Comparative Measurements of Tire/Pavement Noise in Europe and the United States

A Summary of the NITE Study

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Background

The effect of changes in pavement surface on traffic noise has been widely demonstrated in the literature for situations typical of community noise exposure. Much of this work has been presented in studies of the application of "quiet pavements" in Europe. In general, the reduction in noise is most effective for higher speeds and for light vehicles, and to a lesser extent for medium and heavy-duty trucks. In the states of California and Arizona, reductions in traffic noise of 3 dB to as much as 9 dB have been measured when tire/pavement source levels were reduced by similar amounts[1,2,3]. Because of this potential for affecting noise levels in the community, state departments of transportation have become increasingly interested in the use of "quiet" pavements in highway applications.

With this interest in characterizing pavements for tire noise performance, the sound intensity method has been recently applied to measuring the effect of pavement on tire/pavement noise on active roadways in the states of California and Arizona[4]. The methodology for these measurements has followed that originally developed at the General Motors Corporation for tire noise research[5], and for isolating tire noise under acceleration as in the ISO 362 passby test[6]. Under this methodology, a fixture is mounted on the wheel of a test vehicle so that sound intensity can be measured very close to the tire/pavement interface as illustrated in Fig. 1. Data are collected opposite the leading and trailing edge of the tire contact patch and averaged together to obtain the acoustic energy propagating away from the tire to the wayside. In 2002, the California Department of Transportation (Caltrans) funded the development of the application of this technique to evaluating the performance of highway pavements[4]. After demonstrating the correlation of sound intensity levels to cruise passby levels for a test vehicle on multiple pavements using multiple tires, a large database of tire/pavement noise was developed covering a range of pavements used in California and Arizona.

With the development of this database, there was considerable interest in applying this same measurement approach to pavements in Europe. In May of 2004, a delegation from the United States (US) undertook a "Scanning" tour 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 no was common scale to compare the performance of European pavements to those in the US. To fill this void, Caltrans funded a project to perform sound intensity measurements in Europe that could be compared directly to those in the California/Arizona (CA/AZ) database. This became the Noise Intensity Testing in Europe or "NITE" Project.

Project Definition & Preliminary Work

In principle, sound intensity measurements of European roadways could readily be accomplished because 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 (Goodyear Aquatred 3) 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 2004 Chevrolet Malibu and 2004 Opel Vectra had common wheel designs and could accommodate the P205/15R 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 4 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 Chevrolet Malibu. In this testing, the levels for normal test car were found to be on average 0.5 dB higher than the Malibu. Consistent with other testing of this tire design mounted on other vehicles and test trailers, the range of difference was 0.1 to 0.8 dB.

For testing in Europe, an Opel Vectra was provided by General Motors. Prior to the pavement testing, sound intensity and passby tests were conducted at the Opel Proving Ground on their ISO 10844 test track surface used for vehicle passby noise development. For constant-speed-cruise-conditions, the relationship between sound intensity and passby levels was identical to that demonstrated in the CA/AZ testing, as illustrated in Fig. 2.

After the verification testing at the Opel Proving Ground, sound intensity measurements began on the European roadways in late September of 2004. 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[a]/FHWA[b] 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. Prior to the start of testing, the scope was limited to five countries that were in the closest geographic proximity, and possessed some pavements that were know 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. In all, 68 pavements were measured. Of those, 61 were measured at 97 km/h (60 mph) and 34 were measured at 56 km/h (35 mph) with the Goodyear Aquatred 3. An alternate tire, which had been occasionally used in CA/AZ testing (Uniroyal Tiger Paw AWP), was also measured at 56 km/h on 32 pavements. Some of the sites in Germany had been included in a CPX round robin study conducted in July of 2003[7], which would allow some comparison to the NITE results.

