quietest, followed by longitudinal tined, and then the transverse (Fig. 57). The limited data for uniform traverse tined surfaces indicated that it was typically quieter than the random transverse, but recent CPX data for the Phoenix area has indicated a significant (higher) range in the noise performance of uniform transverse tine PCC such that more overlap between the uniform and random transverse tining may actually occur (Ref. 18). If the uniform and transverse categories are grouped together, these data indicate that although there is a range of performance within each grouping, picking a given surface type will "lock-in" an expected performance. That is, a transversely tined/textured surface will not perform as well as a longitudinal tined surface, which in turn will not perform as well as a ground surface. It should also be noted that grinding an existing tined surface would almost always produce a reduction in tire/pavement noise. To compare these surface categories to the European data, it is useful to average the noise level of each grouping resulting the levels given in Fig. 58.

Within the European data, examples of both random transverse texture and ground, non-porous PCC surfaces were measured. As illustrated in Fig. 59, the levels for these surfaces fit well into the ranges defined by the averages of the groupings from Fig. 58. In Fig. 60, test results of three European exposed aggregate PCC surfaces are compared to the CA/AZ averages. These data indicate that EA can span the range from ground PCC surfaces to longitudinally tined depending on aggregate size. This implies that for new PCC surfaces, EA PCC with finer aggregate may be a lower noise option than longitudinal tining. Also, a finer aggregate EA would not have need of grinding to achieve the lower noise performance. Longitudinally textured (broomed) PCC surfaces were also found to perform close to the average of ground surface average from the CA/AZ database (Fig. 61). As noted in Section 4.1.5, porous PCC pavements have the potential to perform quite well for tire/pavement noise with levels approaching those of the quieter AC surfaces. Two examples of porous PCC, ground and unground, are compared to the CA/AZ averages in Fig. 62. These data indicate the porous PCC has the potential of being an entire new grouping with performance better than any other PCC grouping.

For the PCC constructions that are common between California and Arizona and Europe, performance was quite comparable. For surfaces that are not typically found in the US, that is, porous and exposed aggregate PCC, it appears that some noise performance improvement may be possible with the development and verification of these pavements.

5.2.3 Variation of Pavements of Similar Design/Construction

Another issue of interest in comparing the CA/AZ and Europe pavements is the variation of noise between pavements of same specification. Recently, variation of noise levels for older pavements of the same design has become an issue in the US with some large variations being reported depending on sample averaging (Ref. 10, 17). In Europe, variation of noise from newer constructions of the same specification has also become a concern. In the Netherlands, multiple sample sections of DLPA have been constructed to the same specification, but by different contractors. This was done on two different motorways of slightly different age. For each motorway, the variation from section to section was just slightly more that 1 dB (Fig. 63). Comparing both motorways, the range was about 2 dB with the more recently constructed motorway sections being typically quieter. As a follow-up to the NITE testing, newer ARFC pavements were also measured in the Phoenix area in October of 2004. This data set also included pavements of slightly different age, built by different contractors to the same specification. Similar to the results from the Netherlands, these data indicated that within the same pavement project, the levels typically varied by about 1 dB, while across different projects and contractors, the variation was about 2 dB (Fig. 64).

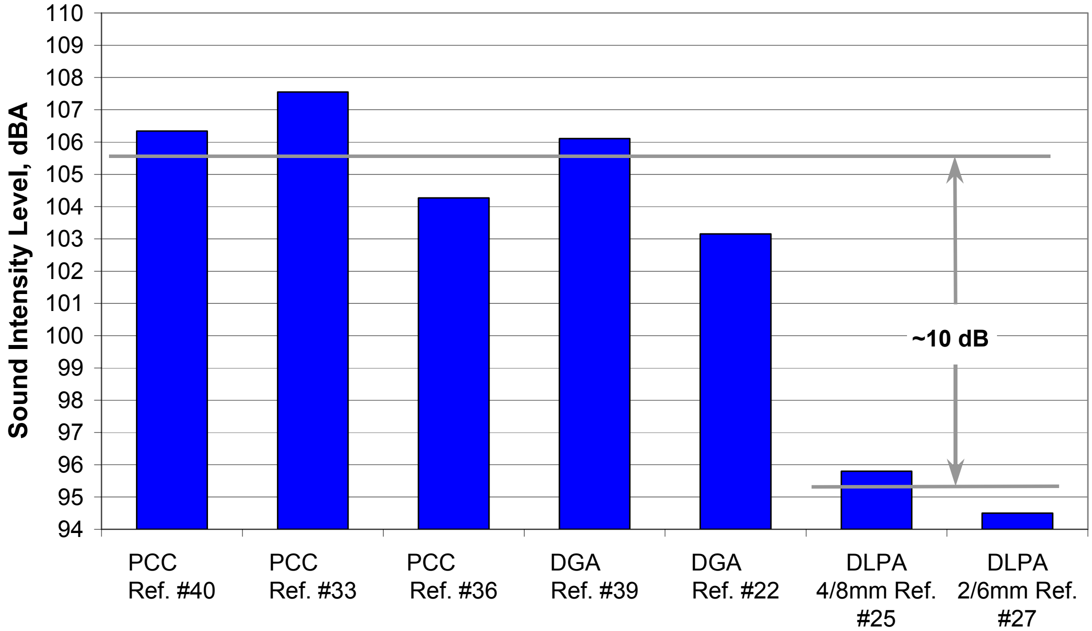

Figure 48: Overall A-weighted sound intensity levels for quieter and noisier pavements in the Netherlands – Goodyear Aquatred 3 at 60 mph

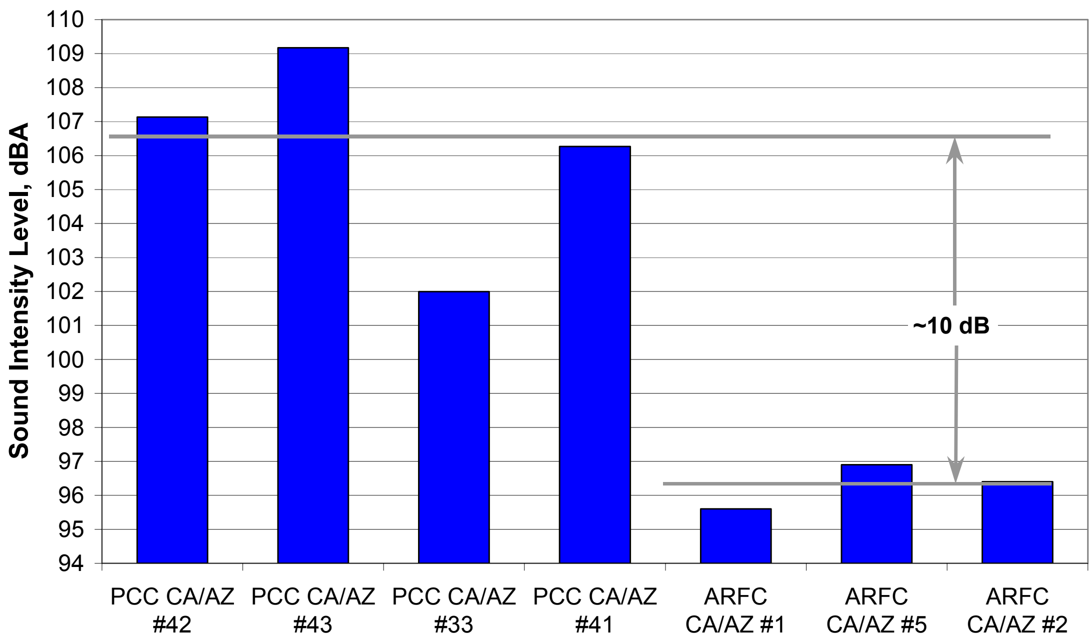

Figure 49: Overall A-weighted sound intensity levels for quieter and noisier pavements in Arizona – Goodyear Aquatred 3 at 60 mph

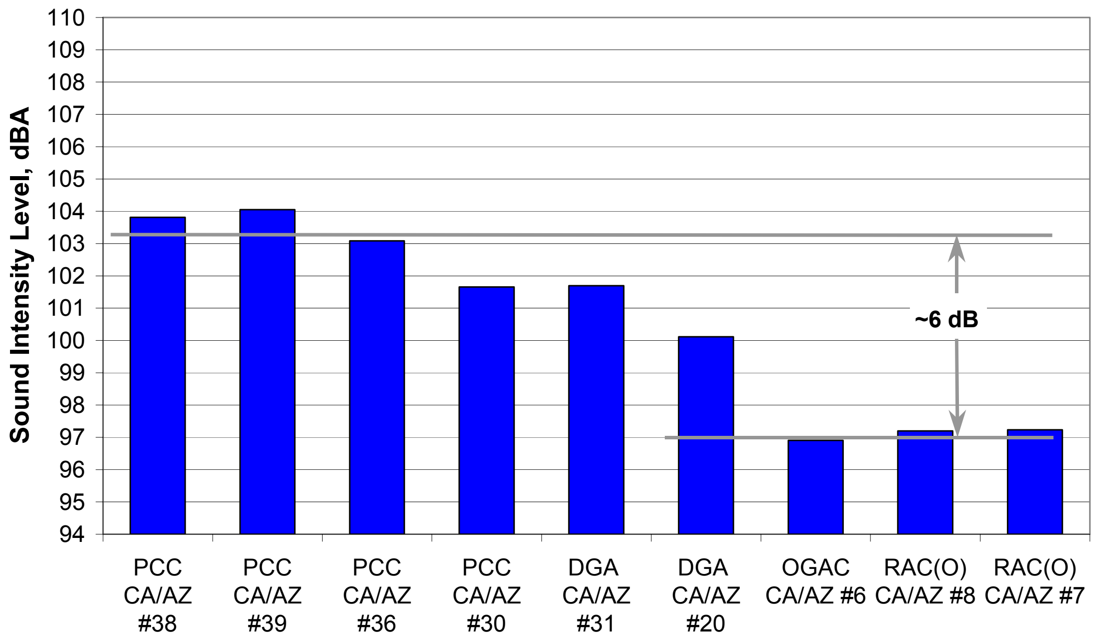

Figure 50: Overall A-weighted sound intensity levels for quieter and noisier pavements in California – Goodyear Aquatred 3 at 60 mph

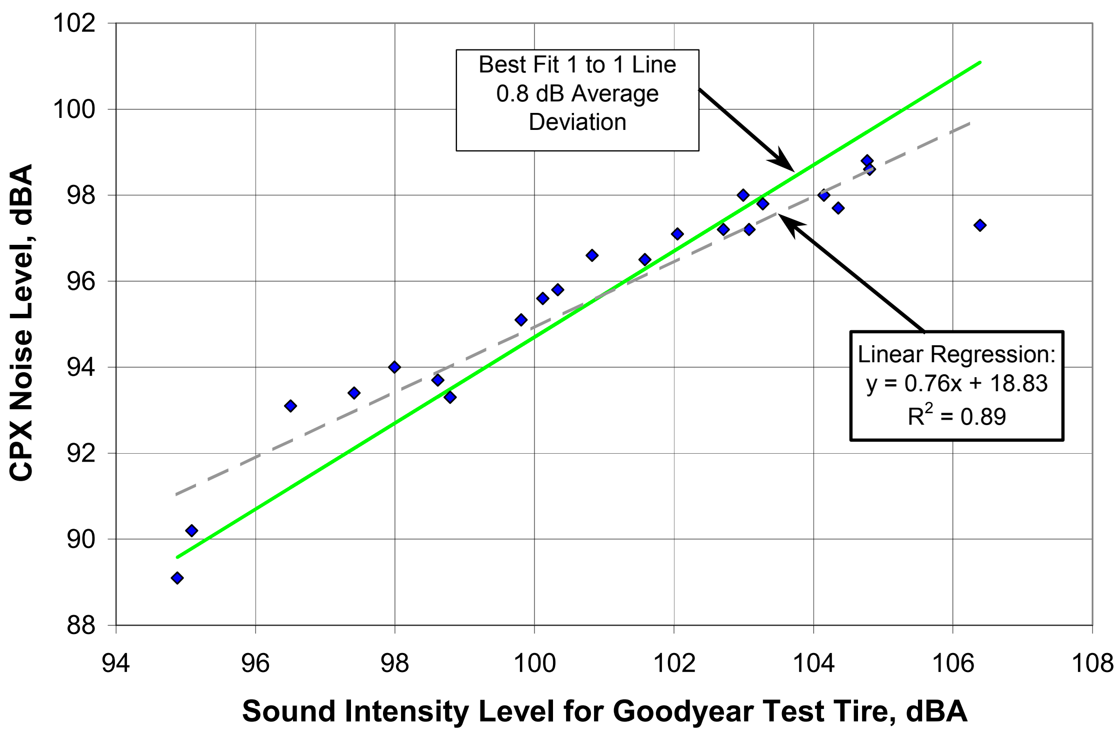

Figure 51: Relationship between sound intensity level for the Goodyear Aquatred 3 tire at 60 mph and M+P CPX index levels at 50 mph (80 km/h) for pavements at Sperenberg and Düren

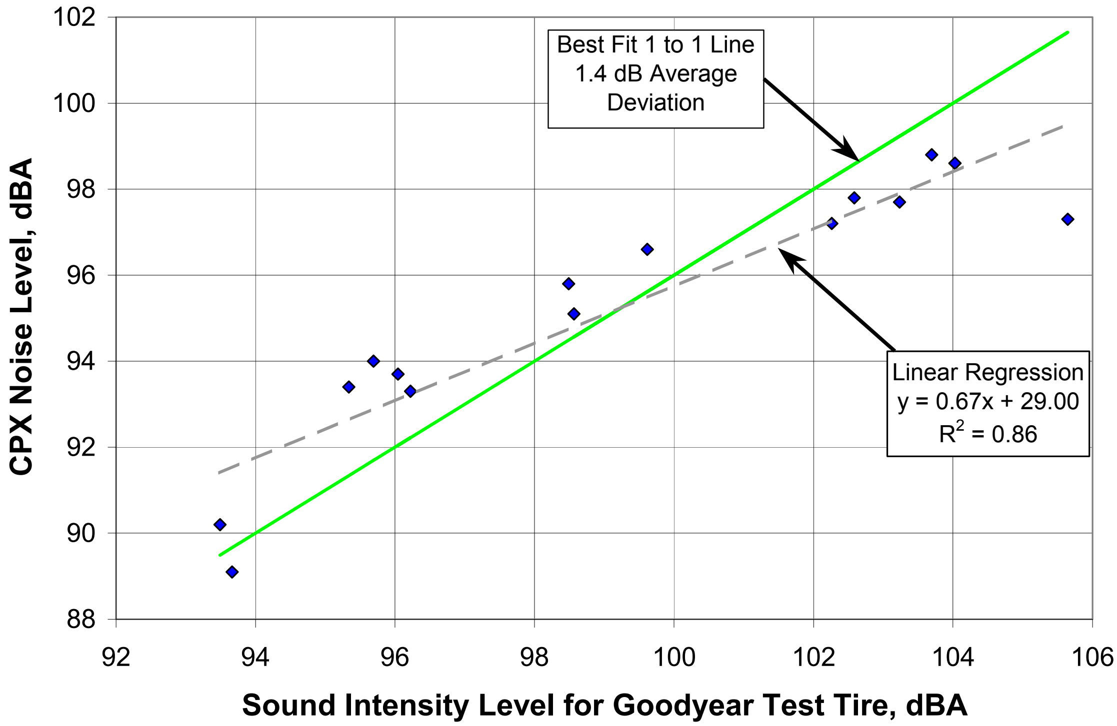

Figure 52: Relationship between sound intensity level for the Uniroyal Tiger Paw AWP tire at 60 mph and M+P CPX index levels at 50 mph (80 km/h) for pavements at Sperenberg

