

THE EFFECT OF POROUS PAVEMENT ON WAYSIDE TRAFFIC NOISE LEVELS

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ABSTRACT

In 2011, pavement on an eight-lane portion of US Highway 101 in San Rafael, California was rehabilitated with the application of open-graded asphalt concrete (OGAC) overlay as part of larger project to improve traffic flow along the 101 corridor. Residents in the area of the rehabilitation have periodically complained to the local transportation agency about traffic noise. To obtain some understanding of the noise reduction expected by the new OGAC, wayside traffic noise levels and on-board sound intensity (OBSI) levels were measured at two sites: one where the new pavement was to be placed and one nearby site that had received new OGAC one year earlier. These results indicated that a reduction of 7.8 dB of OBSI tire-pavement noise should be expected along with a reduction of 7.8 dB to 8.4 dB in wayside traffic noise. Measurements were repeated after the OGAC application and OBSI reductions of 7.1 dB were found and reductions of 10.5 and 11.3 dB were found for the wayside levels measured 60 feet from the highway. From previous studies of sound propagation over porous pavements, it was concluded that this additional reduction in the wayside levels by 3.4 and 4.1 dB compared to the tire-pavement source levels was due to the sound absorption provided by the porous pavement. The results of this investigation are presented in this paper.

INTRODUCTION

In conjunction with the Marin-Sonoma Narrows Project, a portion of US Highway 101 was rehabilitated with the addition of a new overlay of Open Graded Asphalt Concrete (OGAC) over an existing Dense Graded Asphalt Concrete (DGAC) pavement in 2011. This section of US 101 lies just north of the recently completed Highway 101 Gap Closure Project ending at North San Pedro Road¹ in San Rafael and extends to the new high occupancy vehicle (HOV) lanes on US 101 for 8 miles further north. In the highway immediately north of the Gap Closure Project, HOV lanes with the older pavement already existed and the highway was not modified other than the addition of the new pavement. Under these conditions, this section of US 101 could not be considered for new noise abatement in the form of barriers under Federal Highway Administration (FHWA) and Caltrans highway noise polices. However, in the Gap Closure project, reductions in traffic noise level were documented and found to result primarily from the new OGAC pavement that was used throughout the project¹. This same pavement was to be used for the pavement rehabilitation and it was expected that the traffic noise levels along the rehabilitation corridor would also be reduced with the new pavement. In order to initially predict and later verify the noise reduction produced by the pavement rehabilitation, a program of noise measurements prior to and after the completion of the project was conducted and is documented in this paper.

MEASUREMENT PROGRAM

Measurement Description

Prior to the OGAC pavement overlay, attended wayside noise measurements were made at two locations, Site A which was within the rehabilitation project area about 2,000 ft north of North San Pedro Road, and Site B which was located at the north end the Gap Closure Project area about 1,500 ft south of North San Pedro Road in an area absent of noise walls. Both sites are shown in Figure 1. At the time of the measurements, the pre-rehabilitation pavement at Site A appeared to be older dense graded asphalt while Site B was newer OGAC that was part of the Gap Closure Project¹. These sites were selected due to their close proximity and absence of substantial obstruction to the highway. The intent of these measurements was not to perform a rigorous comparison of the sites, but rather to give an indication that lower tire-pavement noise levels at Site B produced lower wayside levels relative to pre-habilitation levels at Site A. For this purpose, the traffic was assumed to be sufficiently similar between the sites such that comparisons could be made without traffic volume adjustments. The measurements were not made simultaneously, but were done midday, between 10:40 am and 12:25 pm on June 10, 2011.

For the pre-project wayside measurements, microphones at both Site A and B were 60 ft from the center of the nearest southbound lane of vehicle travel. Microphones were positioned at heights of 5 and 10 ft above the roadway surface at both sites as shown in Figure 1. The noise measurements were made using a two-channel Larson-Davis Model 3000 real time analyzer to acquire 5 minute L_{eq} one-third octave band spectra data captured simultaneously at the two microphone heights used at each location. Traffic was also video recorded at Site A in order to later determine traffic volumes by vehicle type and an estimation of average speeds. During the measurements (10:40 am to 11:35 am) at Site A, the air temperature was about 67 to 70°F while it was about 70 to 71°F for the measurements at Site B (12:10 pm to 12:25 pm) and the wind was



FIGURE 1 Microphone locations at Site A and Site B

generally calm but with some occasional speeds as great as 5 mph. With the exception of the 10 ft microphone height (instead of 12 ft), the wayside measurements followed the American Association of State Highway Officials (AASHTO) TP-99 Standard Method of Test for the Continuous-Flow Traffic Time-Integrated Method (CTIM)².

To quantify tire/pavement noise levels for pavement prior to the OGAC overlay, measurements were conducted using the on-board sound intensity (OBSI) method as standardized by AASHTO³ in the TP 76 Standard Method of Test. OBSI was measured for a standard length of 440 ft alongside of the locations of the wayside measurements at Site A and B on June 10, 2011 prior to the pavement overlay. Data was collected for the 3 outer most lanes in both the south and northbound directions. Multiple data runs were made on each lane segment and these were later averaged together to obtain a single value for each lane. In addition to the measurements at Site A and B, data were also collected along the length of the project.

After the pavement overlay, the OBSI and wayside measurements at Site A were repeated. on August 10, 2012. During the wayside measurements (10:45 am to 11:45 am), the air temperature was 74 to 78°F, 7° to 8° higher than for the pre-overlay measurements. The wind was generally calm or up to 3 mph.