Results of Testing

As a prelude to the NITE results, it is instructive to review the results of testing on various pavements in California and Arizona. Since its inception, the database has grown to over 100 different pavements and bridge decks. The overall, A-weighted sound intensity levels of a representative cross section of these different pavements are given in Fig. 3. These data, collected at a test speed of 97 km/h and excluding the typically higher level bridge decks, display a range of over 13 dB. Within this data set, generic pavement groupings include "PCC" for Portland Cement Concrete, "DGA" or "DGAC" for Dense

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[a] AASHTO is the American Association of State Highway Transportation Officials
[b] FHWA is the U.S. Federal Highway Administration

Graded Asphalt Concrete, and "OG/RAC" for Open Graded/Rubber Asphalt Concrete. The data of Figure 3 can be coarsely grouped by performance and pavement type. First, the pavements with the lowest one-third of the levels are either open-graded and/or rubberized asphalt. The middle one-third are mostly dense-graded asphalt with some overlap of OGAC and the quieter of the PCC surfaces. The upper One-third is dominated by PCC except for a "chip seal" surface that contained very large, angular aggregate that generated high levels of lower frequency noise. With some idea of type and condition of existing pavement on highway, these data can be used to roughly estimate what improvement might be expected by modifying an existing surface.

A portion of overall results of the NITE testing is provided in Fig. 4 in a format analogous to the CA/AZ results of Fig. 3. Figure 4 spans the loudest pavement measured with an overall A-weighted level of 107.6 dB for a transversely tined PCC in the Netherlands to the quietest A-weighted level at 94.6 dB, 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 dB[A]) although the absolute levels are shifted slightly upward. It should be noted that no attempt was made to account of different test temperatures in these data. The measurements in Europe were completed in a relatively small temperature range spanning about 15° to 21° C (60° to 70° F). The CA/AZ data base span a generally wider range, from about 13° to 32° C (55° to 90° F) with some more extreme temperatures both lower and higher. Any effect of temperature on sound intensity measurements has not been documented at this time and as a result no corrections were applied. Also, no offset was applied to account for the apparent average difference between the NITE test tire/car and that used for collecting the CA/AZ data.

For NITE data of Fig. 4, in addition to DLPA, 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 generally used, as it is some other states in the US. Although SMA is somewhat similar to DGAC, it characterized by high stone-to-stone contact, a more viscous binder, and low air voids.

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. 5, 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 the low and high ends of the data, as illustrated in Fig. 6. The quietest European surfaces are typically double layer porous AC and are about 1 to 2 dB quieter than the lowest CA/AZ surfaces. An example of DLPA pavement is shown in Fig. 7. Typically, the top layer is constructed of smaller aggregate to reduce noise while the lower layer uses larger aggregate to improve drainage. Different top layer aggregate sizes are used to optimize noise performance. On the higher end, the noisier European surfaces are single layer porous with larger aggregate sizes. Sound intensity levels for PCC are given in Fig. 8. For these surfaces, the higher levels in both Europe and CA/AZ are transversely tined with the highest being the random transverse tined studied in Arizona[8]. On the quieter end, one European 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.

Results for the 56 km/h NITE data are shown in Fig. 9. The range of these data is smaller than that in the 97 km/h data. However, the noisier transversely tined PCC surfaces were not included in this data set. Relative to limited 56 km/h data obtained in California, the range of 10 dB is similar. Further, the levels for the quietest and loudest pavements in both data sets are virtually identical between the NITE and CA/AZ data. Similar to the 97 km/h results, the ground porous PCC pavement was almost as quiet as the quietest AC pavements. A second, unground porous PCC, is also included in this data set (not in the 97 km/h data set), and it also performed well -- being only about 1 dB higher than the ground section. Also included in the data of Fig. 9 are two ISO 10844 test track surfaces. These data, along with that from a test track in the US, have recently been used to examine the relationship between the tire/pavement noise of the ISO surface and pavements more commonly occurring in both US and Europe [9].

Comparisons between the NITE and CA/AZ Results

One of main purposes of the NITE project was to determine if the pavement technology in Europe produced quieter pavements. Large reductions for quiet pavements relative to some baseline pavements have been reported in the literature from Europe. Comparing Figs. 3 and 4, 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 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. 10, several DGAC and PCC pavements, which were found on existing motorways, are plotted with two different DLPA pavements. The typical improvement in level with the DLPA is about 10 dB. In Arizona, although there is a limited amount of longitudinal and random transverse tined PCC, the bulk of the PCC is uniform transverse tined. Relative to Arizona Asphalt Rubber Friction Courses (ARFC) overlays that have been recently applied in the Arizona Quiet Pavement Pilot Project, reductions on the order of 9 dB are typical as illustrated in Fig. 11. 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. See Fig. 12. As a result, the typical higher levels are about 3 dB lower than Arizona or the Netherlands and the range of possible improvement is on the order of 6 dB. 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.