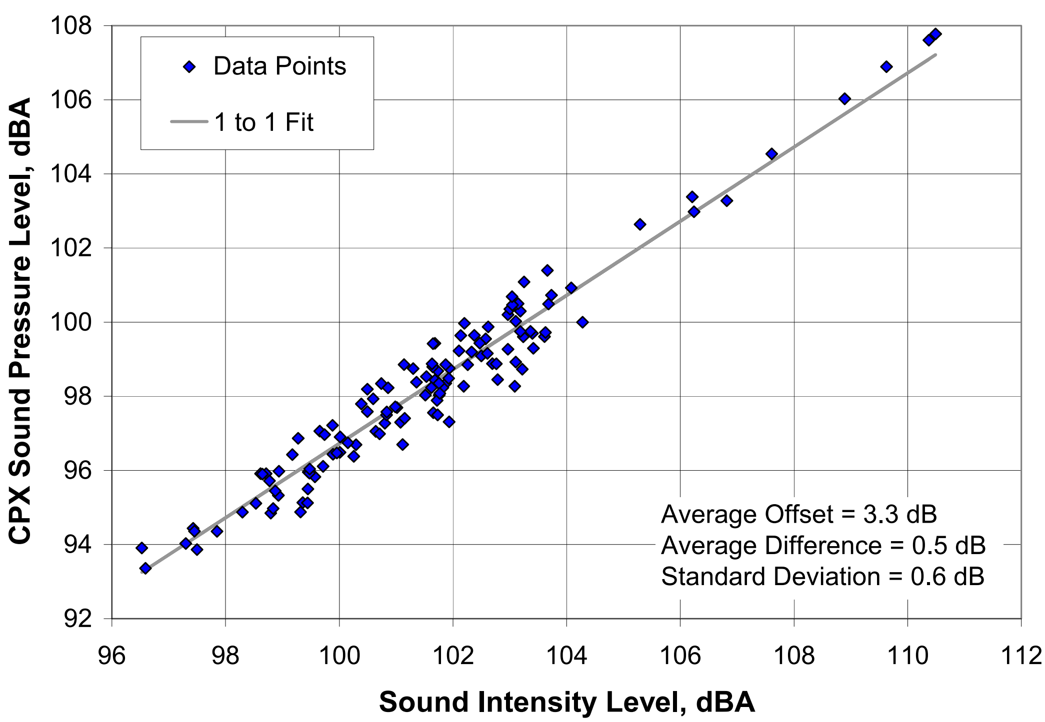

Figure 53: Relationship between sound intensity level and CPX sound pressure level for the Goodyear Aquatred 3 tire at 60 mph for pavements in Arizona using the ADOT CPX trailer

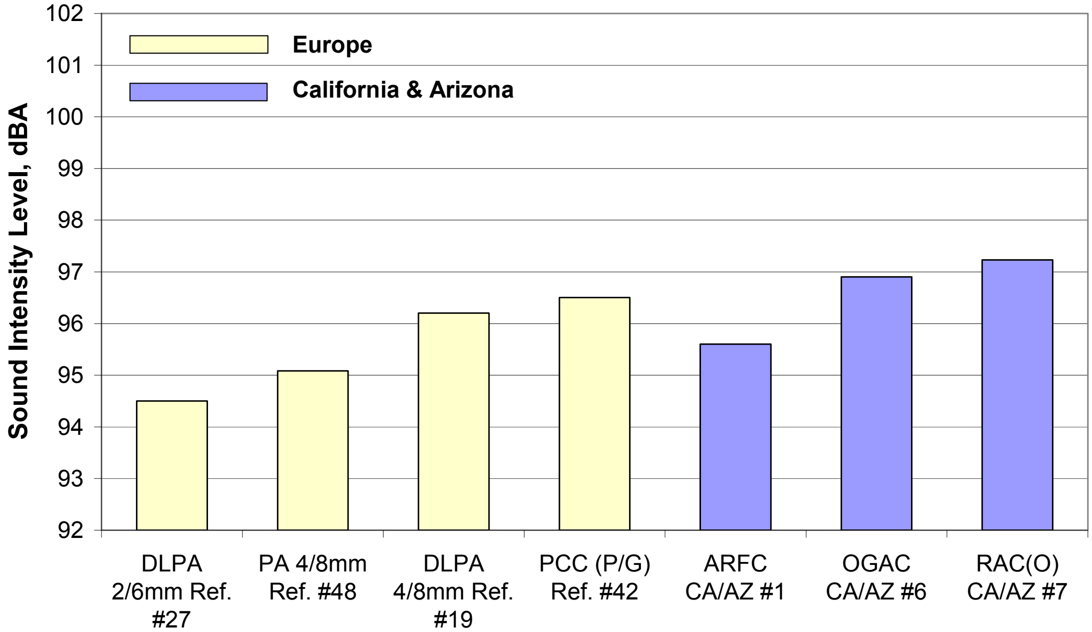

Figure 54: Overall A-weighted sound intensity levels for quieter pavements in Europe, California, and Arizona – Goodyear Aquatred 3 at 60 mph

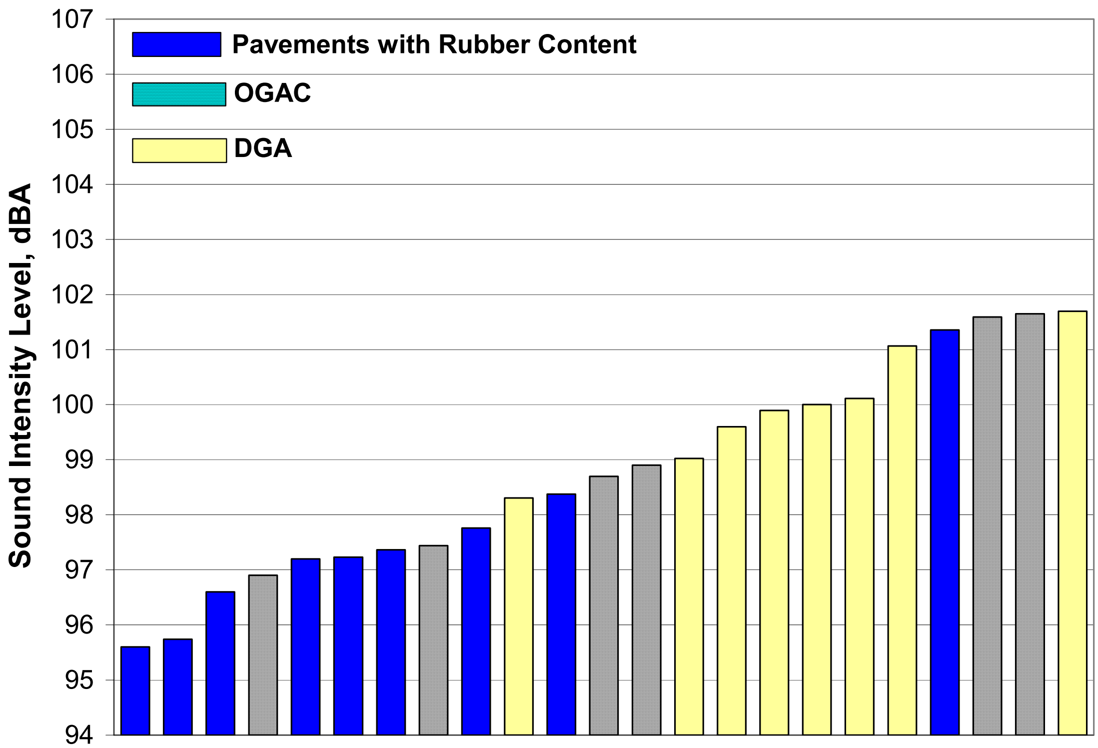

Figure 55: Overall A-weighted sound intensity levels for rubber contented, open graded, and dense graded asphalt pavements in California and Arizona – Goodyear Aquatred 3 at 60 mph

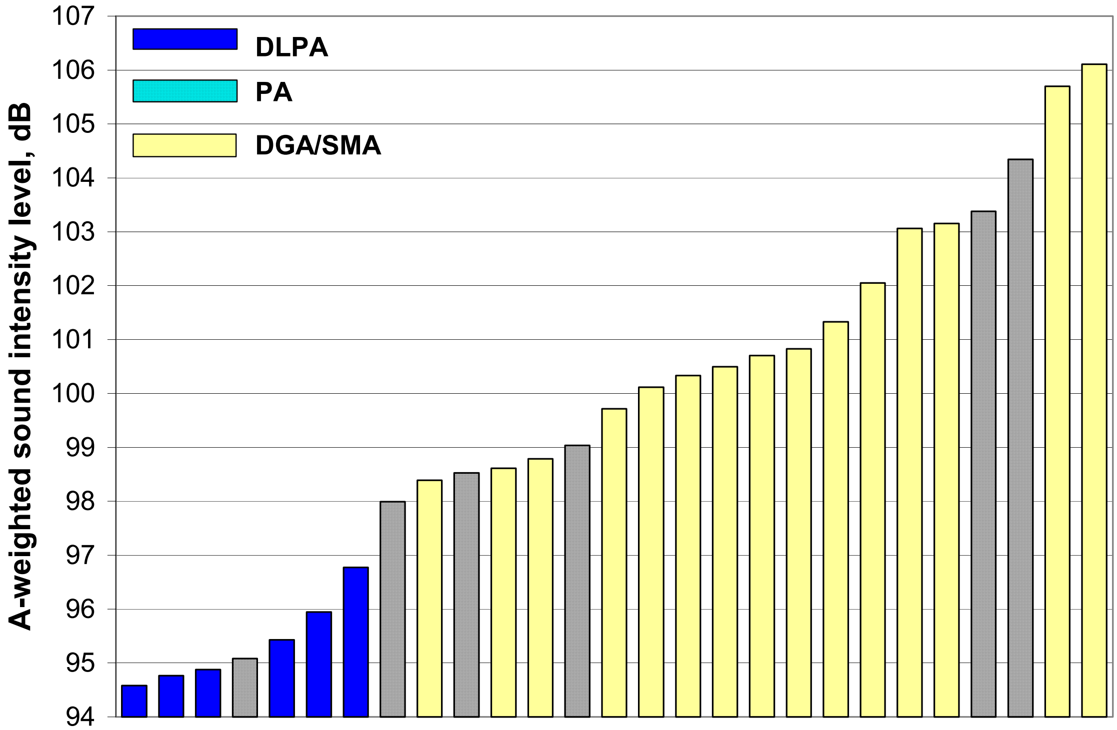

Figure 56: Overall A-weighted sound intensity levels for double and single layer porous AC, and dense graded and stone mastic asphalt pavements in Europe – Goodyear Aquatred 3 at 60 mph

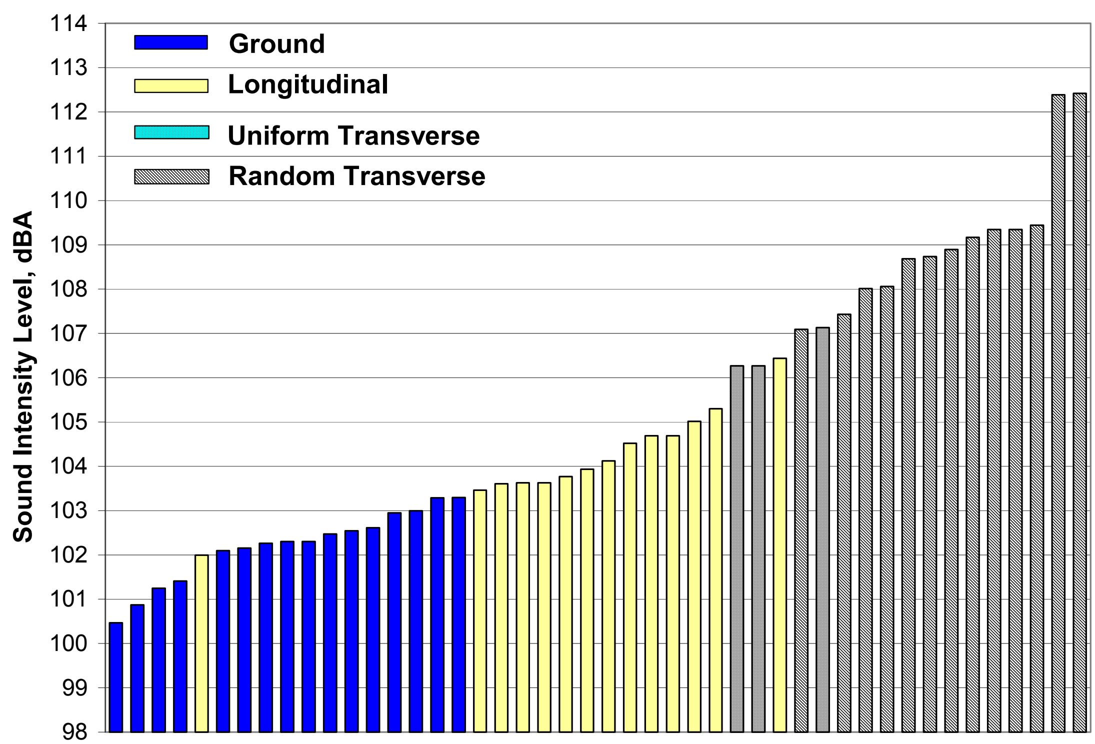

Figure 57: Overall A-weighted sound intensity levels for PCC pavements of different surface characteristics from the CA/AZ database – Goodyear Aquatred 3 at 60 mph

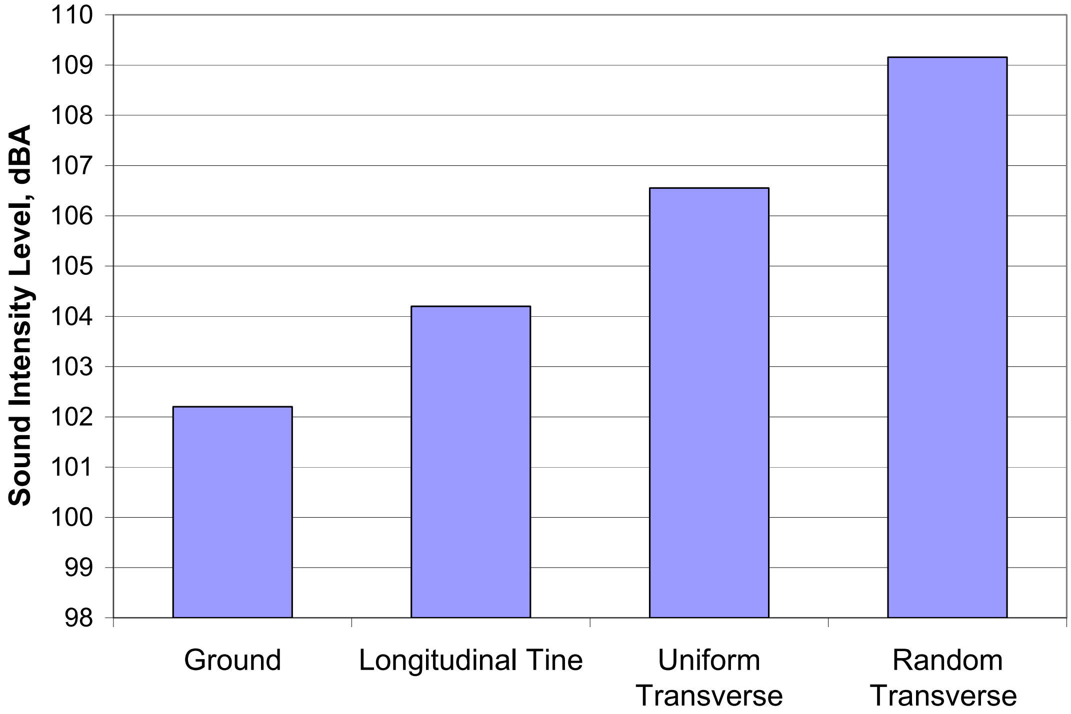

Figure 58: Overall A-weighted sound intensity levels for the average of groupings of different PCC pavement surface characteristics from the CA/AZ database – Goodyear Aquatred 3 at 60 mph