MEASUREMENT RESULTS

Comparison of Sites A and B Levels Prior to Rehabilitation

Based on the findings of the noise evaluation of the Gap Closure Project just to the south of the Pavement Rehabilitation project area, it was anticipated that the wayside noise levels along the rehabilitation would also be decreased with the application of new OGAC surface¹. The overall wayside and OBSI levels measured at Site A and B are shown in Figure 2 along with those from the Gap Closure Project in which the wayside levels were measured above an existing noise wall. Comparing the results to those of Site A and B to the Gap Closure, it appears that there is potential for even more reduction in wayside noise level for locations along the rehabilitation corridor. For the OBSI tire/pavement noise source levels, the OGAC should produce slightly more reduction (7.8 dB) for the Rehabilitation Project than found for the Gap Closure Project as

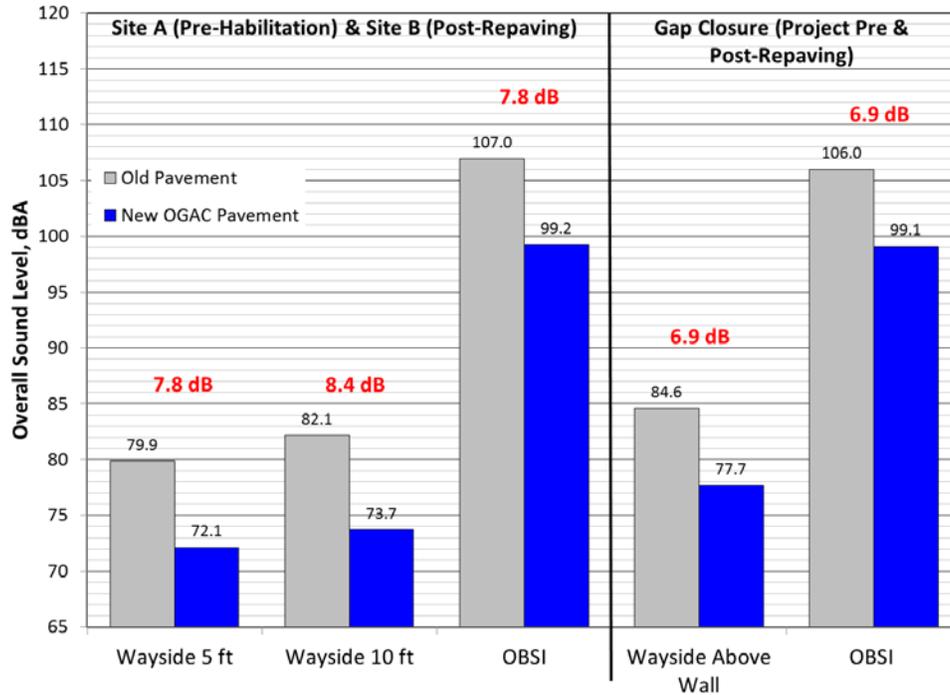


FIGURE 2 Wayside and OBSI levels at Sites A prior to rehabilitation and B after re-paving and results for the previous Gap Closure Project with noise reductions indicated (red)

the levels for existing pavement are 1 dB higher. For the wayside levels, this corresponds to a reduction of 7.8 dB to 8.4 dB compared to 6.9 dB from the Closure Project.

Comparison of Pre and Post Pavement Rehabilitation Levels

Wayside Noise Levels

The overall A-weighted wayside noise levels measured at Site A, at a distance of 60 ft away from the center of the outside lane of vehicle travel, are presented in Figure 3 for each 5-minute time block. For this comparison, the pre-rehabilitation levels have been adjusted for traffic conditions to match those of the post measurements using the Federal Highway (FHWA) Traffic Noise Model TNM®. For the one-hour measurement periods, the total volume of vehicles was greater for the post-rehabilitation measurements by about 1,500 which generated a 0.4 dB adjustment to be added to the pre-rehabilitation levels. In both cases, the traffic was composed mostly by light vehicles which accounted for 96% of the total volume for the pre measurements and 97% for the post. Averaging over the individual 5-minute L_{eq} levels produced a 10.5 dB reduction in noise with the new OGAC at the 5 ft high microphone position and a 11.2 dB reduction at the 12 ft position. These reductions are about 3 dB greater than those predicted from the 2011 measurements at Site B. The reductions due to the OGAC at 60 ft are similar to the 10 dB reduction expected from an effective barrier, although actual performance is a function of other variables including barrier height, distance from the barrier, and receiver height⁴. Figure 3 also indicates that the levels at the higher microphone position are about 2 dB higher than the 5 ft