The quieter pavements measured in Europe, California, and Arizona are compared in Fig. 13. In Europe, the quieter pavements are “drainage” pavements, intentionally constructed to be water (and air) permeable. As a result, they should provide sound absorptive characteristics, which would decrease tire noise generation and propagation. For the CA/AZ surfaces, high permeability is not necessarily achieved with the open-graded designs. Further, there has been no indication of improved sound absorption of these surfaces relative to others. However, two of three CA/AZ pavements contain rubber, which is not commonly found in European pavements. At this time, the role of the rubber content on noise performance is not understood. Another difference is that

European porous pavements tend to be thicker, by 40 to 120 mm, than porous pavements in the US. For the CA/AZ rubberized pavements (AZ ARFC & LA 138 RAC[O]), the overlays are thinner (25 to 30 mm total thickness), but can achieve virtually the same acoustical performance of the thicker permeable European surfaces. A final difference between the European pavements and the CA/AZ pavements is aggregate size. The European pavements have maximum aggregate sizes of 6 to 8 mm. The CA/AZ pavements range from 9.5 mm to 12.5 mm. The relationships between permeability, porosity, pavement thickness, aggregate size, and rubber content are clearly an area for further investigation.

Summary

Although not a replacement for wayside traffic noise measurements, the sound intensity method has proven to be a very useful approach in evaluating the influence of pavement on tire/pavement noise generation. With its ease of deployment, portability, and time efficiency, sizable, consistent databases have been readily developed for California, Arizona, and four countries in Europe. 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 Caltrans studies performed in California and Arizona, the following observations have been made:

1. Pavement type can reduce tire/pavement noise up to 8 or 10 dB depending on the existing and final pavement.
2. A significant range in tire/pavement noise performance is in each of the generic groupings of pavement (PCC, DGAC, and OGAC/RAC).
3. Surface roughness/texture controls the lower tire/pavement noise frequencies (below approximately 1000 hertz).
4. As a group, open-graded and/or rubberized asphalt concrete show the best tire/pavement noise performance.
5. Grinding of PCC surfaces can be effective in reducing tire/pavement noise by reducing texture effect (such as transverse tining) and by reducing joint slap.

The first three of these where confirmed in the NITE testing. Since ground PCC and rubberized AC surfaces were not studied in the NITE project, these were neither confirmed nor discounted. From the NITE testing, the following observations were made:

1. Highly porous 2-layer AC constructions can provide only slightly better tire/pavement noise performance than the quiet pavements currently in use in California and Arizona.
2. Porous PCC can produce tire/pavement noise performance similar to that of other quiet pavements.
3. Exposed aggregate PCC surfaces were not found to be particularly quiet relative to longitudinal texture.
4. The range in tire/pavement noise performance of SMA pavements is similar to that of DGAC, and both are at least loosely related to aggregate size.

Acknowledgements

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Fig. 1. Sound intensity probe mounted on right rear wheel of test vehicle