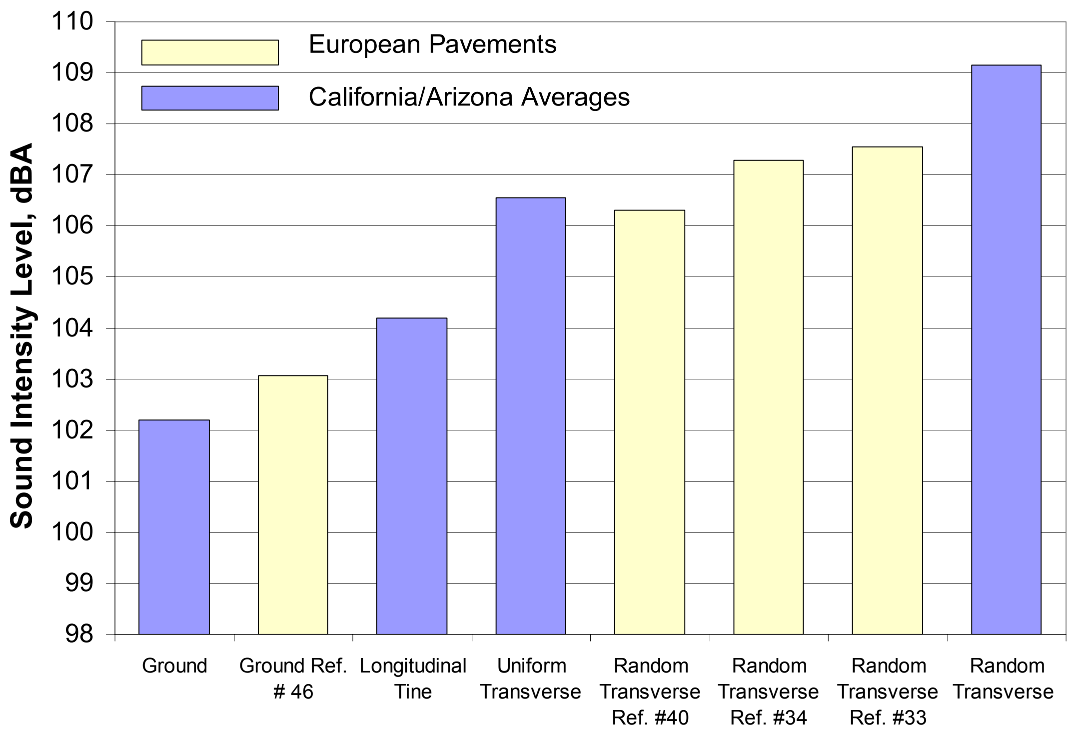

Figure 59: Overall A-weighted sound intensity levels for European random transverse textured and ground PCC pavements and the average of groupings from the CA/AZ database – Goodyear Aquatred 3 at 60 mph

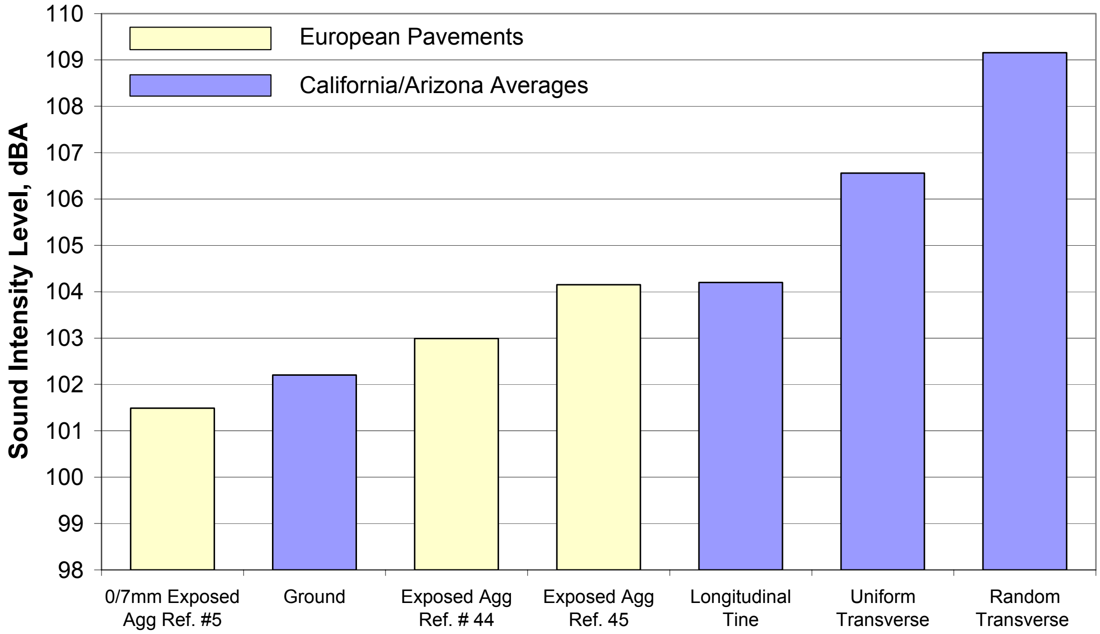

Figure 60: Overall A-weighted sound intensity levels for European exposed aggregate PCC pavements and the average of groupings from the CA/AZ database – Goodyear Aquatred 3 at 60 mph

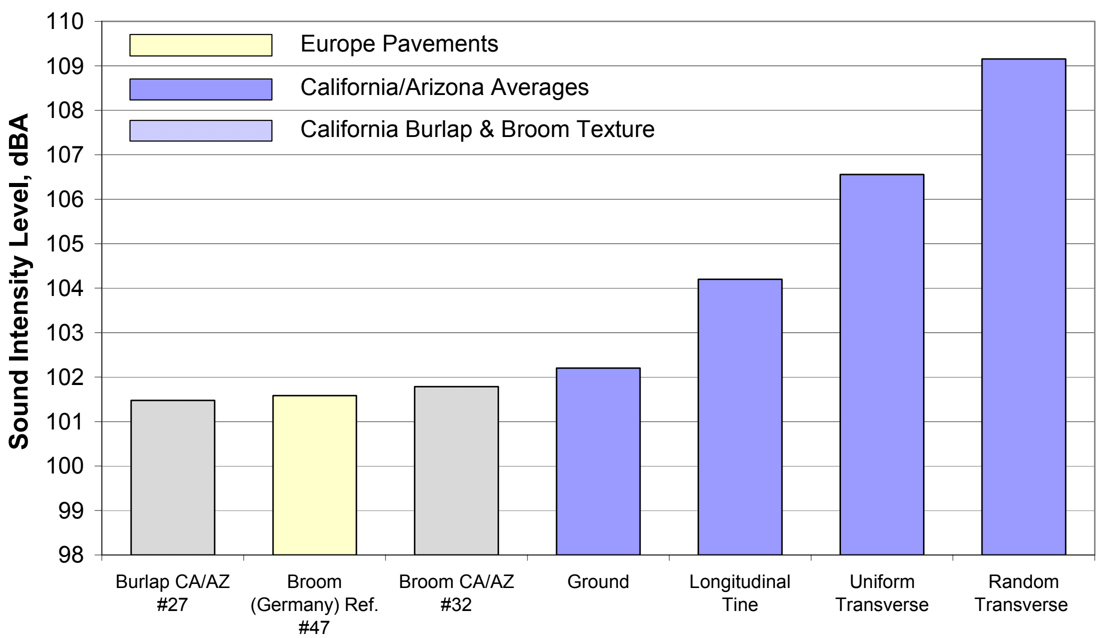

Figure 61: Overall A-weighted sound intensity levels for a European longitudinally broom PCC pavement, averages from the CA/AZ database, and broom and burlap drag textures from California – Goodyear Aquatred 3 at 60 mph

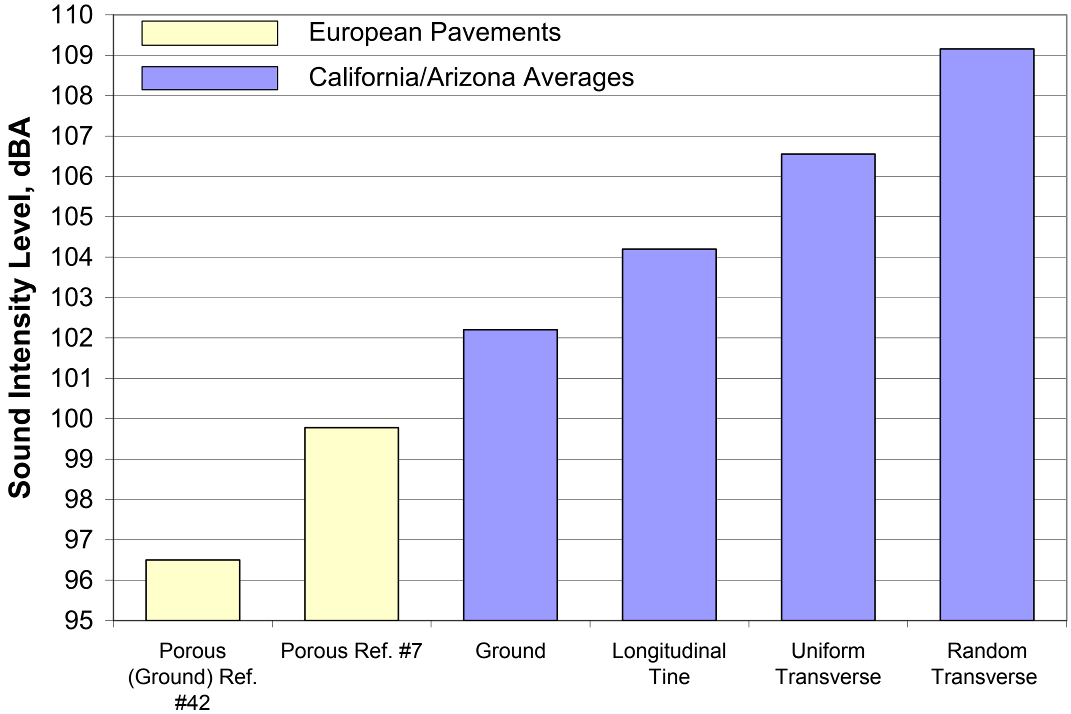

Figure 62: Overall A-weighted sound intensity levels for European porous PCC pavements and the average of groupings from the CA/AZ database – Goodyear Aquatred 3 at 60 mph

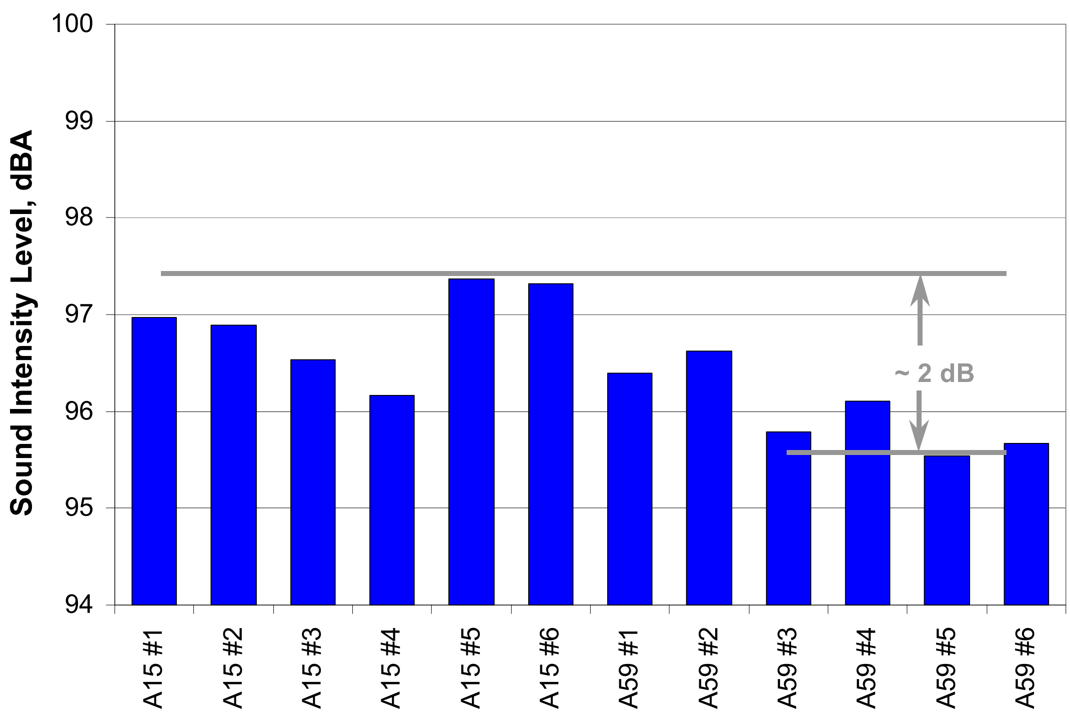

Figure 63: Overall A-weighted sound intensity levels for the "Zebra" test sections of double layer porous asphalt (4/8mm) on the A15 and A59 in the Netherlands – Goodyear Aquatred 3 at 60 mph

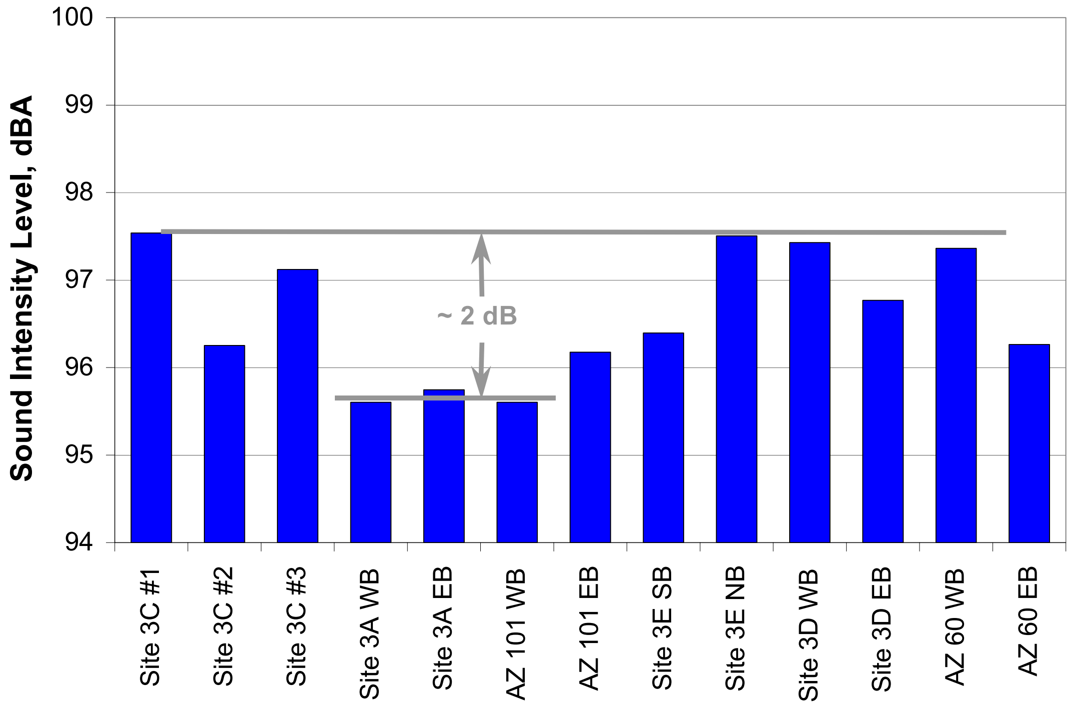

Figure 64: Overall A-weighted sound intensity levels for different sections of ARFC overlay built to the same specification in Arizona – Goodyear Aquatred 3 at 60 mph

6.0 SUMMARY OF NITE FINDINGS

Most of the observations found previously in California and Arizona testing (Section 2.3) were supported by the NITE results. The range of potential tire/pavement noise reduction is common, ranging up to 8 to 10 dB depending the existing and final pavements. The total range in tire/pavement noise for the pavement measured was found to be about 13 dB as it is in California and Arizona for on-grade pavements. With the exception of the European DLPA and porous PCC pavements, generic groupings of pavements displayed significant and overlapping ranges of the performance. Also, surface roughness/texture was found to be one of the major controlling factors in tire/pavement noise generation in the lower frequencies below about 1000 Hertz. Based on very limited data, the European results also indicated that grinding of PCC surfaces could produce lower tire/pavement noise levels.