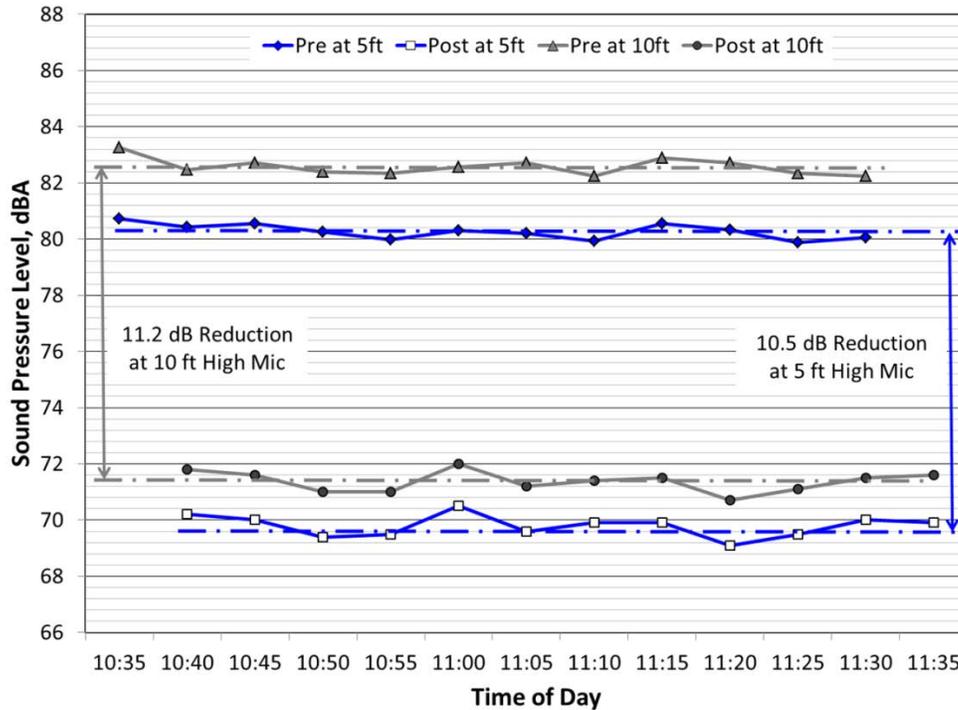


FIGURE 3 Five-minute CTIM results pre- and post-rehabilitation at Site A with average noise reductions shown for 5 and 10 ft microphone heights

position in both the pre- and post-rehabilitation measurements and the reduction is also slightly greater for the higher position consistent with other such measurements.

The 1/3 octave band spectra for both microphone heights for the pre- and post-rehabilitation conditions are shown in Figure 4. These data show that largest noise reduction occurs around

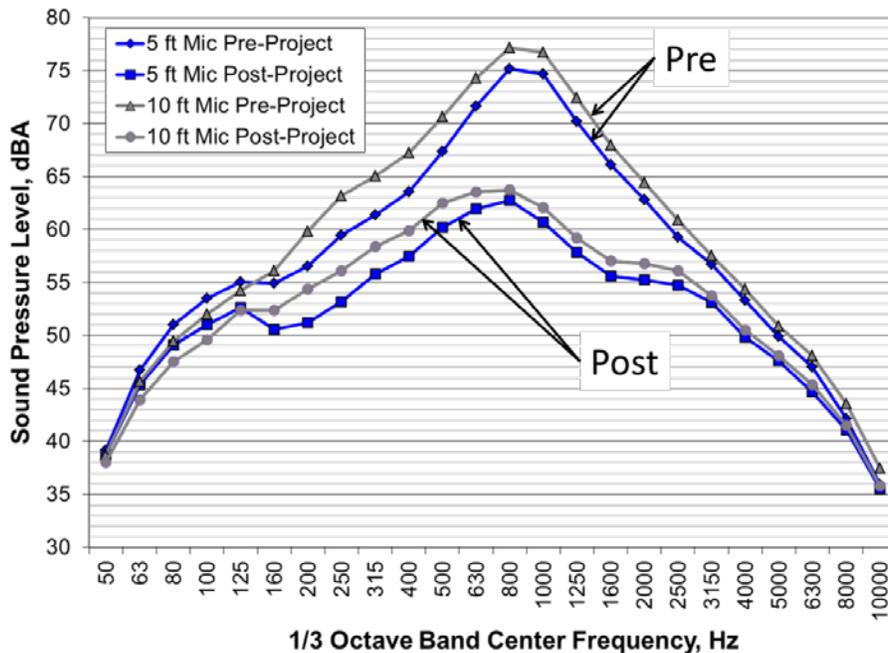


FIGURE 4 One-third octave band levels for CTIM wayside measurements pre- and post-rehabilitation at Site A

1,000 Hz for both heights with reductions of about 10 dB or more occurring in the range from 630 to 1,600 Hz. With the OGAC pavement, there is also some difference in the spectrum shape centered at 1,600 Hz. For the pre-rehabilitation DGAC, the 1/3 octave band levels drop uniformly from 1,000 Hz to 6,300 Hz while for the OGAC spectrum, there is a relative dip in the 1,600 and adjacent bands. This behavior is typical of porous, sound absorbing OGAC as demonstrated in the Caltrans long term quieter pavement research site on I-80 near Davis, CA⁵ and a rubberized OGAC test site on the SR 299 in Shasta County⁶. Figure 4 also suggests that there will be a change in the perception of the sound produced by pavement rehabilitation. Because the larger reductions are from 630 to 1,600 Hz, lower frequencies sounds will be more prevalent in the character of the sound.