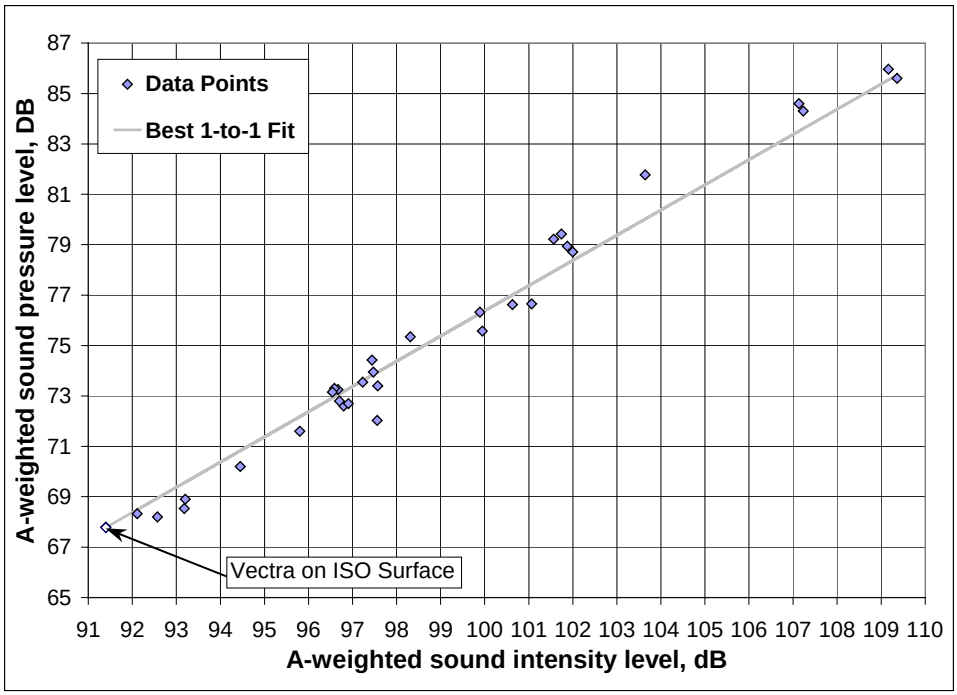

Fig. 2. Comparison of passby noise levels for cruise operation measured at 7.5 m to sound intensity for vehicle speeds of 56 to 97 km/h on 12 different pavements using 3 different tire designs with results from the Opel ISO 10844 test track surface

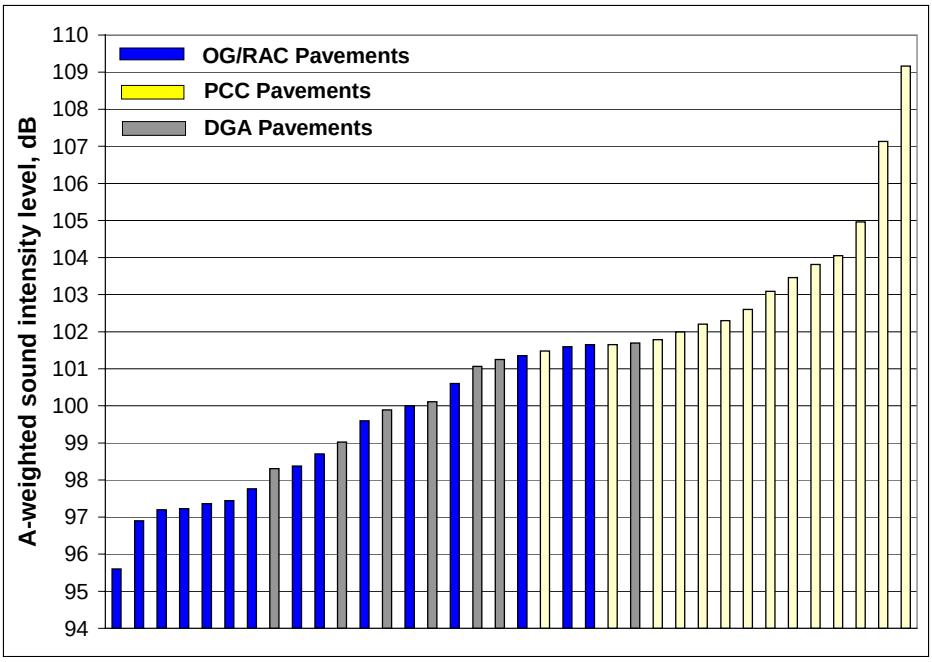

Fig. 3. Range of tire/pavement noise sound intensity levels for pavements in California and Arizona