New information was also added to the growing knowledge from the NITE testing. One of the most remarkable findings was that porous PCC could perform almost as well as the quieter porous AC pavements. Another significant finding was that although very quietest DLPA surfaces were remarkably quiet, they were only slightly (1 to 2 dB) quieter than the quieter RAC and OGAC pavements in California and Arizona. Although not systematically investigated, it was found that exposed aggregate PCC has the potential to achieve performance within the range of California and Arizona ground and longitudinally tined PCC. It was also found that SMA surfaces provided a similar range of the performance as DGA surfaces and that surface texture appears to be a dominant factor in both. Finally, variation in tire/pavement noise performance for pavement constructed to the same specification could be as much as 2 dB.

7.0 SUGGESTIONS FOR FURTHER INVESTIGATION

Clearly the subject of the reducing and managing tire/pavement noise by pavement selection could benefit from research in many specific areas. From the NITE Study, some more immediate questions or topics became apparent. For California and the rest of the US, one of these immediate questions is how can the pavements be improved to meet or exceed the performance of the those measured in Europe. Double layer, highly porous, fine aggregate top layer pavements should be investigated and evaluated in the US. Besides noise performance, other pavement performance aspects such as safety, self-cleaning ability, spray reduction, etc., should be investigated along with cost. Ideally, test sections in actual roadways would be constructed to complete this assessment.

Another area for research is the variation of pavements constructed to the same specification. This applies to both AC and PCC pavements. Prior to the recent use of on-board tire/pavement noise measurement technologies, this aspect has been difficult to quantify. However, recently, with these methods, significant variations are being discovered. In addition to the variation in AC overlays shown in Fig. 57, variations in nominally identical uniformly transversely tined PCC of 5 dB or more have been reported (Ref. 18). When considering the magnitude of improvement expected from pavement modifications, this amount of variation becomes quite significant. The parameters controlling these performance variations in both AC and PCC should be understood sufficiently so that the expected performance of a pavement can realized consistently.

One of the key findings of the NITE Study was actually the competitive performance of rubberized asphalt surfaces in the US compared to the double layer, highly porous AC pavements in Europe. These RAC pavements typically do not have the porosity of the double layer constructions yet perform remarkably well. The double layer constructions are thought to perform well due to absorptive surfaces and the fine top surface aggregate. There is no correspondingly well-developed theory to explain the performance of the rubberized pavements. Understanding the reasons for this performance is critical for improving its performance further.

Another key finding of the NITE Study was the performance of the porous PCC. This type of construction should be investigated further for use in the US. Based on the performance measured in Europe, this type of construction has the potential of supplying nearly the same performance of "quiet" AC surfaces and maybe more desirable in some circumstances. Also in regard to PCC, it was found that fine exposed aggregate produced levels comparable to ground surfaces and superior to longitudinally tining. This type of construction also warrants further investigation for application in the US.

A topic of interest to both European researchers and American researchers has been in understanding if there is a difference in the degree that truck tires respond to pavement changes compared to passenger car tires. Typically, it is found both in Europe and the US that pavement changes are more effective at reducing passby noise for passenger cars than for trucks. One explanation for this is the difference in tires. Tire/pavement noise for different truck tires has been recently investigated in Europe at the Sperenberg facility using a modified, non-trailer, CPX method (Ref. 19). Using sound intensity, this type of work could be extended to a direct comparison of tire/pavement noise source levels for passenger car tires and truck tires for various pavement types.

A final area investigation is additional testing in Europe using the NITE approach. This would include some additional countries, which were included in the AASHTO/FWA Scan Tour, but not visited in the NITE Study. Of particular interest are the porous pavements in Italy with embedded Helmholtz resonators, the thin, very porous overlays used in Demark, the all rubber pavement concepts being prototyped in Sweden, and the proprietary AC pavements being used in the UK for noise mitigation. In addition to AC surfaces, PCC quieting techniques should be evaluated. The primary emphasis of the first NITE Study was on the "quiet" AC concepts, however, there has been considerable work in Europe on quieter PCC textures. As texturing of PCC for lower noise receives more attention in the US, it would be useful to quantify and document and quieter PCC surfaces in Europe. Additional testing in Europe should also address direct comparison between the CPX and sound intensity methods. This was done only indirectly in the current study. This would consist of "back-to-back" CPX and sound intensity measurement on the same surface using the same test tire. Although some of this has been done in the US, the European CPX trailers are more well developed and validated than those in the US and may demonstrate even closer correlation between the methods.

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APPENDIX 1

TEST DATA AND PAVEMENT DOCUMENTATION:

PAVEMENTS TESTED IN CALIFORNIA AND ARIZONA

Pavement CA/AZ #1

State: AZ

Roadway: SR 101

Location: MP 20.5 WB

Description: ARFC - AZ QPPP Site 3A

Test Date: 10/26/2004

Speed	1/3 Octave Band Sound Intensity Level, dB (A-Weighted)											Overall
(mph)	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	A-Wtd,dB
60	84.0	86.0	90.4	88.9	85.6	86.0	82.6	79.5	76.5	74.9	72.3	95.6

Pavement CA/AZ #2

State: AZ

Roadway: SR 101

Location: MP 46.5 SB

Description: ARFC - AZ QPPP Site 3E

Test Date: 10/26/2004

Speed	1/3 Octave Band Sound Intensity Level, dB (A-Weighted)											Overall
(mph)	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	A-Wtd,dB
60	85.9	88.4	91.1	89.1	85.7	85.9	83.0	80.6	77.5	75.1	72.5	96.4

Pavement CA/AZ #3

State: AZ

Roadway: I-10

Location: MP 190 EB

Description: ARFC - AZ Test Section 13

Test Date: 5/21/2002

No Image Available

Speed	1/3 Octave Band Sound Intensity Level, dB (A-Weighted)											Overall
(mph)	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	A-Wtd,dB
60	86.9	89.5	91.2	88.3	85.9	85.4	83.9	81.3	77.9	75.4	72.5	96.6

Pavement CA/AZ # 4

State: CA

Roadway: Caltrans Track

Location: CHP Academy

Description: DGAC - Fine Aggregrate

Test Date: 6/11/2002

Speed	1/3 Octave Band Sound Intensity Level, dB (A-Weighted)											Overall
(mph)	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	A-Wtd,dB
60	82.2	85.2	91.5	87.7	87.0	90.0	85.2	81.3	78.9	75.7	72.0	96.7
35	80.8	79.5	81.8	83.6	81.1	78.8	75.4	71.6	67.8	65.5	62.1	89.3

Pavement CA/AZ #5

State: AZ

Roadway: I-10

Location: MP 159.5 EB

Description: ARFC - AZ QPPP Site 3C

Test Date: 10/26/2004

No Image Available

Speed (mph)	1/3 Octave Band Sound Intensity Level, dB (A-Weighted) 500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	Overall A-Wtd,dB
60	84.7	88.1	92.3	90.7	87.5	84.7	79.2	77.0	75.3	73.2	69.9	96.9

Pavement CA/AZ #6

State: CA

Roadway: LA 138

Location: Sta 108+00.00 EB

Description: OGAC (non-porous) 75mm thick on DGA

Test Date: 10/6/2002

Speed (mph)	1/3 Octave Band Sound Intensity Level, dB (A-Weighted) 500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	Overall A-Wtd,dB
60	84.5	87.7	92.2	90.2	87.5	86.0	82.5	79.8	76.8	73.9	70.4	96.9
35	82.3	81.2	84.3	83.6	81.0	78.3	75.4	71.5	67.7	64.3	60.6	90.2

Pavement CA/AZ #7

CA/AZ #: 7
State: CA
Roadway: LA 138
Location: Sta 148+00.00 EB
Description: RAC(O) (non-porous) 30mm thick on DGAC
Test Date: 10/6/2002

Speed	1/3 Octave Band Sound Intensity Level, dB (A-Weighted)											Overall
(mph)	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	A-Wtd,dB
60	84.9	86.2	91.9	90.4	89.0	87.9	84.3	81.2	78.5	75.9	72.1	97.2

Pavement CA/AZ #8

CA/AZ #: 8
State: CA
Roadway: SM I-280
Location: Sta 125 SB
Description: RAC(O) (non-porous)
Test Date: 11/5/2002

Speed	1/3 Octave Band Sound Intensity Level, dB (A-Weighted)											Overall
(mph)	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	A-Wtd,dB
60	88.8	89.2	91.7	89.1	86.0	87.1	84.4	80.9	77.8	75.4	72.1	97.2

Pavement CA/AZ #9

CA/AZ #:	9
State:	AZ
Roadway:	I-8
Location:	MP 70 & 68
Description:	ARFC (installed 1994)
Test Date:	5/22/2002

No Image Available

Speed	1/3 Octave Band Sound Intensity Level, dB (A-Weighted)											Overall
(mph)	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	A-Wtd,dB
60	85.6	88.9	92.1	90.9	88.5	85.3	83.5	80.4	77.3	73.9	70.8	97.4

Pavement CA/AZ #10

CA/AZ #:	10
State:	AZ
Roadway:	SR 202
Location:	MP 18.5 WB
Description:	ARFC - AZ QPPP Site 3D
Test Date:	10/26/2004

Speed	1/3 Octave Band Sound Intensity Level, dB (A-Weighted)											Overall
(mph)	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	A-Wtd,dB
60	87.3	89.6	92.5	90.2	86.7	85.5	83.2	80.7	78.0	76.1	73.3	97.4

Pavement CA/AZ #11

CA/AZ #:	11
State:	CA
Roadway:	LA 138
Location:	Sta 120+00.00 EB
Description:	OGAC (non-porous) 30mm thick on DGA
Test Date:	10/6/2002

Speed	1/3 Octave Band Sound Intensity Level, dB (A-Weighted)											Overall
(mph)	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	A-Wtd,dB
60	84.8	85.9	91.6	91.1	89.6	88.3	84.4	81.6	78.8	76.2	72.7	97.4

Pavement CA/AZ #12

CA/AZ #:	12
State:	CA
Roadway:	FRE I-5
Location:	MP 15-17.5
Description:	RAC(O) "crumb rubber"
Test Date:	3/19/2002

Speed	1/3 Octave Band Sound Intensity Level, dB (A-Weighted)											Overall
(mph)	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	A-Wtd,dB
60	87.5	89.6	92.4	90.4	86.8	87.1	84.5	81.9	79.2	77.2	73.7	97.8

Pavement CA/AZ #13

CA/AZ #: 13

State: CA

Roadway: LA 138

Location: Sta 101+00 to 180+00 EB

Description: DGAC - average of new sections

Test Date: 3/21/2002

Speed	1/3 Octave Band Sound Intensity Level, dB (A-Weighted)											Overall
(mph)	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	A-Wtd,dB
60	85.9	87.6	93.4	90.8	88.5	89.7	86.0	82.0	79.5	77.0	73.0	98.3

Pavement CA/AZ #14

CA/AZ #: 14

State: CA

Roadway: SBd I-40

Location: MP 3-4.5

Description: RAC(O) average of sections

Test Date: 3/22/2002

Speed	1/3 Octave Band Sound Intensity Level, dB (A-Weighted)											Overall
(mph)	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	A-Wtd,dB
60	89.1	91.8	93.9	91.1	84.9	82.4	80.8	79.4	76.8	73.9	70.6	98.4

Pavement CA/AZ #15

CA/AZ #: 15
State: AZ
Roadway: I-10
Location: MP 193.2 WB
Description: P-ACFC (porpous) - AZ Test Section 24
Test Date: 5/22/2002

No Image Available

Speed	1/3 Octave Band Sound Intensity Level, dB (A-Weighted)											Overall
(mph)	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	A-Wtd,dB
60	88.8	91.9	94.3	92.0	86.4	80.0	80.5	79.5	77.1	72.3	69.6	98.7

Pavement CA/AZ #16

CA/AZ #: 16
State: CA
Roadway: LA 138
Location: Sta 180+00.00 EB
Description: DGAC (older)
Test Date: 3/21/2002

No Image Available

Speed	1/3 Octave Band Sound Intensity Level, dB (A-Weighted)											Overall
(mph)	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	A-Wtd,dB
60	85.5	87.3	94.2	92.4	89.6	90.0	86.1	82.9	80.3	78.0	74.0	99.0

Pavement CA/AZ #17

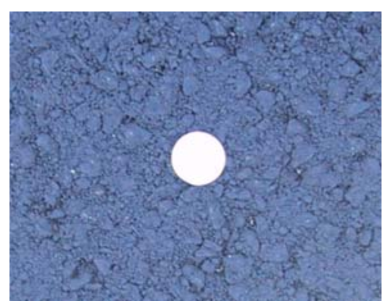
CA/AZ #:	17
State:	AZ
Roadway:	I-10
Location:	MP 190.6 EB
Description:	SMA - AZ Test Section 15
Test Date:	5/22/2002

No Image Available

Speed	1/3 Octave Band Sound Intensity Level, dB (A-Weighted)											Overall
(mph)	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	A-Wtd,dB
60	90.3	92.9	94.8	92.2	88.1	85.3	83.9	81.2	78.2	75.1	72.1	99.6

Pavement CA/AZ #18

CA/AZ #:	18
State:	CA
Roadway:	LA 138
Location:	Sta 120+00.00 EB
Description:	BWC 30mm thick on DGAC
Test Date:	10/6/2002



Speed	1/3 Octave Band Sound Intensity Level, dB (A-Weighted)											Overall
(mph)	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	A-Wtd,dB
60	87.1	90.2	95.1	93.2	90.8	89.8	85.9	82.7	79.9	77.4	73.2	99.9

Pavement CA/AZ #19

CA/AZ #:	19
State:	AZ
Roadway:	I-10
Location:	MP 192.3 WB
Description:	ACFC (non-porous)
Test Date:	5/22/2002

No Image Available

Speed	1/3 Octave Band Sound Intensity Level, dB (A-Weighted)											Overall
(mph)	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	A-Wtd,dB
60	88.5	92.9	95.8	93.9	88.4	80.9	79.4	78.4	76.7	73.6	70.6	100.0

Pavement CA/AZ #20

CA/AZ #:	20
State:	CA
Roadway:	SBd I-40
Location:	MP 2.5-3
Description:	DGAC - average of sections
Test Date:	3/21/2002