OBSI Tire-Pavement Noise Levels

The overall A-weighted on-board sound intensity levels measured adjacent the wayside location are shown in Figure 5 for the three outer-most lanes of the vehicle travel in the south and

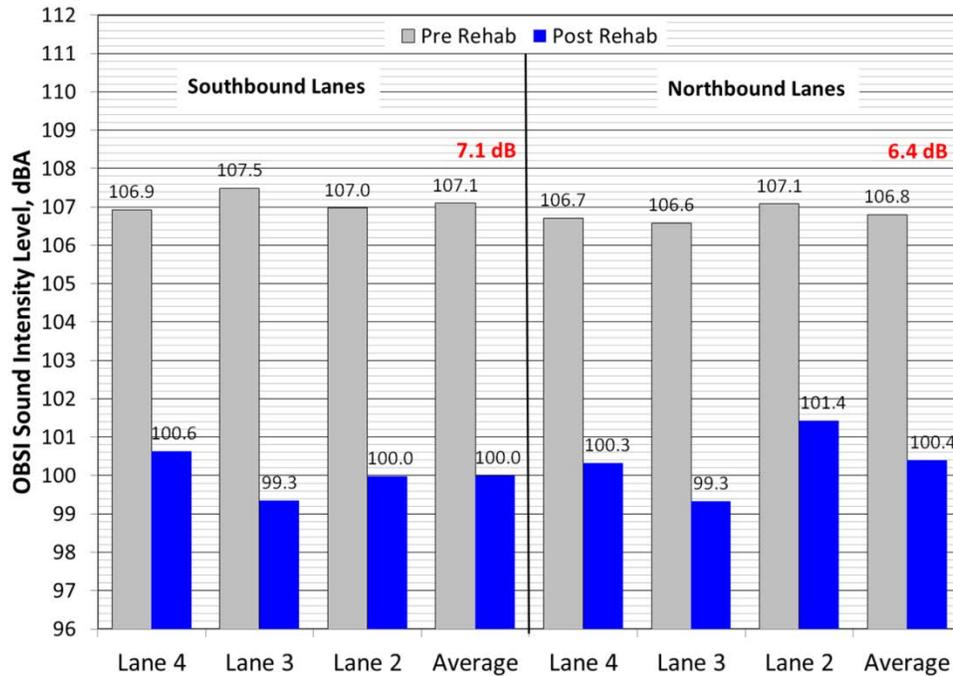


FIGURE 5 Overall pre- and post-rehabilitation OBSI levels opposite the Site A CTIM measurement location with indicated average noise reduction (red)

northbound directions. As was found in the previous the Gap Closure OBSI measurements¹, there is some variation from lane-to-lane in the levels of the new OGAC. Typically, this variation is about 1 dB, although differences of as much as 2.1 dB occurred in the northbound lanes. The variation in the old DGAC pavement is lower, more typically about 1/2 dB. The reduction for the southbound lanes closest to the wayside microphone locations is 7.1 dB while the reduction for the northbound lanes is 6.4 dB. Given the median barrier separating the two directions of travel, it is expected that tire-pavement noise from the southbound lanes would have the greater impact on determining the wayside levels. As a result, the average of the southbound lanes is used for comparison to the pre- and post-rehabilitation wayside results.

The overall CTIM and OBSI levels for the initial Site A/B comparison, the Gap Closure Project, and the rehabilitation results are shown in Figure 6. The reductions in OBSI levels

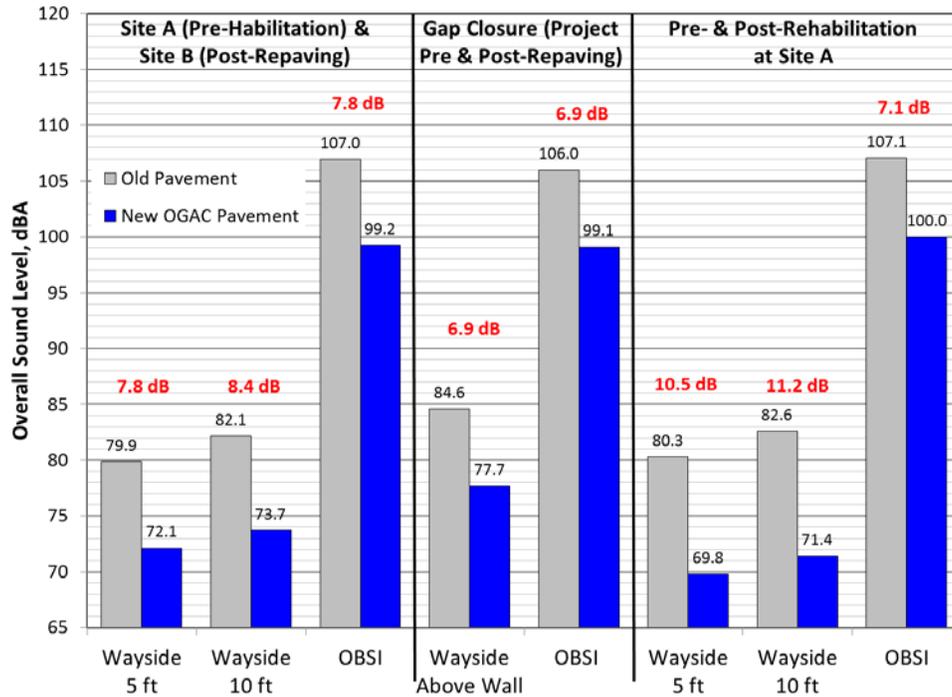


FIGURE 6 Comparison of overall wayside and OBSI levels and reductions for the pre-rehabilitation Site A/B comparison, the Gap Closure Project, and pavement rehabilitation project at Site A with noise reduction indicated (red)

measured at this site are also similar to those found in the Site A/B comparison and the Gap Closure Project with the OBSI levels of the new OGAC being about 1 dB higher than the others. For the rehabilitation project, the 7.1 dB reduction of OBSI levels is about 3 to 4 dB lower than the reductions measured with the wayside measurements. Unlike the rehabilitation results, the Site A/B comparison and the Gap Closure results for wayside noise is about the same as those for the OBSI results.