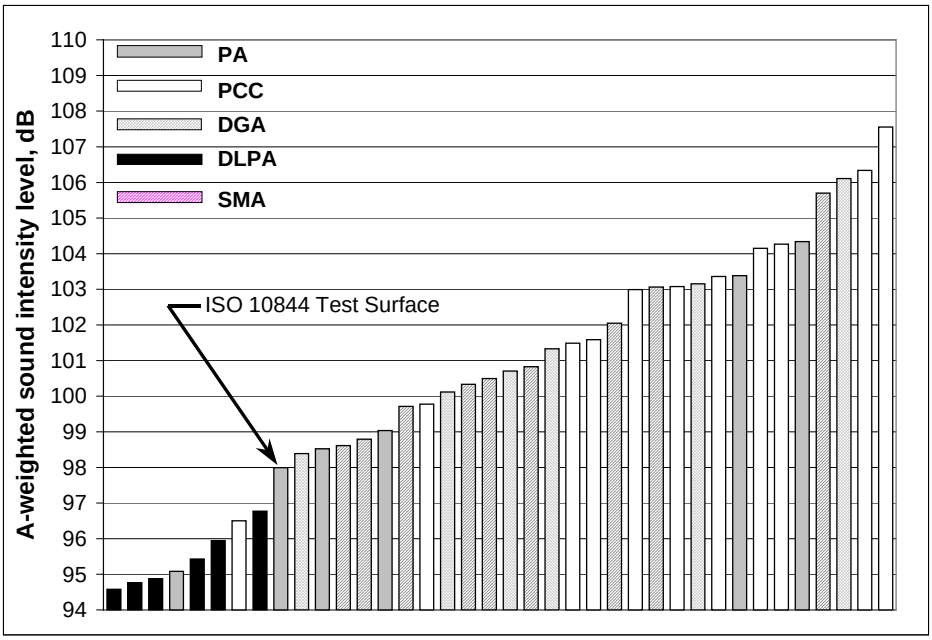

Fig. 4. Range of tire/pavement noise sound intensity levels for pavements in Europe under the NITE Project measured at 97 km/h

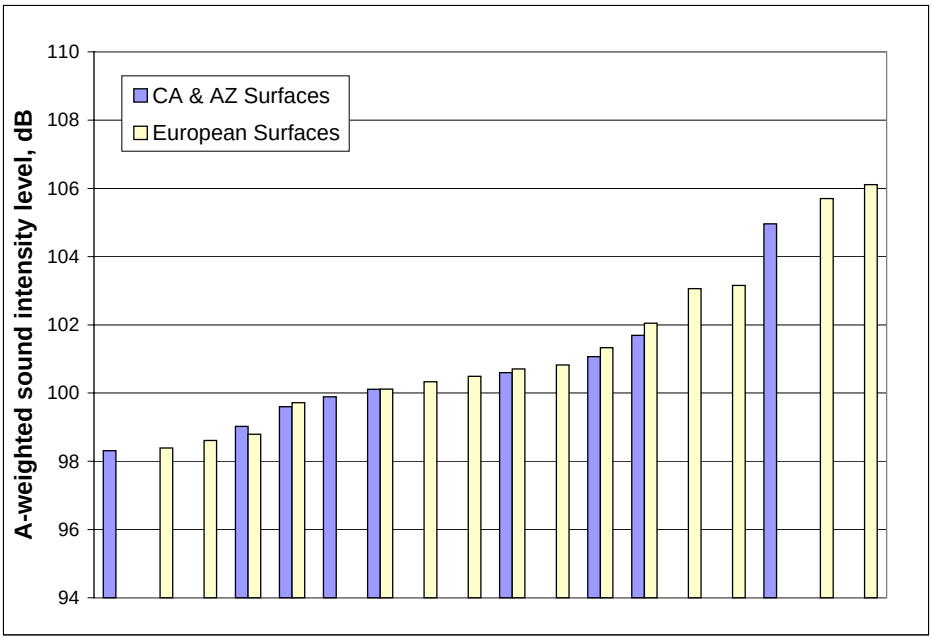

Fig. 5: Comparison of sound intensity levels for DGA and SMA pavements in California, Arizona, and Europe at 97 km/h

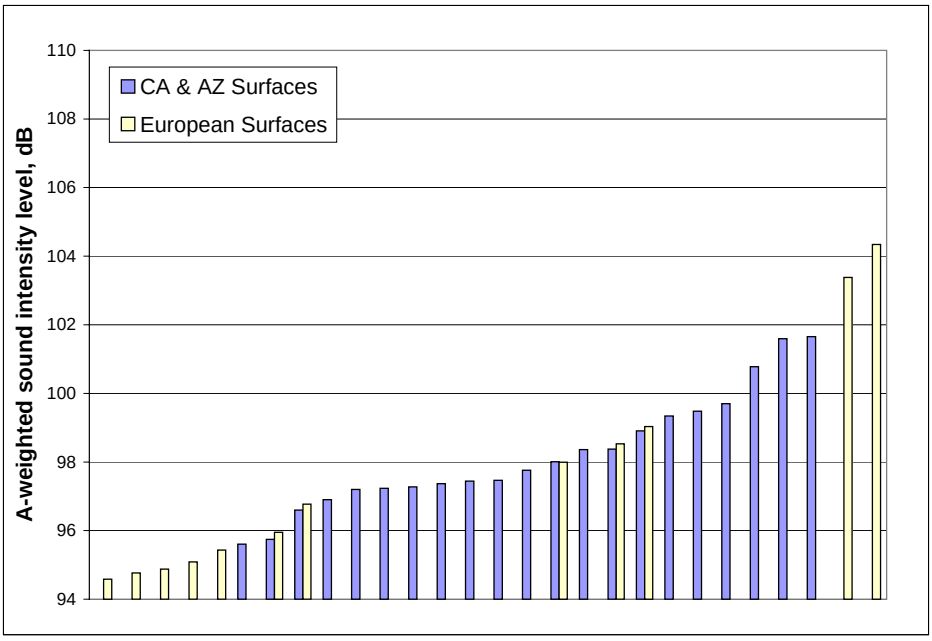

Fig. 6: Comparison of sound intensity levels for DLPA, PA, OGAC, and RAC pavements in California, Arizona, and Europe at 97 km/h

