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Reduction of vehicle noise at lower speeds due to a porous open-graded asphalt pavement

Paul Donavan[1]

[1] Illingworth & Rodkin, Inc., USA

ABSTRACT

Vehicle noise measurements were made on an arterial roadway in San Rafael, California before and after a 25 mm overlay of open graded asphalt concrete (OGAC). The purpose of these measurements was to document any reduction in vehicle noise due to the overlay on a 0.8 km section of pavement prior to repaving the entire length of the roadway. The posted speed limit along this test section is 56 km/hr. Of particular concern was the reduction of noise produced by medium and heavy duty trucks accessing a quarry. To quantify the noise reduction, statistical isolated pass-by (SIP) measurements were conducted before and after the overlay along with 10-minute Leq's with traffic counts, and on-board sound intensity measurements (OBSI). The SIP measurements indicated a 9.2 dB reduction for light vehicles averaging 64 km/hr, 5.1 dB for heavy trucks under cruise/deceleration averaging 48 km/hr, and 3.1 dB for heavy trucks under acceleration averaging 42 km/hr. The hourly Leq for all vehicles was reduced by 5.0 dB. The OBSI measurements displayed reductions of 3.5 dB implying that porous nature of the OGAC was significantly influencing the measured wayside noise reduction.

Keywords: Tire Noise, Vehicle Noise, Quieter Pavement I-INCE Classification of Subjects Number(s): 11.7.1, 13.2.4, 13.2.1

1. INTRODUCTION

The Marin County Department of Public Works had received on-going complaints of traffic noise from local residences along Point San Pedro Road near the City of San Rafael, California. Of particular concern was the noise from heavy and medium duty trucks going to and from a rock quarry located at the eastern end of a primarily residential area. Trucks from quarry travel about 6.5 km along Point San Pedro Road to the closest major highway. In an attempt to reduce the noise generated by traffic, the County was considering using a quieter, porous asphalt overlay that had been used for this purpose on a freeway in the county. Prior to repaving the entire length, it was decided to apply this design to a smaller, 0.8 km section first and validate its acoustic performance. The posted speed limit along the road is 56 km/h and the effectiveness of the quieter pavement at this low speed and high truck volume was to be tested. The test section area was in the vicinity of the Dutra San Rafael Rock Quarry extending about 0.8 km mile west of the quarry entrance as shown in Figure 1. Near the quarry entrance, westbound trucks are accelerating after turning out of the quarry entrance road, and eastbound trucks are either cruising or beginning to decelerate as they approach the entrance.

Under conditions of low speed cruise, deceleration, and acceleration, it is typically considered that a quieter pavement will have very limited effect on heavy vehicle noise emissions. The US Federal Highway administration data base of vehicle noise emissions indicates that at speeds of 56 km/h and less, the noise from heavy trucks is dominated by sources other than tire-pavement noise (1). Further at 56 km/h, the average difference between loudest pavement type, portland cement concrete, and quietest OGAC is 1.6 dB for heavy trucks, 2.1 dB for medium trucks, and 4.5 dB for light vehicles under cruise conditions. Experiences in Denmark with thin porous layers are also not encouraging, as reductions of just 2.9 dB at 60 km/h for light vehicles (2) and 1.2 dB at 56 km/h for heavy trucks (3) have been reported comparing the levels to a reference density graded reference asphalt to thin porous layers. More encouraging results were obtained from previous pavement rehabilitation on a major arterial in the City of San Rafael with a posted speed of 56 km/h. In that case, an improvement of 5 dB in hourly Leq was achieved when an older dense graded asphalt pavement was replaced by quieter

[1] pdonavan@illingworthrodkin.com

Figure 1 - Aerial view of project area with pavement limits indicated and wayside noise measurement locations noted

rubberized asphalt (4). However, the traffic contained only about 1% heavy trucks and 2% medium trucks.