The 1/3 octave band spectra of OBSI levels for the average of the south and northbound lanes pre and post-rehabilitation are shown in Figure 7 along with the wayside results. Between 400 and 2,000 Hz, the differences between the pre and post OBSI levels are about 6 to 8 dB with the difference shrinking to about 4 dB in the higher frequencies. As noted for the wayside spectra, there is somewhat of a dip in the post-rehabilitation OBSI levels centered on the 1,600 Hz band. The difference in the noise reductions in the wayside levels and the OBSI levels is seen to be greatest in frequency bands from 800 to 1,250 Hz. In this region, the difference in the noise reductions ranges from 4.4 to 7.4 dB.

Effect of Porous Pavement

As noted previously, the shape of the 1/3 octave band noise level from the post-habilitation wayside measurement is consistent with the effects of porous, sound absorptive pavement as found in other projects. The additional attenuation of the wayside levels compared to the OBSI level is also indicative of the effect of the sound propagating over the absorptive surface^{6,7}. To

explore this further, the 1/3 octave band spectra of wayside and OBSI levels for Site B and Site A after rehabilitation are shown in Figure 8. For OBSI data, the levels at Site B are lower than

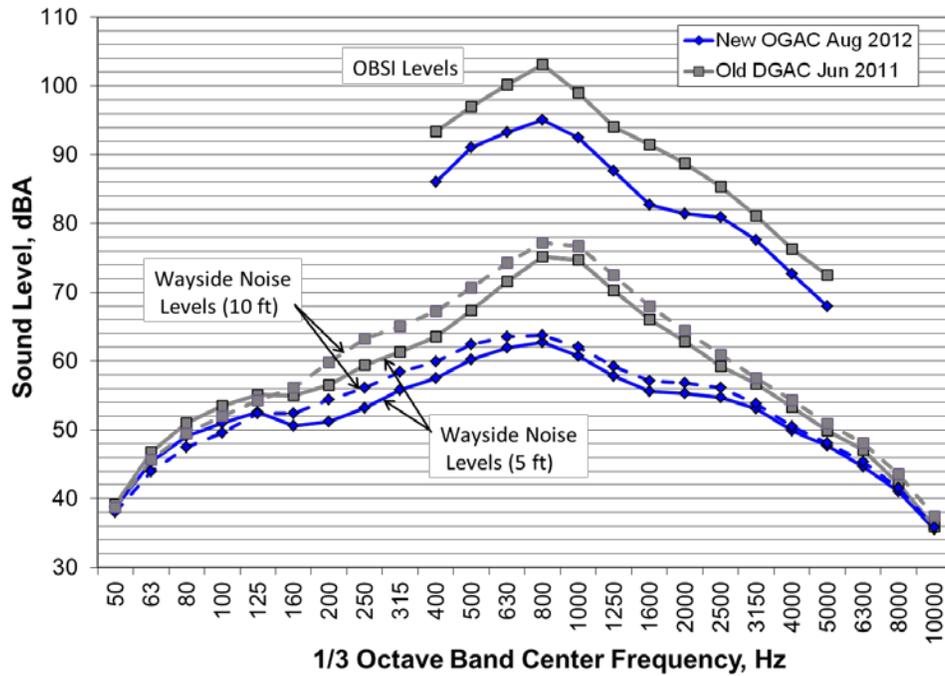


FIGURE 7 One-third octave band levels for OBSI and CTIM wayside measurements pre- and post-rehabilitation

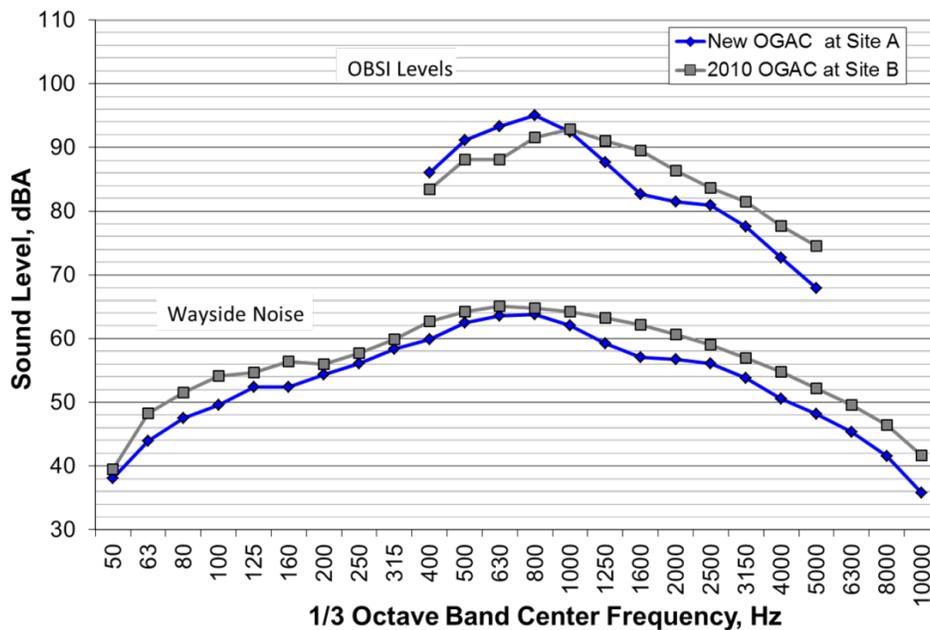


FIGURE 8 One-third octave band levels for OBSI and CTIM wayside measurements at Site B and Site A after pavement rehabilitation with OGAC