Fig. 7: Double layer porous AC construction in the Netherlands with 6 to 8 mm aggregate on top layer

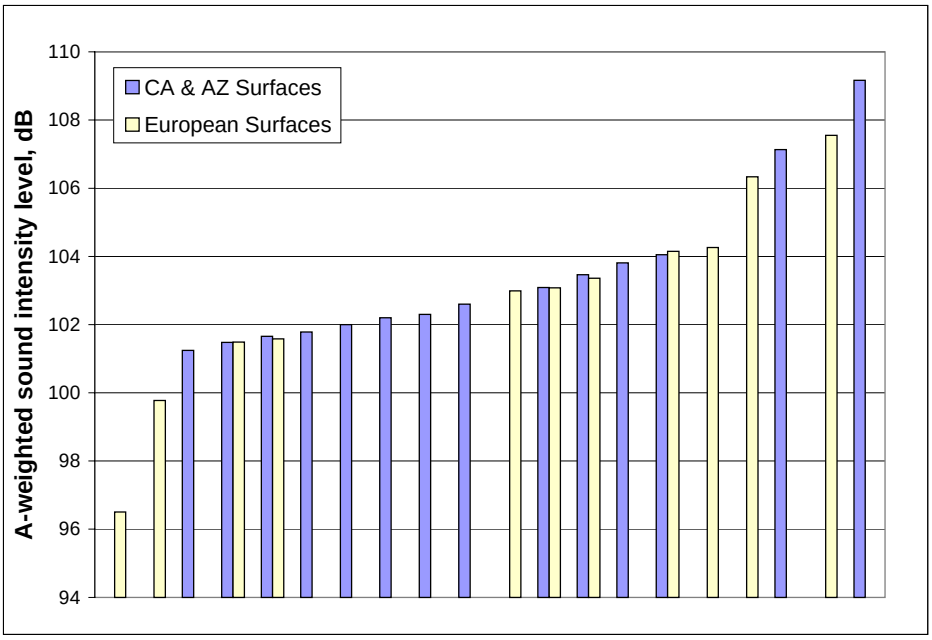

Fig. 8: Comparison of sound intensity levels for PCC pavements in California, Arizona, and Europe at 97 km/h

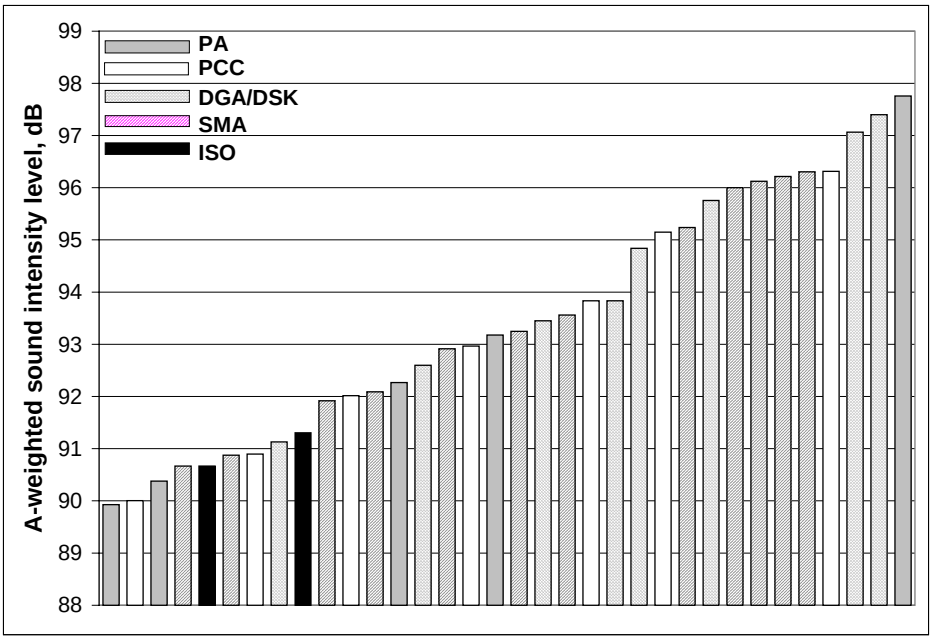

Fig. 9. Range of tire/pavement noise sound intensity levels for pavements in Europe under the NITE Project measured at 56 km/h