2. Description of the Measurements

Several types of measurements were made to evaluate the before and after noise performance of the new pavement on Point San Pedro Road. To directly evaluate the noise reduction in the tire-pavement noise source strength, sound intensity measurements were made on-board a vehicle, very close to a test tire as shown in Figure 2. This measurement technique is standardized by the American Association

Figure 2 - On-Board Sound Intensity fixture mounted on test vehicle

of State Highway and Transportation Officials as AASHTO procedure TP 76, Standard Method of Test for Measurement of Tire/Pavement Noise Using the On-Board Sound Intensity (OBSI) Method. The OBSI measurements were conducted for a vehicle speed of 56 km/h

A second type of measurement utilized a microphone positioned 7.5 m from the center of the westbound lane of travel as shown in Figure 3. The output from this microphone was captured with a

Figure 3 - Pass-by microphone located a site along Point San Pedro Road 7.5 m from the center of the near, westbound lane of travel

real-time analyzer that measured sound pressure level as individual, isolated vehicles passed by. From the level versus time data, the maximum pass-by level for each vehicle was determined. Vehicle speed was measured with a radar gun so that the maximum sound level as a function of speed could be determined and later plotted. This procedure is also standardized by AASHTO as the Standard Method of Test for Determining the Influence of Road Surfaces on Vehicle Noise Using the Statistical Isolated Pass-By (SIP) Method, TP 98. This procedure differs only slightly from ISO Statistically Pass-By (SPB) procedure. Vehicles were divided into three groups for this testing: light vehicles (passenger cars and light trucks), medium trucks, and heavy trucks. Pass-bys for individual vehicles traveling the eastbound direction were also measured with the same microphone and analyzer but for a distance of 11.3 m from the center of the lane of travel.

Attended, short-term traffic noise levels were also measured using a sound level meter positioned away from the pass-by location as shown in site diagram of Figure 1. For these measurements, noise levels from all vehicles were captured in 10 minute intervals. Counts of light vehicles and trucks were also made so that before and after data could be compared for similar traffic conditions.

On October 24 and 25, 2013, the measurements prior to the new pavement were made along a two lane portion of Point San Pedro Road (see Figure 1). The pass-by and traffic noise measurements were made from 8:00 to 11:00 on both days with little to no wind and temperatures from about 12 to 15ºC. Over two days of measurements, valid pass-by data were obtained for 58 heavy trucks traveling in the eastbound direction and 84 in the westbound direction. All of the trucks were going to or coming from the quarry entrance. Those coming from the quarry going in the westbound direction were typically accelerating while those approaching the quarry in the eastbound direction were either cruising or decelerating. The light vehicle pass-bys numbered 81 in the eastbound direction and 127 westbound. The light vehicles were typically cruising at constant speed. The numbers of medium trucks were fewer, 11 eastbound and 16 westbound with some trucks not related to the quarry. The OBSI measurements were made after the completion of the pass-by and traffic noise measurements on October 24th.

The OBSI measurements after the new pavement were made on January 31, 2014 when the temperature was 14ºC. The pass-by and traffic noise measurements were made on February 25, 2014 from 9:00 am to 14:00 under the same temperature conditions as the October 2013 measurements but with winds occasionally up to 2 to 4 m/sec. For this period, 41 heavy truck pass-bys were measured in the eastbound direction and 40 westbound. The light vehicles numbered 72 eastbound and 127 westbound. For medium trucks, 5 eastbound and 7 westbound pass-by events were measured.

The old and new pavements are shown Figure 4. The old pavement appears to be dense graded asphalt with larger aggregate, considerable positive texture, and little surface void area. The new pavement is open graded asphalt with a maximum aggregate size of 9.5 mm (⅜ in), primarily negative texture and some void area. The pavement design is the same as that used in a recent pavement rehabilitation project on Highway US 101 in Marin County, except that the 101 pavement had a maximum aggregate size of 12.7 mm (½ in). This pavement was found to produce a 10 to 11 dB reduction in wayside traffic noise levels as measured 15 m from the center of the near lane of travel of the eight lane freeway, with speeds from 88 to 100 km/h and about 6% heavy trucks and 1% medium trucks. A portion of the reduction was due to the porosity of the pavement (5). Porosity generally reduces the strength of the tire-pavement noise source and also reduces the wayside noise through sound absorption as it propagates over the pavement surface (6).