Site A below 1000 Hz contributing to the overall level of Site B being slightly lower than Site A. Above 1000 Hz, the Site A levels are consistently below those of Site B especially in the region

around 1600 Hz. From evaluations of porous and non-porous pavements conducted at the National Center for Asphalt Technology (NCAT), these differences spectral shape are indicative of the influence of pavement porosity⁸. Average OBSI levels for known porous and non-porous from these evaluations are shown in Figure 9 along with the range of percent of air voids in both data sets. The differences of these spectra are quite similar to those of Figure 8. This implies

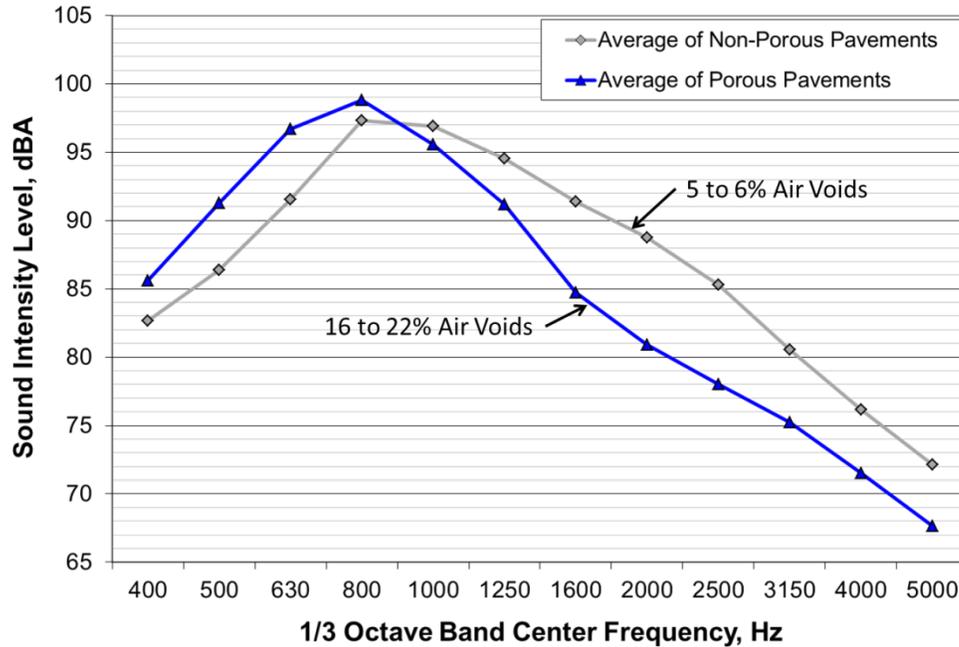


FIGURE 9 Comparison of OBSI $\frac{1}{3}$ octave band spectra for averages of porous and non-porous pavements as measured at the NCAT test track

that the OGAC at Site A is porous while the pavement at Site B is not. The effect of the porous pavement on sound propagation for tire-like loudspeaker placement was also determined in the NCAT study using the measurement method shown in Figure 10. Comparison of the difference in sound level measured at the 50 ft microphone position between the non-porous pavements and the single layer porous pavements is shown in Figure 11. Although the frequency content of the maximum additional attenuation provided by the porous pavements varies with the specific pavement, these data illustrate that additional noise reduction in the wayside noise shown in Figures 7 and 8 correspond to the influence of sound absorbing, porous pavement.

The pre- and post-rehabilitation OBSI measurements taken along the full length of the project also demonstrate variation in the occurrence of porous pavement similar to the differences shown between the Site B and post-rehabilitation Site A spectra (Figure 8). In Figure 12, OBSI levels for various 440 ft sections of pavement pre- and post-rehabilitation are shown for lane 3 in the southbound direction. The post-rehabilitation results demonstrate two behaviors; one in which the lower frequencies (630 to 1000 Hz) are elevated and levels around 1600 Hz are reduced corresponding to porous pavement and one in which the lower frequency levels are reduced, those around 1600 Hz are elevated. For OGAC pavements, increased porosity is often achieved with larger aggregate size which creates more void area in the pavement. The larger aggregate size also generates higher lower frequency noise due to increased surface roughness⁹. For the non-porous OGAC, the aggregate is smaller creating less roughness and lower frequency noise, but also resulting in less void area and porosity.