Speed	1/3 Octave Band Sound Intensity Level, dB (A-Weighted)											Overall
(mph)	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	A-Wtd,dB
60	89.1	92.3	95.9	93.3	88.7	86.4	83.1	80.4	77.8	75.6	72.2	100.1

Pavement CA/AZ #21

CA/AZ #:	21
State:	AZ
Roadway:	SR 202
Location:	MP 55-56 Sta 2040+60
Description:	PCC Grind 0.110 blade spacing
Test Date:	10/26/2004

No Image Available

Speed	1/3 Octave Band Sound Intensity Level, dB (A-Weighted)											Overall
(mph)	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	A-Wtd,dB
60	81.5	85.6	94.3	95.3	91.4	93.1	88.3	83.4	80.4	79.1	76.1	100.5

Pavement CA/AZ #22

CA/AZ #:	22
State:	AZ
Roadway:	I-10
Location:	MP 187.5 EB
Description:	PEM (porous) - Test Section 4
Test Date:	5/22/2002

No Image Available

Speed	1/3 Octave Band Sound Intensity Level, dB (A-Weighted)											Overall
(mph)	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	A-Wtd,dB
60	88.3	92.1	96.1	95.1	90.5	85.9	85.1	81.8	78.4	75.2	72.3	100.6

Pavement CA/AZ #23

CA/AZ #: 23

State: CA

Roadway: LA 138

Location: Sta 120+00.00 EB

Description: DGAC (Type B) 30mm thick on DGAC

Test Date: 10/6/2002

No Image Available

Speed	1/3 Octave Band Sound Intensity Level, dB (A-Weighted)											Overall
(mph)	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	A-Wtd,dB
60	85.5	89.6	96.2	94.7	92.4	92.0	87.6	83.8	80.8	78.3	74.3	101.1
35	83.1	82.8	87.7	88.3	85.6	83.7	80.1	75.0	71.3	68.5	64.5	93.8

Pavement CA/AZ #24

CA/AZ #: 24

State: CA

Roadway: SM I-280

Location: Sta 95 NB

Description: PCC Interim Grind)

Test Date: 6/6/2002

No Image Available

Speed	1/3 Octave Band Sound Intensity Level, dB (A-Weighted)											Overall
(mph)	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	A-Wtd,dB
60	86.7	89.1	96.4	96.1	91.9	90.6	87.3	83.2	80.4	77.9	74.3	101.2

Pavement CA/AZ #25

CA/AZ #:	25
State:	AZ
Roadway:	I-10
Location:	MP 124 & 127
Description:	ACFC (installed 1992)
Test Date:	5/22/2002

No Image Available

Speed	1/3 Octave Band Sound Intensity Level, dB (A-Weighted)											Overall
(mph)	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	A-Wtd,dB
60	83.8	87.5	94.3	96.7	94.9	91.1	88.5	84.7	80.9	77.5	74.1	101.4

Pavement CA/AZ #26

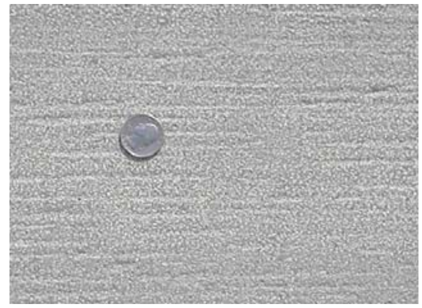
CA/AZ #:	26
State:	AZ
Roadway:	SR 202
Location:	MP 55-56 Sta 2050+60
Description:	PCC Grind 0.120 blade spacing
Test Date:	10/26/2004

No Image Available

Speed	1/3 Octave Band Sound Intensity Level, dB (A-Weighted)											Overall
(mph)	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	A-Wtd,dB
60	84.1	87.5	95.8	96.3	92.8	92.6	88.4	83.7	80.7	79.1	76.1	101.4

Pavement CA/AZ #27

CA/AZ #:	27
State:	CA
Roadway:	Ker 58
Location:	MP 166
Description:	PCC Burlap Drag
Test Date:	3/11/2003



Speed	1/3 Octave Band Sound Intensity Level, dB (A-Weighted)											Overall
(mph)	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	A-Wtd,dB
60	83.7	86.6	95.6	96.0	91.9	94.4	90.0	84.3	80.8	78.6	74.7	101.5

Pavement CA/AZ #28

CA/AZ #:	28
State:	CA
Roadway:	Yub 70
Location:	MP 7.35
Description:	OGAC
Test Date:	4/23/2003

No Image Available

Speed	1/3 Octave Band Sound Intensity Level, dB (A-Weighted)											Overall
(mph)	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	A-Wtd,dB
60	90.5	94.4	96.8	95.4	91.6	86.6	82.3	80.0	78.7	76.4	72.7	101.6

Pavement CA/AZ #29

CA/AZ #:	29
State:	CA
Roadway:	Sol I-80
Location:	MP 5
Description:	OGAC (porous)
Test Date:	9/11/2002

Speed	1/3 Octave Band Sound Intensity Level, dB (A-Weighted)											Overall
(mph)	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	A-Wtd,dB
60	91.3	95.6	97.4	94.6	88.2	83.3	82.5	81.0	78.9	75.8	72.5	101.7

Pavement CA/AZ #30

CA/AZ #:	30
State:	CA
Roadway:	SCI 85
Location:	MP 14
Description:	PCC grind/groove
Test Date:	6/4/2002

No Image Available

Speed	1/3 Octave Band Sound Intensity Level, dB (A-Weighted)											Overall
(mph)	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	A-Wtd,dB
60	84.5	87.9	96.6	95.9	92.3	93.0	89.8	84.8	82.2	79.7	76.0	101.7

Pavement CA/AZ #31

CA/AZ #: 31
State: CA
Roadway: Sol I-80
Location: MP 39 WB
Description: DGAC newer
Test Date: 9/11/2002

Speed	1/3 Octave Band Sound Intensity Level, dB (A-Weighted)											Overall
(mph)	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	A-Wtd,dB
60	86.2	89.1	96.6	95.8	93.8	91.9	88.4	84.1	81.9	79.5	76.0	101.7

Pavement CA/AZ #32

CA/AZ #: 32
State: CA
Roadway: Ker 58
Location: MP 166
Description: PCC Longitudinal Broom
Test Date: 3/11/2003

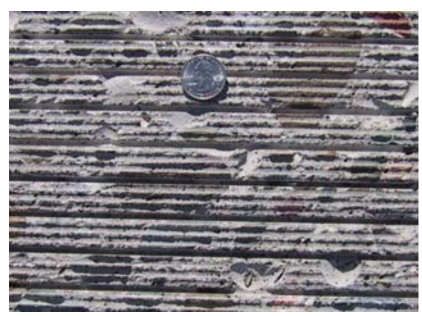
Speed	1/3 Octave Band Sound Intensity Level, dB (A-Weighted)											Overall
(mph)	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	A-Wtd,dB
60	83.9	86.9	95.9	96.3	92.5	94.5	90.4	84.5	80.9	78.5	74.6	101.8

Pavement CA/AZ #33

CA/AZ #:	33
State:	AZ
Roadway:	SR 202
Location:	MP 16 WB
Description:	PCC Longitudinal Tine
Test Date:	9/27/2002

Speed	1/3 Octave Band Sound Intensity Level, dB (A-Weighted)											Overall
(mph)	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	A-Wtd,dB
60	86.9	89.0	96.5	97.0	93.8	92.1	88.1	83.1	80.1	77.3	73.7	102.0

Pavement CA/AZ #34



CA/AZ #:	34
State:	CA
Roadway:	SM I-280
Location:	Sta 110 SB
Description:	PCC Texture Grind
Test Date:	11/5/2002

Speed	1/3 Octave Band Sound Intensity Level, dB (A-Weighted)											Overall
(mph)	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	A-Wtd,dB
60	85.5	90.1	97.8	96.8	92.6	92.2	88.8	84.9	82.5	80.2	75.8	102.3

Pavement CA/AZ #35

CA/AZ #: 35
State: CA
Roadway: SM I-280
Location: Sta 100 SB
Description: PCC "Regular" Grind
Test Date: 11/5/2002

Speed (mph)	1/3 Octave Band Sound Intensity Level, dB (A-Weighted)											Overall
	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	A-Wtd,dB
60	87.0	90.4	97.9	97.4	93.2	92.0	88.3	84.9	82.5	80.3	75.8	102.6

Pavement CA/AZ #36

CA/AZ #: 36
State: CA
Roadway: LA 14
Location: MP 72-74
Description: PCC longitudinal texture - avg of sections
Test Date: 3/21/2002

Speed (mph)	1/3 Octave Band Sound Intensity Level, dB (A-Weighted)											Overall
	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	A-Wtd,dB
60	86.5	90.0	97.1	96.9	93.6	95.8	92.6	86.9	83.7	82.2	78.7	103.1

Pavement CA/AZ #37

CA/AZ #: 37

State: CA

Roadway: Ker 58

Location: MP 166

Description: PCC Longitudinal Tine

Test Date: 3/11/2003

Speed	1/3 Octave Band Sound Intensity Level, dB (A-Weighted)											Overall
(mph)	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	A-Wtd,dB
60	87.8	89.9	97.6	98.5	94.8	94.9	90.5	85.1	81.3	78.9	74.8	103.5

Pavement CA/AZ #38

CA/AZ #: 38

State: CA

Roadway: SM I-280

Location: Sta 90 to 150

Description: PCC older - average of sections

Test Date: 6/6/2002

Speed	1/3 Octave Band Sound Intensity Level, dB (A-Weighted)											Overall
(mph)	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	A-Wtd,dB
60	88.5	92.8	98.8	97.8	94.9	94.6	90.6	85.6	82.9	80.8	77.2	103.8

Pavement CA/AZ #39

CA/AZ #:	39
State:	CA
Roadway:	Sol I-80
Location:	MP 34
Description:	PCC older
Test Date:	9/11/2002

Speed	1/3 Octave Band Sound Intensity Level, dB (A-Weighted)											Overall
(mph)	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	A-Wtd,dB
60	85.4	89.0	97.8	98.7	96.0	96.1	92.6	86.8	84.2	82.0	78.7	104.1

Pavement CA/AZ #40

CA/AZ #:	40
State:	CA
Roadway:	SM 84
Location:	MP 1-3
Description:	Chip Seal - average of sections
Test Date:	6/4/2002

Speed	1/3 Octave Band Sound Intensity Level, dB (A-Weighted)											Overall
(mph)	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	A-Wtd,dB
60	95.6	97.3	101.1	97.8	91.3	90.0	86.9	84.1	80.9	78.0	74.3	105.0

Pavement CA/AZ #41

CA/AZ #: 41

State: AZ

Roadway: SR 202

Location: MP 56 EB

Description: PCC uniform transverse tine

Test Date: 10/28/2004

Speed	1/3 Octave Band Sound Intensity Level, dB (A-Weighted)											Overall
(mph)	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	A-Wtd,dB
60	89.1	91.9	98.8	103.0	96.9	96.9	92.8	87.2	83.1	80.2	77.5	106.3

Pavement CA/AZ #42

CA/AZ #: 42

State: AZ

Roadway: SR 202

Location: MP 17 WB

Description: PCC Uniform Transverse Tine

Test Date: 9/27/2002

No Image Available

Speed	1/3 Octave Band Sound Intensity Level, dB (A-Weighted)											Overall
(mph)	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	A-Wtd,dB
60	87.3	90.5	98.0	104.3	100.2	95.9	92.1	87.1	83.9	80.6	77.3	107.1

Pavement CA/AZ #43

CA/AZ #:	43
State:	AZ
Roadway:	SR 202
Location:	MP 18 WB
Description:	PCC Random Transverse Tine
Test Date:	9/27/2002

Speed	1/3 Octave Band Sound Intensity Level, dB (A-Weighted)											Overall
(mph)	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	A-Wtd,dB
60	94.3	97.5	103.6	104.9	101.6	96.1	90.9	85.4	81.8	78.5	75.4	109.2

Pavement CA/AZ #44

CA/AZ #:	44
State:	CA
Roadway:	4th Street
Location:	City of San Rafael
Description:	RAC newer (2 months)
Test Date:	12/12/3/03

Speed	1/3 Octave Band Sound Intensity Level, dB (A-Weighted)											Overall
(mph)	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	A-Wtd,dB
35	87.3	84.3	86.1	86.4	84.1	82.5	77.7	74.9	70.8	67.6	64.1	93.4

Pavement CA/AZ #45

CA/AZ #:	45
State:	CA
Roadway:	4th Street
Location:	City of San Rafael
Description:	DGAC cracked
Test Date:	9/25/2003

Speed	1/3 Octave Band Sound Intensity Level, dB (A-Weighted)											Overall
(mph)	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	A-Wtd,dB
35	88.8	89.6	94.7	94.1	91.3	87.3	83.5	80.5	75.7	73.0	70.1	99.8

APPENDIX 2

EUROPEAN TEST SITES AND PAVEMENTS

Ref. #	Country	Roadway	Designation	Description	Classification
1	Belgium	N255	Section #1	Stone Mastic Asphalt, 0/10 mm	SMA 0/10
2	Belgium	N255	Section #2	Stone Mastic Asphalt, 0/14 mm	SMA 0/14
3	Belgium	N255	Section #3	Porous Cement Concrete 0/7 mm	PCC (P) 0/7
4	Belgium	N255	Section #4	Porous Asphalt 0/14 mm	PA 0/14
5	Belgium	N255	Section #5	Fine Cement Concrete 0/7 mm	PCC (EA) 0/7
6	Belgium	N255	Section #6	Non-Porous Asphalt 0/10 mm + 10/14mm Chippings	DGA 0/10/14
7	France	LCPC	Section B	Porous Cement Concrete	PCC (P)
8	France	LCPC	Section A	Surface Dressing 8/10 mm (Stone Mastic)	SMA 8/10
9	France	LCPC	Section C	Fine Surface Dressing 0.8/1.5 mm (Stone Mastic)	SMA 0.8/1.5
10	France	LCPC	Section L	Fine Dense Graded Asphalt	DGA (F)
11	France	LCPC	Section G	Porous Asphalt 0/10 mm	PA 0/10
12	France	LCPC	Section H	Dense Graded Asphalt 0/10 mm	DGA 0/10
13	France	LCPC	Section J	Thin Semi-Porous Layer Asphalt 0/6 mm	PA 0/6
14	the Netherlands	A15	Section #1	Double Layer Porous Asphalt - 4/8mm	DLPA 4/8
15	the Netherlands	A15	Section #2	Double Layer Porous Asphalt - 4/8mm	DLPA 4/8
16	the Netherlands	A15	Section #3	Double Layer Porous Asphalt - 2/6mm	DLPA 2/6
17	the Netherlands	A15	Section #4	Double Layer Porous Asphalt - 2/6mm	DLPA 2/6
18	the Netherlands	A15	Section #5	Double Layer Porous Asphalt - 4/8mm	DLPA 4/8
19	the Netherlands	A15	Section #6	Double Layer Porous Asphalt - 4/8mm	DLPA 4/8
20	the Netherlands	A15	Section #7	Double Layer Porous Asphalt - 4/8mm	DLPA 4/8
21	the Netherlands	A15	Section #8	Double Layer Porous Asphalt - 4/8mm	DLPA 4/8
22	the Netherlands	A15	Eastbound	Dense Graded Asphalt	DGA
23	the Netherlands	A59	Section #1	Double Layer Porous Asphalt - 4/8mm	DLPA 4/8
24	the Netherlands	A59	Section #2	Double Layer Porous Asphalt - 4/8mm	DLPA 4/8
25	the Netherlands	A59	Section #3	Double Layer Porous Asphalt - 4/8mm	DLPA 4/8
26	the Netherlands	A59	Section #4	Double Layer Porous Asphalt - 4/8mm	DLPA 4/8
27	the Netherlands	A59	Section #5	Double Layer Porous Asphalt - 2/6mm	DLPA 2/6
28	the Netherlands	A59	Section #6	Double Layer Porous Asphalt - 2/6mm	DLPA 2/6
29	the Netherlands	A59	Section #7	Double Layer Porous Asphalt - 4/8mm	DLPA 4/8
30	the Netherlands	A59	Section #8	Double Layer Porous Asphalt - 4/8mm	DLPA 4/8
31	the Netherlands	A326	Westbound	Double Layer Porous Asphalt - Fine	DLPA 2/6
32	the Netherlands	A326	Eastbound	Double Layer Porous Asphalt - Fine	DLPA 2/6
33	the Netherlands	A270	Section #1 (EB)	Random Transverse Tine Cement Concrete	PCC (RT)
34	the Netherlands	A270	Section #2 (WB)	Random Transverse Tine Cement Concrete	PCC (RT)
35	the Netherlands	A270	Section #3 (WB)	Expoxy/Stone Layer on Cement Concrete	PCC (Ex)
36	the Netherlands	A270	Section #4 (EB)	Expoxy/Stone Layer on Cement Concrete	PCC (Ex)