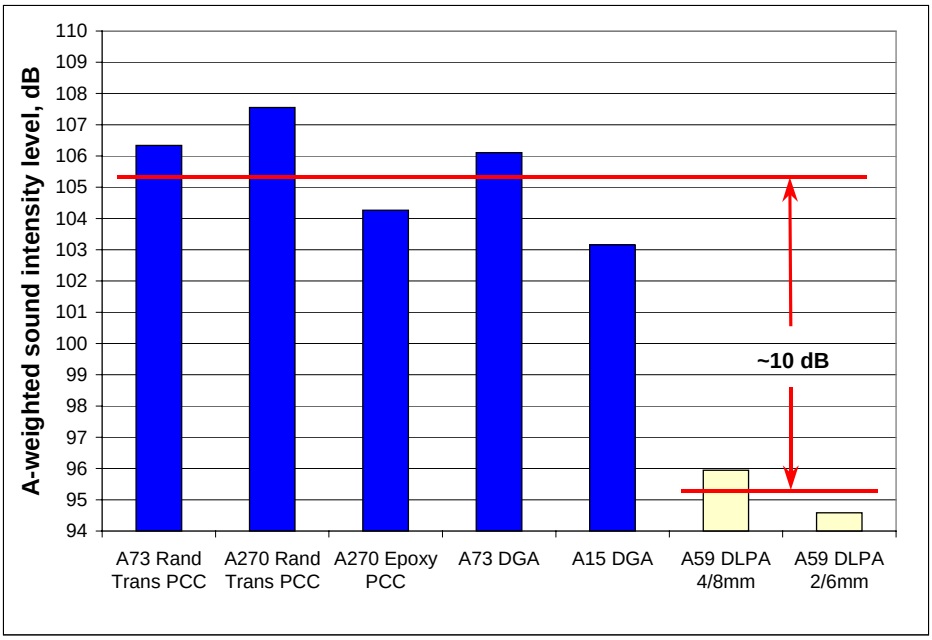

Fig. 10: Typical noisier pavements in the Netherlands compared to typical quiet pavements

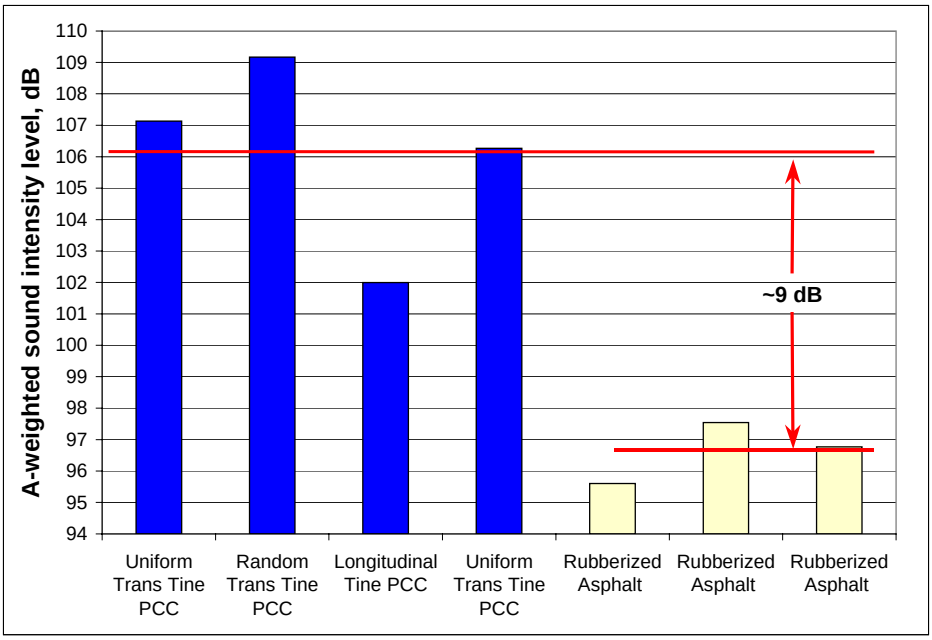

Fig. 11: Typical noisier pavements in the Arizona compared to typical quiet pavements