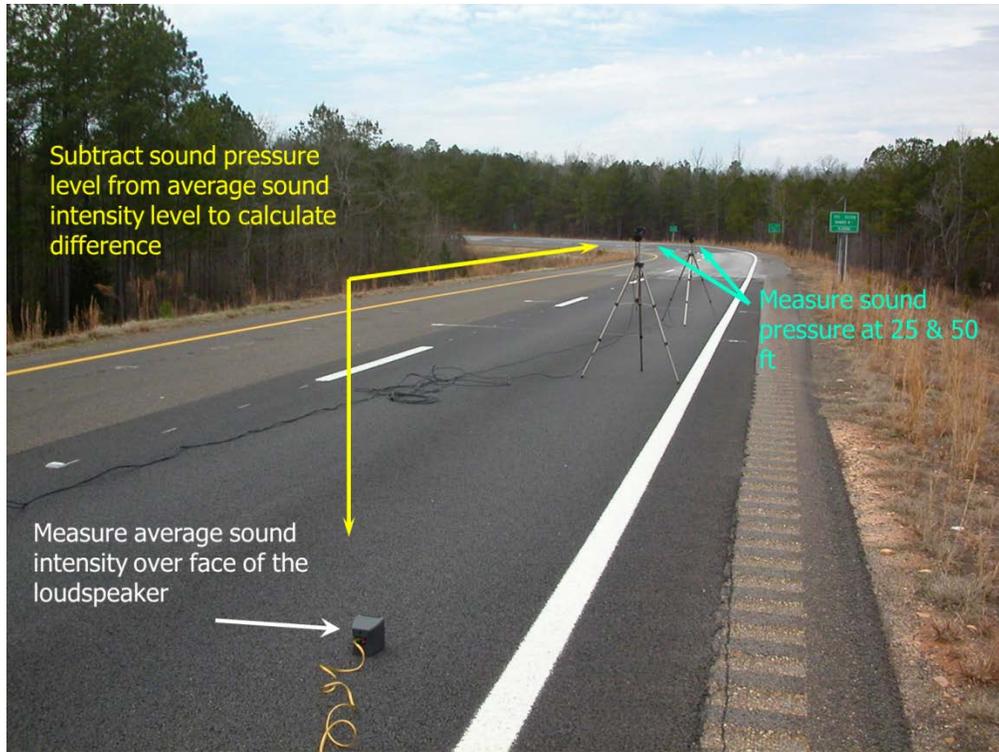


FIGURE 10 Methodology for determining the effect on sound absorption on propagation over porous and non-porous pavements

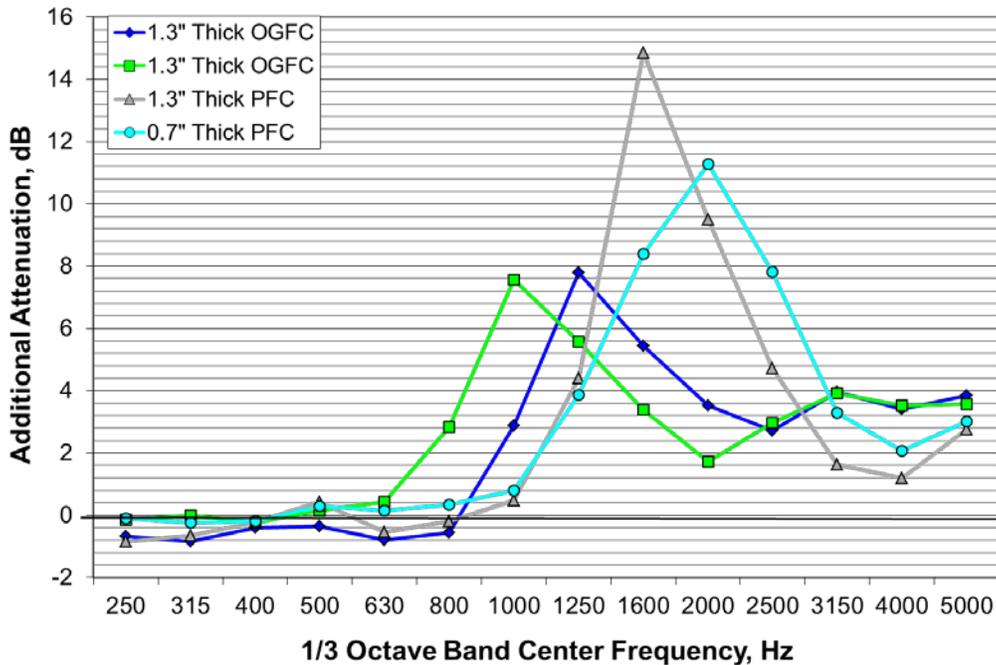


FIGURE 11 Additional sound attenuation provided by several porous pavements relative to non-porous pavements as measured at a distance of 50 ft for 5 ft microphone height