Ref. #	Country	Roadway	Designation	Description	Classification
37	the Netherlands	A73	Section #1	Porous Asphalt	PA
38	the Netherlands	A73	Section #2	Dense Graded Asphalt (medium)	DGA (M)
39	the Netherlands	A73	Section #3	Dense Graded Asphalt (coarse)	DGA (C)
40	the Netherlands	A73	Section #4	Random Transverse Tine Cement Concrete	PCC (RT)
41	Germany	B56	Track #1	Stone Mastic Asphalt, 0/8 mm	SMA 0/8
42	Germany	B56	Track #3	Ground Porous Cement Concrete 4/8 mm	PCC (P/G)
43	Germany	B56	Track #5	Dense Graded Asphalt 0/8 mm	DGA 0/8
44	Germany	B56	Track #7	Exposed Aggregrate Cement Concrete	PCC (EA)
45	Germany	B56	Track #8	Exposed Aggregrate Cement Concrete (rough)	PCC (EA)
46	Germany	B56	Track #9	Ground Cement Concrete 4/8 mm (Exposed Aggregate)	PCC (G)
47	Germany	B56	Track #10	Cement Concrete with Transverse Broom Finish	PCC
48	Germany	Sperenberg	Section A1	Porous Asphalt 4/8 mm	PA 4/8
49	Germany	Sperenberg	Section A2	Double Layer Porous Asphalt 4/8 mm	DLPA 4/8
50	Germany	Sperenberg	Section A3	Novachip 0/8 mm	NCP 0/8
51	Germany	Sperenberg	Section A4	ISO 10844	PA
52	Germany	Sperenberg	Section A5	Stone Mastic Asphalt, 0/3 mm	SMA 0/3
53	Germany	Sperenberg	Section A6	Stone Mastic Asphalt, 0/5 mm	SMA 0/5
54	Germany	Sperenberg	Section A7	Stone Mastic Asphalt, 0/8 mm	SMA 0/8
55	Germany	Sperenberg	Section A8	Stone Mastic Asphalt, 0/11 mm	SMA 0/11
56	Germany	Sperenberg	Section A9/10	Stone Mastic Asphalt, 0/8 mm	SMA 0/8
57	Germany	Sperenberg	Section A11	Smooth Surface (Stone Mastic 0/8 with Epoxy Coat)	SMA (Ex)
58	Germany	Sperenberg	Section A12	DSK 0/3 mm	DSK 0/3
59	Germany	Sperenberg	Section A13	DSK 0/5 mm	DSK 0/5
60	Germany	Sperenberg	Section A14	Surface Dressing OB 2/3 Round	SD 2/3 Rd
61	Germany	Sperenberg	Section A15	Surface Dressing OB 3/5 Round	SD 3/5 Rd
62	Germany	Sperenberg	Section A16	Surface Dressing OB 5/8 Round	SD 5/8 Rd
63	Germany	Sperenberg	Section A20	Surface Dressing OB 5/8 Sharp	SD 5/8 Shp
64	Germany	Sperenberg	Section B2	Polished Cement Concrete	PCC (Pl)
65	Germany	Sperenberg	Section B5	Diamond Cross-Grooved Cement Concrete	PCC (DC)
66	Germany	Sperenberg	Section B17	Porous Cement Concrete	PCC (P)
67	Germany	Sperenberg	Section B18	Porous Cement Concrete	PCC (P)
68	Germany	Opel PG	Passby Test Site	ISO 10844	PA

APPENDIX 3

TEST DATA AND PAVEMENT DOCUMENTATION:

PAVEMENTS TESTED IN EUROPE

Pavement Reference #1

Country: Belgium

Roadway: N255

Designation: Section #1

Description: Stone Mastic Asphalt, 0/10 mm

Classification: SMA 0/10

Tire/Speed (mph)	1/3 Octave Band Sound Intensity Level, dB (A-Weighted) 400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	Overall A-Wtd,dB
Goodyear/35	81.7	83.5	84.1	90.6	91.1	87.9	85.4	81.7	77.4	74.0	71.1	68.1	96.3

Pavement Reference #2

Country: Belgium

Roadway: N255

Designation: Section #2

Description: Stone Mastic Asphalt, 0/14 mm

Classification: SMA 0/14

Tire/Speed (mph)	1/3 Octave Band Sound Intensity Level, dB (A-Weighted) 400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	Overall A-Wtd,dB
Goodyear/60		86.6	90.2	97.8	97.6	94.9	93.4	90.1	86.3	82.6	79.6	76.4	103.1
Goodyear/35	81.5	83.2	84.1	90.6	90.9	87.6	85.5	81.9	77.7	74.2	71.2	68.0	96.2

Pavement Reference #3

Country:	Belgium
Roadway:	N255
Designation:	Section #3
Description:	Porous Cement Concrete 0/7 mm
Classification:	PCC (P) 0/7

	1/3 Octave Band Sound Intensity Level, dB (A-Weighted)												Overall
Tire/Speed (mph)	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	A-Wtd,dB
Goodyear/60		88.6	91.5	98.7	97.2	95.2	92.9	89.5	86.2	82.5	78.6	74.7	103.4
Goodyear/35	82.5	83.8	84.5	91.1	90.4	88.1	85.0	81.6	78.0	74.3	69.9	66.2	96.3

Pavement Reference #4

Country:	Belgium
Roadway:	N255
Designation:	Section #4
Description:	Porous Asphalt 0/14 mm
Classification:	PA 0/14

	1/3 Octave Band Sound Intensity Level, dB (A-Weighted)												Overall
Tire/Speed (mph)	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	A-Wtd,dB
Goodyear/60		90.3	93.2	100.0	98.7	95.5	91.9	88.6	85.7	82.1	78.3	74.8	104.3
Goodyear/35	83.6	85.5	87.0	93.1	92.1	88.6	84.4	80.9	77.9	74.7	70.4	66.9	97.8

Pavement Reference #5

Country: Belgium

Roadway: N255

Designation: Section #5

Description: Exposed Aggregate Cement Concrete 0/7 mm

Classification: PCC (EA) 0/7

	1/3 Octave Band Sound Intensity Level, dB (A-Weighted)												Overall
Tire/Speed (mph)	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	A-Wtd,dB
Goodyear/60		85.6	88.6	95.5	96.0	94.2	91.4	89.2	85.8	81.9	78.7	76.2	101.5
Goodyear/35	80.9	82.2	82.4	88.2	90.0	88.0	84.2	81.8	77.9	73.9	70.6	68.3	95.2

Pavement Reference #6

Country: Belgium

Roadway: N255

Designation: Section #6

Description: Non-Porous Asphalt 0/10 mm + 10/14mm Chippings

Classification: DGA 0/10/14

	1/3 Octave Band Sound Intensity Level, dB (A-Weighted)												Overall
Tire/Speed (mph)	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	A-Wtd,dB
Goodyear/35	83.4	85.3	86.3	92.2	91.4	87.8	84.4	80.6	77.1	74.0	70.5	67.7	97.1

Pavement Reference #7

Country:	France
Roadway:	LCPC
Designation:	Section B
Description:	Porous Cement Concrete
Classification:	PCC (P)

	1/3 Octave Band Sound Intensity Level, dB (A-Weighted)												Overall
Tire/Speed (mph)	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	A-Wtd,dB
Goodyear/60		88.6	91.6	96.7	90.9	88.1	85.5	82.9	80.9	77.5	73.6	70.3	99.8
Uniroyal/60		86.6	90.9	95.4	90.6	87.5	84.6	82.5	79.8	76.8	73.7	70.5	98.8
Goodyear/35	82.27	84.7	85.5	87.6	84.6	81.8	78.6	74.9	72.9	70.4	66.0	62.5	93.0

Pavement Reference #8

Country:	France
Roadway:	LCPC
Designation:	Section A
Description:	Surface Dressing 8/10 mm
Classification:	SD 8/10

	1/3 Octave Band Sound Intensity Level, dB (A-Weighted)												Overall
Tire/Speed (mph)	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	A-Wtd,dB
Goodyear/60		97.5	98.5	101.6	98.5	91.0	88.8	85.8	83.7	80.6	77.4	73.5	105.7
Uniroyal/60		96.2	97.6	100.0	95.8	89.6	88.7	85.8	82.1	80.0	76.8	73.0	104.1
Goodyear/35	86.36	88.3	88.1	91.0	87.8	82.0	80.2	77.1	75.3	72.2	68.8	65.1	96.0

Pavement Reference #9

Country: France

Roadway: LCPC

Designation: Section C

Description: Fine Surface Dressing 0.8/1.5 mm

Classification: SD 0.8/1.5

	1/3 Octave Band Sound Intensity Level, dB (A-Weighted)												Overall
Tire/Speed (mph)	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	A-Wtd,dB
Goodyear/60		84.0	86.6	94.9	94.1	90.1	90.2	87.3	83.4	79.9	77.3	74.7	99.7
Uniroyal/60		79.0	84.9	91.9	91.3	88.9	88.7	87.1	82.9	80.2	76.9	74.4	97.6
Goodyear/35	79.55	81.9	80.0	86.0	86.7	82.0	80.6	78.3	75.5	72.4	69.4	66.9	92.1

Pavement Reference #10

Country: France

Roadway: LCPC

Designation: Section L

Description: Fine Dense Graded Asphalt

Classification: DGA (F)

	1/3 Octave Band Sound Intensity Level, dB (A-Weighted)												Overall
Tire/Speed (mph)	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	A-Wtd,dB
Goodyear/60		82.1	85.5	93.6	91.7	87.9	90.4	87.2	83.0	79.9	77.0	74.1	98.4
Uniroyal/60		77.1	82.1	88.5	90.0	86.3	87.5	87.1	83.3	80.0	77.8	75.2	95.8
Goodyear/35	82.12	84.4	82.3	87.0	85.7	81.0	80.2	77.5	74.9	71.9	68.6	65.6	92.6

Pavement Reference #11

Country: France

Roadway: LCPC

Designation: Section G

Description: Porous Asphalt 0/10 mm

Classification: PA 0/10

	1/3 Octave Band Sound Intensity Level, dB (A-Weighted)												Overall
Tire/Speed (mph)	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	A-Wtd,dB
Goodyear/60		92.4	92.0	92.9	89.4	85.1	84.3	82.4	80.5	76.9	72.8	69.3	98.5
Uniroyal/60		89.9	90.8	91.3	88.7	84.1	83.1	81.5	78.9	76.0	72.2	68.5	97.0
Goodyear/35	84.7	88.1	86.4	85.6	82.2	78.7	75.8	73.4	71.6	68.8	64.9	61.6	93.2

Pavement Reference #12

Country: France

Roadway: LCPC

Designation: Section H

Description: Dense Graded Asphalt 0/10 mm

Classification: DGA 0/10

	1/3 Octave Band Sound Intensity Level, dB (A-Weighted)												Overall
Tire/Speed (mph)	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	A-Wtd,dB
Goodyear/60		86.3	89.2	96.6	95.4	92.7	90.8	88.2	85.1	81.2	77.8	74.3	101.3
Uniroyal/60		83.3	87.7	93.6	92.7	90.8	89.5	87.8	84.0	81.3	77.4	74.3	99.1
Goodyear/35	80.15	82.2	82.2	87.8	87.8	84.4	82.1	78.8	75.6	71.7	68.3	65.3	93.5

Pavement Reference #13

Country: France

Roadway: LCPC

Designation: Section J

Description: Thin Layer Asphalt 0/6 mm

Classification: PA 0/6

	1/3 Octave Band Sound Intensity Level, dB (A-Weighted)												Overall
Tire/Speed (mph)	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	A-Wtd,dB
Goodyear/60		86.4	90.3	96.1	91.2	87.1	84.8	80.7	80.0	78.0	74.4	69.9	99.0
Uniroyal/60		83.2	87.6	90.2	90.3	87.5	82.7	79.6	78.2	77.3	74.3	69.6	95.9
Goodyear/35	80.43	84.8	84.4	86.9	85.3	79.9	74.8	71.2	71.1	69.1	64.8	60.2	92.3

Pavement Reference #14

Country: the Netherlands

Roadway: A15

Designation: Section #1

Description: Double Layer Porous Asphalt - 4/8mm

Classification: DLPA 4/8

	1/3 Octave Band Sound Intensity Level, dB (A-Weighted)												Overall
Tire/Speed (mph)	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	A-Wtd,dB
Goodyear/60		87.7	85.5	90.0	89.3	89.4	88.8	84.2	82.1	79.2	75.3	72.0	97.0
Uniroyal/60		86.0	82.9	85.1	90.1	89.4	87.6	84.2	81.0	79.2	76.3	72.5	95.9

Pavement Reference #15

Country: the Netherlands

Roadway: A15

Designation: Section #2

Description: Double Layer Porous Asphalt - 4/8mm

Classification: DLPA 4/8

	1/3 Octave Band Sound Intensity Level, dB (A-Weighted)												Overall
Tire/Speed (mph)	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	A-Wtd,dB
Goodyear/60		85.8	84.1	89.4	89.2	90.0	89.6	85.0	82.1	79.5	76.3	73.4	96.9
Uniroyal/60		84.3	81.7	84.5	90.6	90.0	88.3	84.3	81.2	79.5	76.9	73.5	96.1

Pavement Reference #16

Country: the Netherlands

Roadway: A15

Designation: Section #3

Description: Double Layer Porous Asphalt - 2/6mm

Classification: DLPA 2/6

	1/3 Octave Band Sound Intensity Level, dB (A-Weighted)												Overall
Tire/Speed (mph)	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	A-Wtd,dB
Goodyear/60		81.1	81.5	89.0	89.1	87.1	86.5	82.3	79.4	77.2	74.2	71.0	95.0
Uniroyal/60		79.7	78.6	83.0	90.0	87.4	84.8	81.5	78.7	77.5	75.1	71.0	94.0

Pavement Reference #17

Country: the Netherlands

Roadway: A15

Designation: Section #4

Description: Double Layer Porous Asphalt - 2/6mm

Classification: DLPA 2/6

	1/3 Octave Band Sound Intensity Level, dB (A-Weighted)											Overall
Tire/Speed (mph)	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	A-Wtd,dB
Goodyear/60		80.8	83.0	90.6	90.3	86.5	86.7	83.3	79.9	77.9	75.0	71.8	95.9
Uniroyal/60		78.3	80.2	85.8	90.2	86.6	85.0	82.8	79.1	77.7	75.5	72.0	94.4