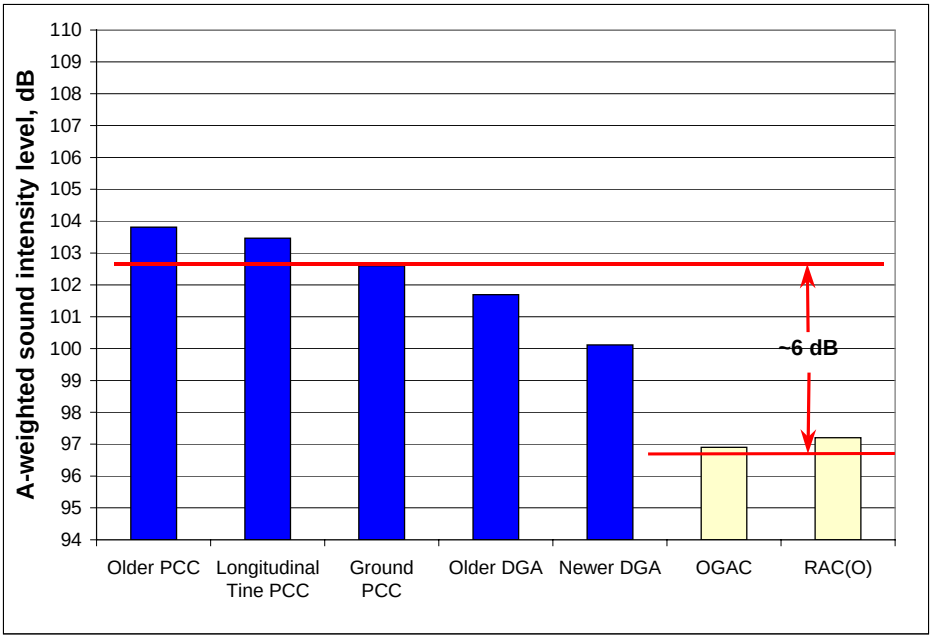

Fig. 12: Typical noisier pavements in the California compared to typical quiet pavements

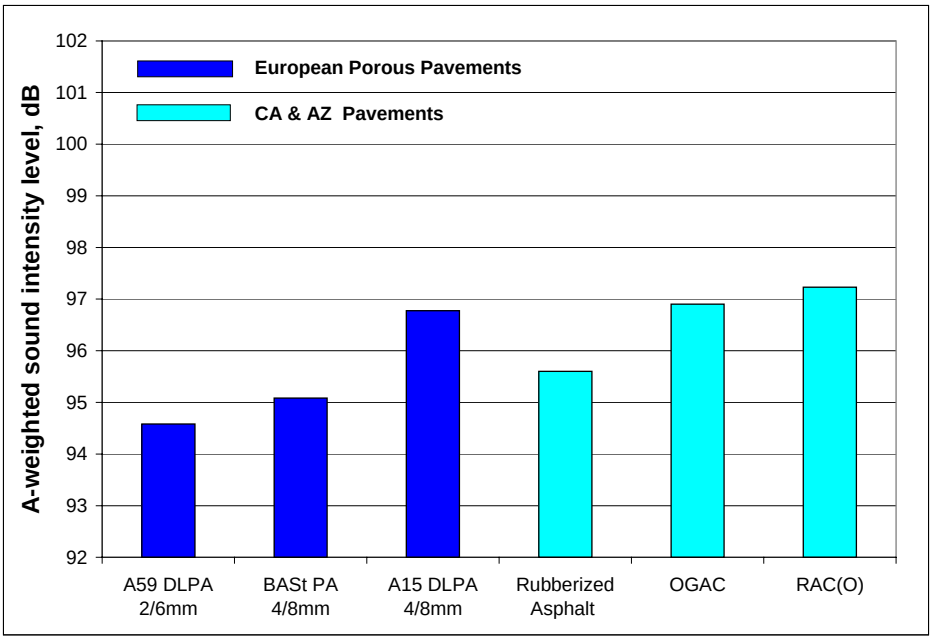

Fig. 13: Quietest pavements in Europe and California/Arizona