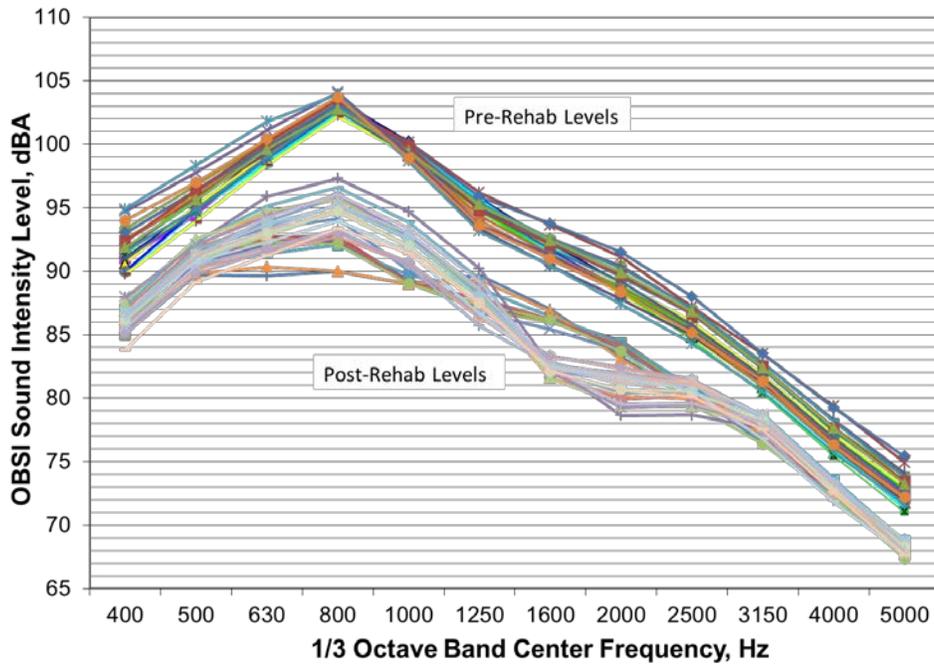


FIGURE 12 Pre- and post-rehabilitation OBSI $\frac{1}{3}$ octave band spectra for various sections over the project length in the number 3 southbound lanes

Using the results of Figure 12, an attempt to more systematically identify the occurrence of porous pavement was considered. In Figure 13, levels in the 800 and 1600 Hz $\frac{1}{3}$ octave bands are plotted against the overall level. These frequencies were selected with the intent of

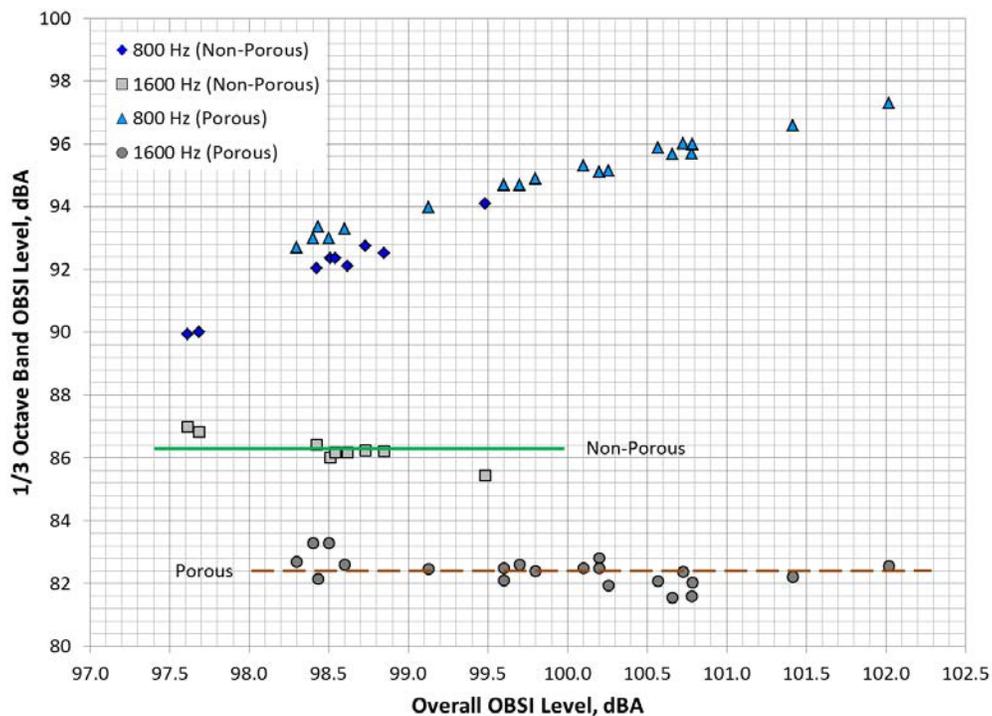


FIGURE 13 One-third octave bands OBSI levels for 800 and 1600 Hz versus overall level

identifying porosity based on higher low frequency levels with increased aggregate size and increased sound absorption as indicated by the characteristic porosity dip around 1600 Hz. For the 800 Hz, the band levels increase fairly uniformly with overall level and the behavior of the porous and non-porous pavement overlap. For the 1600 Hz, the levels are grouped in two bands separated by about 4 dB. With further development and refinement, this approach or something similar may be useful in identifying when pavements are sufficiently porous to affect wayside noise levels.

CONCLUSIONS

The application of the new OGAC pavement in the US Highway 101 Pavement Rehabilitation Project made a significant reduction in tire-pavement noise along the project corridor. Tire-pavement noise source levels were reduced by more than 7 dB consistent with the reductions documented for the US 101 Gap Closure Project in San Rafael completed in 2011. The new OGAC also produced reductions in traffic noise levels by about 10½ to 11½ dB alongside the highway as measured at a distance of 60 ft from the highway. This amount of reduction is consistent with that which would be expected by the installation of an effective noise barrier. Traffic noise levels were reduced by the lower tire-pavement noise source levels and by a reduction in the noise due to the propagation of tire-pavement noise over the new porous, sound absorbing pavement. The role of the sound absorption due to tire noise propagating over the porous OGAC pavement was found to provide an additional 3 to 4 dB reduction in the wayside noise beyond the reduction in tire-pavement noise source strength alone. Methods of incorporating this additional reduction into traffic noise prediction models should be developed along with a method(s) to rapidly identify and quantify the occurrence of porous pavements.

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