Pavement Reference #18

Country: the Netherlands

Roadway: A15

Designation: Section #5

Description: Double Layer Porous Asphalt - 4/8mm

Classification: DLPA 4/8

	1/3 Octave Band Sound Intensity Level, dB (A-Weighted)												Overall
Tire/Speed (mph)	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	A-Wtd,dB
Goodyear/60		86.4	83.9	89.1	90.3	89.3	87.1	84.4	82.2	79.4	75.8	72.8	96.5
Uniroyal/60		85.3	81.5	84.5	91.0	89.8	85.9	84.0	81.6	79.7	77.0	73.3	95.9

Pavement Reference #19

Country: the Netherlands

Roadway: A15

Designation: Section #6

Description: Double Layer Porous Asphalt - 4/8mm

Classification: DLPA 4/8

	1/3 Octave Band Sound Intensity Level, dB (A-Weighted)												Overall
Tire/Speed (mph)	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	A-Wtd,dB
Goodyear/60		83.0	83.3	90.2	89.8	87.3	87.8	84.6	82.2	79.3	75.9	72.8	96.2
Uniroyal/60		85.6	82.0	85.2	90.9	90.4	87.9	85.0	82.5	80.0	77.5	74.2	96.5

Pavement Reference #20

Country: the Netherlands

Roadway: A15

Designation: Section #7

Description: Double Layer Porous Asphalt - 4/8mm

Classification: DLPA 4/8

	1/3 Octave Band Sound Intensity Level, dB (A-Weighted)												Overall
Tire/Speed (mph)	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	A-Wtd,dB
Goodyear/60		88.6	85.8	89.5	89.7	91.0	88.5	83.8	82.3	79.4	76.2	72.9	97.4
Uniroyal/60		87.0	83.9	85.8	91.5	91.4	88.1	83.2	81.6	79.5	77.0	73.2	97.1

Pavement Reference #21

Country: the Netherlands

Roadway: A15

Designation: Section #8

Description: Double Layer Porous Asphalt - 4/8mm

Classification: DLPA 4/8

	1/3 Octave Band Sound Intensity Level, dB (A-Weighted)												Overall
Tire/Speed (mph)	**400**	**500**	**630**	**800**	**1000**	**1250**	**1600**	**2000**	**2500**	**3150**	**4000**	**5000**	**A-Wtd,dB**
Goodyear/60		90.2	87.1	90.1	90.2	88.6	86.8	83.9	82.1	79.8	76.4	73.1	97.3
Uniroyal/60		88.4	84.6	87.1	90.7	89.2	85.6	82.9	80.9	79.8	77.0	73.2	96.4

Pavement Reference #22

Country: the Netherlands

Roadway: A15

Designation: Eastbound

Description: Dense Graded Asphalt

Classification: DGA

	1/3 Octave Band Sound Intensity Level, dB (A-Weighted)												Overall
Tire/Speed (mph)	**400**	**500**	**630**	**800**	**1000**	**1250**	**1600**	**2000**	**2500**	**3150**	**4000**	**5000**	**A-Wtd,dB**
Goodyear/60		85.4	90.3	97.9	97.5	94.1	94.0	91.2	87.6	84.4	81.6	78.1	103.2
Uniroyal/60		83.9	89.2	95.3	94.4	92.7	93.0	90.7	86.6	84.0	81.1	78.3	101.2

Pavement Reference #23

Country: the Netherlands

Roadway: A59

Designation: Section #1

Description: Double Layer Porous Asphalt - 4/8mm

Classification: DLPA 4/8

	1/3 Octave Band Sound Intensity Level, dB (A-Weighted)											Overall
Tire/Speed (mph)	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	A-Wtd,dB
Goodyear/60		86.1	83.2	89.1	89.9	89.0	87.7	84.2	82.0	79.4	76.4	73.0	96.4

Pavement Reference #24

Country: the Netherlands

Roadway: A59

Designation: Section #2

Description: Double Layer Porous Asphalt - 4/8mm

Classification: DLPA 4/8

	1/3 Octave Band Sound Intensity Level, dB (A-Weighted)											Overall
Tire/Speed (mph)	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	A-Wtd,dB
Goodyear/60		87.2	85.4	90.6	90.7	87.9	85.9	81.8	80.1	79.0	75.5	71.7	96.6

Pavement Reference #25

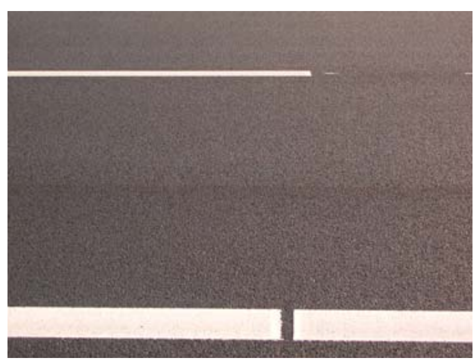
Reference #:	25
Country:	the Netherlands
Roadway:	A59
Designation:	Section #3
Description:	Double Layer Porous Asphalt - 4/8mm
Classification:	DLPA 4/8

Tire/Speed (mph)	1/3 Octave Band Sound Intensity Level, dB (A-Weighted)											Overall
	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	A-Wtd,dB
Goodyear/60		84.9	84.1	89.8	88.8	86.3	87.4	84.3	81.3	78.9	75.9	72.7	95.8

Pavement Reference #26

Country:	the Netherlands
Roadway:	A59
Designation:	Section #4
Description:	Double Layer Porous Asphalt - 4/8mm
Classification:	DLPA 4/8

Tire/Speed (mph)	1/3 Octave Band Sound Intensity Level, dB (A-Weighted)												Overall
	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	A-Wtd,dB
Goodyear/60		84.8	82.5	88.9	89.8	88.8	87.9	83.5	81.2	78.9	76.1	73.0	96.1



Pavement Reference #27

Country: the Netherlands

Roadway: A59

Designation: Section #5

Description: Double Layer Porous Asphalt - 2/6mm

Classification: DLPA 2/6

	1/3 Octave Band Sound Intensity Level, dB (A-Weighted)												Overall
Tire/Speed (mph)	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	A-Wtd,dB
Goodyear/60		80.6	80.5	88.8	88.3	85.3	86.5	82.7	79.2	76.2	74.6	71.5	94.5

Pavement Reference #28

Country: the Netherlands

Roadway: A59

Designation: Section #6

Description: Double Layer Porous Asphalt - 2/6mm

Classification: DLPA 2/6

	1/3 Octave Band Sound Intensity Level, dB (A-Weighted)												Overall
Tire/Speed (mph)	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	A-Wtd,dB
Goodyear/60		76.9	81.0	89.6	89.3	84.5	85.2	83.5	80.4	77.9	74.4	71.2	94.8

Pavement Reference #29

Country:	the Netherlands
Roadway:	A59
Designation:	Section #7
Description:	Double Layer Porous Asphalt - 4/8mm
Classification:	DLPA 4/8

	1/3 Octave Band Sound Intensity Level, dB (A-Weighted)												Overall
Tire/Speed (mph)	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	A-Wtd,dB
Goodyear/60		84.2	82.4	88.8	89.3	88.3	87.3	82.3	79.4	76.5	73.5	70.6	95.5

Pavement Reference #30

Country:	the Netherlands
Roadway:	A59
Designation:	Section #8
Description:	Double Layer Porous Asphalt - 4/8mm
Classification:	DLPA 4/8

	1/3 Octave Band Sound Intensity Level, dB (A-Weighted)												Overall
Tire/Speed (mph)	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	A-Wtd,dB
Goodyear/60		81.7	81.5	89.1	89.2	88.0	87.8	84.5	81.1	77.7	74.4	71.6	95.7

Pavement Reference #31

Country:	the Netherlands
Roadway:	A326
Designation:	Westbound
Description:	Double Layer Porous Asphalt - Fine
Classification:	DLPA 2/6

	1/3 Octave Band Sound Intensity Level, dB (A-Weighted)												Overall
Tire/Speed (mph)	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	A-Wtd,dB
Goodyear/60		83.2	82.0	88.6	87.9	86.7	87.2	82.6	80.1	77.4	73.6	70.4	94.9

Pavement Reference #32

Country:	the Netherlands
Roadway:	A326
Designation:	Eastbound
Description:	Double Layer Porous Asphalt - Fine
Classification:	DLPA 2/6

	1/3 Octave Band Sound Intensity Level, dB (A-Weighted)												Overall
Tire/Speed (mph)	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	A-Wtd,dB
Goodyear/60		83.0	82.1	89.1	87.7	85.7	86.7	82.2	79.0	76.4	73.2	69.9	94.7

Pavement Reference #33

Country: the Netherlands

Roadway: A270

Designation: Section #1 (EB)

Description: Random Transverse Texture Cement Concrete

Classification: PCC (RT)

	1/3 Octave Band Sound Intensity Level, dB (A-Weighted)												Overall
Tire/Speed (mph)	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	A-Wtd,dB
Goodyear/60		93.4	94.4	102.5	102.1	98.9	97.6	94.6	89.5	85.3	82.3	79.5	107.6

Pavement Reference #34

Country: the Netherlands

Roadway: A270

Designation: Section #2 (WB)

Description: Random Transverse Texture Cement Concrete

Classification: PCC (RT)

	1/3 Octave Band Sound Intensity Level, dB (A-Weighted)												Overall
Tire/Speed (mph)	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	A-Wtd,dB
Goodyear/60		93.1	94.3	102.0	102.1	98.6	97.3	94.4	89.6	84.9	81.8	79.1	107.3

Pavement Reference #35

Country: the Netherlands

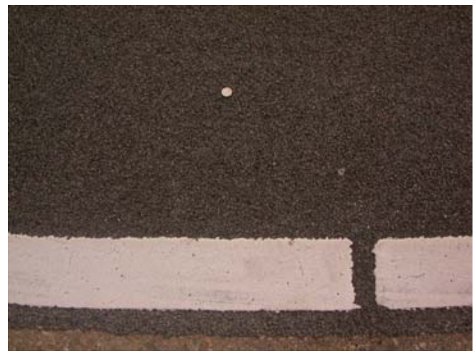
Roadway: A270

Designation: Section #3 (WB)

Description: Expoxy/Stone Layer on Cement Concrete

Classification: PCC (Ex)

	1/3 Octave Band Sound Intensity Level, dB (A-Weighted)												Overall
Tire/Speed (mph)	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	A-Wtd,dB
Goodyear/60		90.5	92.9	99.7	99.3	96.3	93.3	90.4	88.0	84.8	81.5	78.4	104.7



Pavement Reference #36

Country: the Netherlands

Roadway: A270

Designation: Section #4 (EB)

Description: Expoxy/Stone Layer on Cement Concrete

Classification: PCC (Ex)

	1/3 Octave Band Sound Intensity Level, dB (A-Weighted)												Overall
Tire/Speed (mph)	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	A-Wtd,dB
Goodyear/60		90.1	92.3	99.3	98.9	95.7	92.7	90.0	87.6	84.4	81.2	77.9	104.3

Pavement Reference #37

Country:	the Netherlands
Roadway:	A73
Designation:	Section #1
Description:	Porous Asphalt
Classification:	PA

	1/3 Octave Band Sound Intensity Level, dB (A-Weighted)											Overall
Tire/Speed (mph)	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	A-Wtd,dB
Goodyear/60		94.8	96.2	98.1	95.3	92.8	91.0	87.8	86.3	84.0	80.5	77.7	103.4

Pavement Reference #38

Country:	the Netherlands
Roadway:	A73
Designation:	Section #2
Description:	Dense Graded Asphalt (medium)
Classification:	DGA (M)

	1/3 Octave Band Sound Intensity Level, dB (A-Weighted)											Overall
Tire/Speed (mph)	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	A-Wtd,dB
Goodyear/60		94.0	91.8	93.9	93.6	91.3	88.2	85.5	84.7	82.3	78.9	75.9	100.7

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Pavement Reference #39

Country: the Netherlands

Roadway: A73

Designation: Section #3

Description: Dense Graded Asphalt (coarse)

Classification: DGA (C)

	1/3 Octave Band Sound Intensity Level, dB (A-Weighted)												Overall
Tire/Speed (mph)	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	A-Wtd,dB
Goodyear/60		90.8	94.5	102.1	100.0	96.9	94.7	91.2	88.8	85.5	81.7	78.4	106.1

Pavement Reference #40

Country: the Netherlands

Roadway: A73

Designation: Section #4

Description: Random Transverse Texture Cement Concrete

Classification: PCC (RT)

	1/3 Octave Band Sound Intensity Level, dB (A-Weighted)												Overall
Tire/Speed (mph)	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	A-Wtd,dB
Goodyear/60		89.3	91.6	100.2	101.0	96.4	98.0	96.4	92.1	88.1	85.2	82.7	106.3

Pavement Reference #41

Country: Germany

Roadway: B56

Designation: Track #1

Description: Stone Mastic Asphalt, 0/8 mm

Classification: SMA 0/8

	1/3 Octave Band Sound Intensity Level, dB (A-Weighted)											Overall
Tire/Speed (mph)	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	A-Wtd,dB
Goodyear/60		83.9	88.0	97.1	95.8	94.3	92.7	90.0	85.9	81.6	78.6	75.1	102.0

Pavement Reference #42

Country: Germany

Roadway: B56

Designation: Track #3

Description: Ground Porous Cement Concrete 4/8 mm

Classification: PCC (P/G)

	1/3 Octave Band Sound Intensity Level, dB (A-Weighted)												Overall
Tire/Speed (mph)	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	A-Wtd,dB
Goodyear/60		89.0	85.8	89.5	89.9	88.5	85.6	82.0	80.5	77.7	74.2	71.0	96.5

Pavement Reference #43

Country:	Germany
Roadway:	B56
Designation:	Track #5
Description:	Dense Graded Asphalt 0/8 mm
Classification:	DGA 0/8

	1/3 Octave Band Sound Intensity Level, dB (A-Weighted)												Overall
Tire/Speed (mph)	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	A-Wtd,dB
Goodyear/60		84.2	86.9	94.9	94.2	92.4	90.0	87.7	84.4	80.3	77.3	74.7	100.1

Pavement Reference #44

Country:	Germany
Roadway:	B56
Designation:	Track #7
Description:	Exposed Aggregrate Cement Concrete
Classification:	PCC (EA)

	1/3 Octave Band Sound Intensity Level, dB (A-Weighted)												Overall
Tire/Speed (mph)	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	A-Wtd,dB
Goodyear/60		88.6	90.9	97.3	98.0	95.1	91.4	89.1	86.3	82.5	79.1	76.5	103.0

Pavement Reference #45

Country: Germany

Roadway: B56

Designation: Track #8

Description: Exposed Aggregrate Cement Concrete (rough)

Classification: PCC (EA)

	1/3 Octave Band Sound Intensity Level, dB (A-Weighted)												Overall
Tire/Speed (mph)	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	A-Wtd,dB
Goodyear/60		91.6	93.2	99.2	99.2	95.1	91.0	88.5	86.1	82.4	78.8	76.1	104.1

Pavement Reference #46

Country: Germany

Roadway: B56

Designation: Track #9

Description: Ground Cement Concrete 4/8 mm (Exposed Aggregate)

Classification: PCC (G)

	1/3 Octave Band Sound Intensity Level, dB (A-Weighted)												Overall
Tire/Speed (mph)	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	A-Wtd,dB
Goodyear/60		88.7	91.0	97.7	98.2	94.4	92.1	89.0	85.8	81.8	79.0	76.2	103.1

Pavement Reference #47

Country: Germany

Roadway: B56

Designation: Track #10

Description: Cement Concrete with Transverse Broom Finish

Classification: PCC

	1/3 Octave Band Sound Intensity Level, dB (A-Weighted)												Overall
Tire/Speed (mph)	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	A-Wtd,dB
Goodyear/60		85.3	88.2	95.9	96.4	92.2	92.7	90.1	85.4	81.4	78.4	75.5	101.6

Pavement Reference #48

Country: Germany

Roadway: Sperenberg

Designation: Section A1

Description: Porous Asphalt 4/8 mm

Classification: PA 4/8

	1/3 Octave Band Sound Intensity Level, dB (A-Weighted)												Overall
Tire/Speed (mph)	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	A-Wtd,dB
Goodyear/60		86.7	86.3	89.4	86.7	84.3	85.2	83.7	79.9	75.4	72.3	68.5	95.1
Uniroyal/60		83.7	84.1	86.1	87.0	83.5	83.8	83.4	79.4	75.6	72.6	68.4	93.5
Goodyear/35	82.73	85.3	81.8	81.6	79.4	78.5	77.4	75.1	71.7	67.0	63.4	59.9	90.4

Pavement Reference #49

Country: Germany

Roadway: Sperenberg

Designation: Section A2

Description: Double Layer Porous Asphalt 4/8 mm

Classification: DLPA

	1/3 Octave Band Sound Intensity Level, dB (A-Weighted)												Overall
Tire/Speed (mph)	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	A-Wtd,dB
Goodyear/60		86.6	84.6	88.1	87.2	87.0	85.8	80.9	79.0	76.0	71.9	68.5	94.9
Uniroyal/60		84.0	82.9	83.9	87.6	87.2	84.8	80.5	77.7	75.6	72.2	68.0	93.7
Goodyear/35	82.73	85.1	80.0	78.8	79.3	80.6	78.2	71.8	70.3	67.3	62.8	59.2	89.9

Pavement Reference #50

Country: Germany

Roadway: Sperenberg

Designation: Section A3

Description: Novachip 0/8 mm

Classification: NCP 0/8

	1/3 Octave Band Sound Intensity Level, dB (A-Weighted)												Overall
Tire/Speed (mph)	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	A-Wtd,dB
Goodyear/60		85.4	88.9	94.2	89.7	84.9	83.3	81.6	79.8	76.8	73.9	70.7	97.4
Uniroyal/60		81.9	87.1	90.4	89.3	85.5	82.4	80.6	78.2	76.6	73.8	70.5	95.3
Goodyear/35	80.73	82.9	83.6	86.0	83.2	78.6	74.9	72.6	71.4	68.7	64.8	61.9	91.1

Pavement Reference #51

Country: Germany

Roadway: Sperenberg

Designation: Section A4

Description: ISO 10844

Classification: PA

	1/3 Octave Band Sound Intensity Level, dB (A-Weighted)												Overall
Tire/Speed (mph)	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	A-Wtd,dB
Goodyear/60		80.3	83.8	93.1	91.1	87.2	90.6	87.5	82.8	79.6	76.9	73.6	98.0
Uniroyal/60		78.4	81.3	88.2	89.5	85.9	87.4	87.7	83.5	80.2	77.6	75.1	95.7
Goodyear/35	78.5	80.3	77.8	84.9	84.4	81.2	80.1	78.0	73.9	70.7	67.9	65.1	90.7

Pavement Reference #52

Country: Germany

Roadway: Sperenberg

Designation: Section A5

Description: Stone Mastic Asphalt, 0/3 mm

Classification: SMA 0/3

	1/3 Octave Band Sound Intensity Level, dB (A-Weighted)												Overall
Tire/Speed (mph)	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	A-Wtd,dB
Goodyear/60		79.6	84.4	94.1	92.6	87.6	91.0	88.0	83.4	79.0	76.4	73.3	98.8
Uniroyal/60		75.6	82.0	87.9	89.9	85.8	87.9	89.8	84.2	80.1	77.5	74.9	96.2
Goodyear/35	78.19	81.4	76.6	82.6	85.9	81.3	79.9	78.0	74.2	70.4	67.4	64.7	90.7

Pavement Reference #53

Country: Germany

Roadway: Sperenberg

Designation: Section A6

Description: Stone Mastic Asphalt, 0/5 mm

Classification: SMA 0/5

	1/3 Octave Band Sound Intensity Level, dB (A-Weighted)												Overall
Tire/Speed (mph)	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	A-Wtd,dB
Goodyear/60		80.8	84.0	94.1	92.0	87.6	90.8	87.7	83.3	79.7	77.2	74.1	98.6
Uniroyal/60		78.2	81.2	88.0	89.5	86.2	88.2	88.9	83.6	80.5	77.9	75.3	96.0
Goodyear/35	77.84	81.4	77.0	83.5	85.5	81.4	81.0	78.8	74.8	71.3	68.3	65.2	90.9

Pavement Reference #54

Country: Germany

Roadway: Sperenberg

Designation: Section A7

Description: Stone Mastic Asphalt, 0/8 mm

Classification: SMA 0/8

	1/3 Octave Band Sound Intensity Level, dB (A-Weighted)												Overall
Tire/Speed (mph)	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	A-Wtd,dB
Goodyear/60		84.9	87.6	95.2	94.4	92.0	90.6	88.3	84.2	80.1	77.4	73.9	100.3
Uniroyal/60		81.0	86.0	92.4	92.2	90.9	89.4	88.0	83.7	80.5	76.6	73.6	98.5
Goodyear/35	79.8	81.5	81.3	86.8	87.3	84.4	81.8	79.1	75.5	71.9	68.7	65.6	92.9

Pavement Reference #55

Country: Germany

Roadway: Sperenberg

Designation: Section A8

Description: Stone Mastic Asphalt, 0/11 mm

Classification: SMA 0/11

	1/3 Octave Band Sound Intensity Level, dB (A-Weighted)												Overall
Tire/Speed (mph)	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	A-Wtd,dB
Goodyear/60		87.4	89.7	96.5	94.5	91.9	89.6	86.8	83.4	79.8	76.7	73.2	100.8
Uniroyal/60		83.8	89.2	94.8	93.4	91.3	88.6	86.3	83.0	80.4	76.5	73.5	99.6
Goodyear/35	80.71	82.9	83.3	88.8	87.0	84.0	80.9	77.6	74.7	71.2	67.7	64.5	93.6

Pavement Reference #56

Country: Germany

Roadway: Sperenberg

Designation: Section A9/10

Description: Stone Mastic Asphalt, 0/8 mm

Classification: SMA 0/8

	1/3 Octave Band Sound Intensity Level, dB (A-Weighted)												Overall
Tire/Speed (mph)	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	A-Wtd,dB
Goodyear/60		85.3	88.6	95.6	94.0	91.6	91.3	88.6	84.4	80.7	77.7	74.4	100.5
Uniroyal/60		81.9	87.3	93.1	92.0	90.5	89.8	88.0	83.9	81.1	77.5	74.7	98.7
Goodyear/35	80.02	82.2	81.9	87.8	87.2	84.0	82.3	79.1	75.2	71.8	68.6	65.7	93.2

Pavement Reference #57

Country:	Germany
Roadway:	Sperenberg
Designation:	Section A11
Description:	Smooth Surface (Stone Mastic 0/8 with Epoxy Coat)
Classification:	SMA (Ex)

	1/3 Octave Band Sound Intensity Level, dB (A-Weighted)												Overall
Tire/Speed (mph)	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	A-Wtd,dB
Goodyear/60		89.3	90.9	97.9	99.5	95.9	96.4	94.9	90.0	84.9	82.0	79.1	104.8
Uniroyal/60		87.7	90.8	97.4	96.7	93.7	96.0	95.3	89.9	86.4	83.4	81.8	103.7
Goodyear/35	81.29	83.3	83.2	88.6	91.4	86.7	86.8	85.2	80.4	75.7	72.5	70.1	96.1

Pavement Reference #58

Country:	Germany
Roadway:	Sperenberg
Designation:	Section A12
Description:	DSK 0/5 mm
Classification:	DSK 0/3

	1/3 Octave Band Sound Intensity Level, dB (A-Weighted)												Overall
Tire/Speed (mph)	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	A-Wtd,dB
Goodyear/60		92.3	93.8	98.9	96.4	91.7	87.4	84.2	81.3	77.6	74.8	72.0	102.7
Uniroyal/60		91.5	93.8	98.6	95.4	91.1	87.1	84.1	80.5	77.8	73.9	70.9	102.3
Goodyear/35	82.3	84.7	84.6	89.4	87.0	82.0	78.0	75.5	73.1	69.6	66.2	63.6	93.8

Pavement Reference #59

Country: Germany

Roadway: Sperenberg

Designation: Section A13

Description: DSK 0/3 mm

Classification: DSK 0/5

	1/3 Octave Band Sound Intensity Level, dB (A-Weighted)												Overall
Tire/Speed (mph)	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	A-Wtd,dB
Goodyear/60		86.4	89.4	95.9	93.3	89.5	88.6	85.5	81.3	77.8	74.9	71.7	99.8
Uniroyal/60		86.0	90.6	93.5	91.2	89.4	88.1	85.3	80.7	77.7	74.3	71.4	98.6
Goodyear/35	80.41	82.5	82.4	87.3	84.7	80.4	78.6	76.0	72.7	69.8	66.8	63.8	91.9

Pavement Reference #60

Country: Germany

Roadway: Sperenberg

Designation: Section A14

Description: Surface Dressing OB 2/3 Round

Classification: SD 2/3 Rd

	1/3 Octave Band Sound Intensity Level, dB (A-Weighted)												Overall
Tire/Speed (mph)	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	A-Wtd,dB
Goodyear/60		91.2	92.6	98.1	98.2	94.5	90.1	87.6	84.3	80.4	77.5	74.7	103.3
Uniroyal/60		89.9	92.4	98.0	97.0	93.3	89.5	87.7	83.9	81.0	76.9	74.3	102.6
Goodyear/35	81.99	83.8	84.0	89.2	89.5	85.8	81.3	79.4	76.4	72.7	69.5	67.0	94.8

Pavement Reference #61

Country: Germany

Roadway: Sperenberg

Designation: Section A15

Description: Surface Dressing OB 3/5 Round

Classification: SD 3/5 Rd

	1/3 Octave Band Sound Intensity Level, dB (A-Weighted)												Overall
Tire/Speed (mph)	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	A-Wtd,dB
Goodyear/60		93.6	94.7	99.7	99.7	95.5	91.0	88.6	86.1	83.3	81.0	78.8	104.8
Uniroyal/60		92.0	94.7	99.9	98.4	93.2	89.6	87.9	84.2	81.4	77.6	74.4	104.0
Goodyear/35	83.54	85.3	85.6	90.6	90.0	85.6	81.3	79.7	77.3	74.1	70.7	68.0	95.8

Pavement Reference #62

Country: Germany

Roadway: Sperenberg

Designation: Section A16

Description: Surface Dressing OB 5/8 Round

Classification: SB 5/8 Rd

	1/3 Octave Band Sound Intensity Level, dB (A-Weighted)												Overall
Tire/Speed (mph)	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	A-Wtd,dB
Goodyear/60		94.2	95.1	100.7	101.3	98.5	94.6	91.7	87.6	83.2	80.4	77.2	106.4
Uniroyal/60		92.7	95.0	100.9	100.1	96.4	93.5	92.1	87.1	83.3	79.2	76.5	105.6
Goodyear/35	84.81	86.4	86.5	91.4	92.2	88.6	84.5	81.8	78.4	74.3	71.1	68.4	97.4

Pavement Reference #63

Country:	Germany
Roadway:	Sperenberg
Designation:	Section A20
Description:	Surface Dressing OB 5/8 Sharp
Classification:	SB 5/8 Shp

	1/3 Octave Band Sound Intensity Level, dB (A-Weighted)												Overall
Tire/Speed (mph)	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	A-Wtd,dB
Goodyear/60		93.5	95.3	100.1	98.6	92.6	89.5	87.7	86.3	84.0	81.5	78.9	104.4
Uniroyal/60		92.8	94.8	99.0	97.1	91.1	89.0	86.7	83.8	81.5	78.4	75.0	103.2
Goodyear/35	83.63	85.6	85.8	90.0	89.2	83.7	80.5	78.9	77.3	74.5	71.2	68.5	95.2


Pavement Reference #64

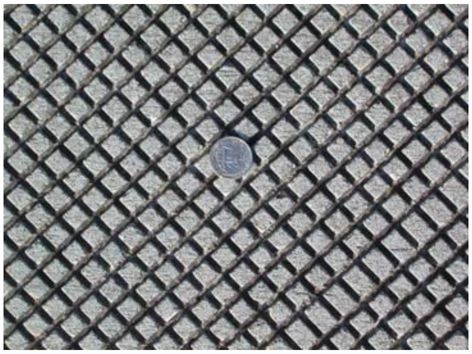
Country:	Germany
Roadway:	Sperenberg
Designation:	Section B2
Description:	Polished Cement Concrete
Classification:	PCC (Pl)

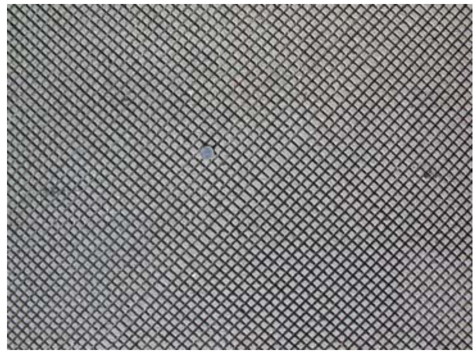
	1/3 Octave Band Sound Intensity Level, dB (A-Weighted)												Overall
Tire/Speed (mph)	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	A-Wtd,dB
Goodyear/35	77.5	81.5	77.2	85.0	87.7	82.3	81.1	79.1	74.8	70.8	67.7	65.2	92.0


Pavement Reference #65

Country:	Germany
Roadway:	Sperenberg
Designation:	Section B5
Description:	Diamond Cross-Grooved Cement Concrete
Classification:	PCC (DC)

	1/3 Octave Band Sound Intensity Level, dB (A-Weighted)												Overall
Tire/Speed (mph)	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	A-Wtd,dB
Goodyear/35	78.8	80.3	83.2	88.1	87.8	85.3	84.3	79.7	76.5	73.3	67.7	64.0	93.8





Pavement Reference #66

Country:	Germany
Roadway:	Sperenberg
Designation:	Section B17
Description:	Porous Cement Concrete
Classification:	PCC (P)

	1/3 Octave Band Sound Intensity Level, dB (A-Weighted)												Overall
Tire/Speed (mph)	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	A-Wtd,dB
Goodyear/35	83.3	83.9	79.4	81.3	81.7	80.0	75.4	71.9	69.9	66.4	62.7	60.0	90.0

Pavement Reference #67

Country:	Germany
Roadway:	Sperenberg
Designation:	Section B18
Description:	Porous Cement Concrete
Classification:	PCC (P)

Tire/Speed (mph)	1/3 Octave Band Sound Intensity Level, dB (A-Weighted) 400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	Overall A-Wtd,dB
Goodyear/35	81.4	83.7	79.9	83.5	83.9	82.4	78.0	73.8	71.8	68.1	64.0	61.0	90.9

Pavement Reference #68

Country:	Germany
Roadway:	Opel PG
Designation:	Passby Test Site
Description:	ISO 10844 Porous Asphalt
Classification:	PA

Tire/Speed (mph)	1/3 Octave Band Sound Intensity Level, dB (A-Weighted) 400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	Overall A-Wtd,dB
Goodyear/35	76.9	80.7	77.7	83.7	86.6	82.5	81.7	79.3	75.4	72.2	69.6	67.0	91.5

No Images Available