Figure 4 - Photograph of old dense grade asphalt (left) and new open-graded asphalt (right)

3. Measurement Results

The 10-minute Leq traffic noise levels measured before and after the pavement overlay are shown in Figure 5. On October 24th and 25th, the pre-overlay 10-minute levels are fairly consistent day-to-day. On February 25th, more variation is apparent in the results; however, in general the levels are lower. The lower levels on February 25th are in part due to lower truck volumes on that day compared to the pre-overlay measurement days. On an hourly basis, the number of trucks averaged 38 for the pre measurements and 25 for the post. Light vehicle counts were similar with 213 for the pre measurements and 199 for the post. To make a more valid comparison, 10-minute intervals from the pre- and post-measurements were considered for those intervals in which the number of trucks was the same. Averaging over difference in level for these 10-minute intervals, the reduction in traffic noise was found to be 5.0 dB.

The maximum pass-by levels for light vehicles are plotted in Figures 6 and 7 for westbound and eastbound directions (respectively) before and after the overlay as a function of vehicle speed. These data fall into very distinct groups of pre and post overlay results; although, there is scatter in the data, as is typically expected. Under the SIP procedure, the pre and post data points are fit with a logarithmic curve. The difference in level defined by these curves at the average vehicle speed is then used as the reported value. For westbound direction (nearest the microphone), the difference at the average speed of 63 km/h is 9.5 dB. For the eastbound direction, the difference was 8.9 dB at an average speed of 64 km/h.

The maximum pass-by levels for heavy trucks are shown in Figures 8 and 9 for the two directions of travel. In the westbound direction (Figure 8), the trucks are typically accelerating away from the entrance of the quarry and still at lower speed. Although there is some overlap in these data, the post overlay results are typically lower than the pre-overlay. Fitting curves to these data yields an average difference of 3.1 dB at the average speed of 42 km/h. Although this reduction is smaller than that for light vehicles, it is larger than what would be typically expected for accelerating trucks at low speed

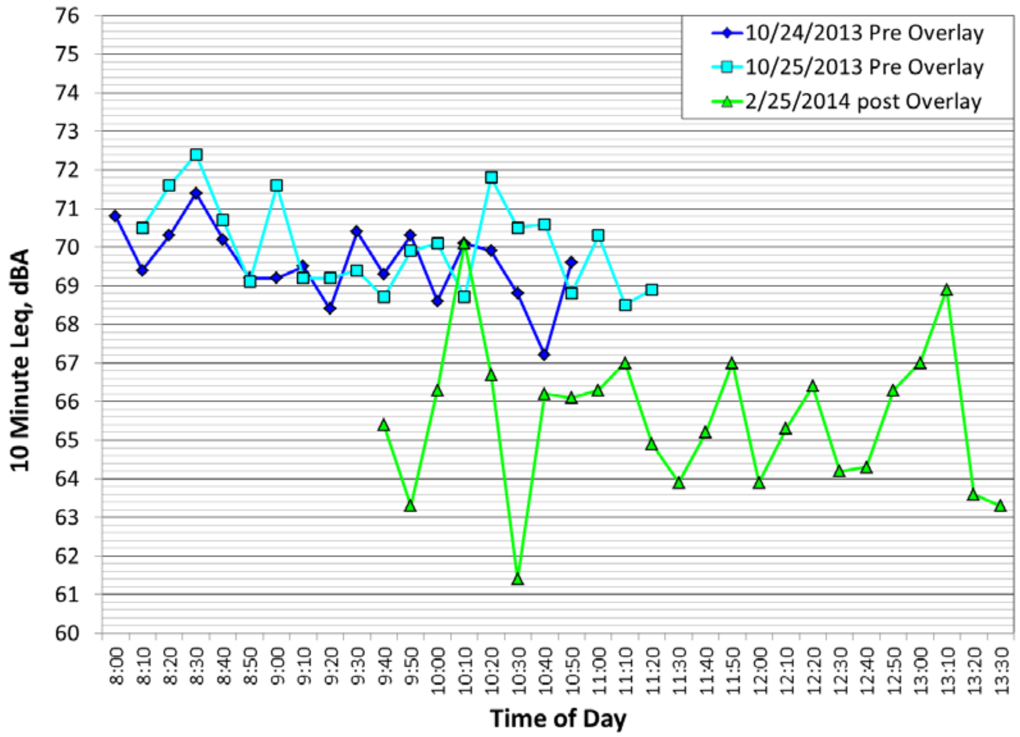

Figure 5: Comparison of 10-minute Leq levels before and after the pavement overlay

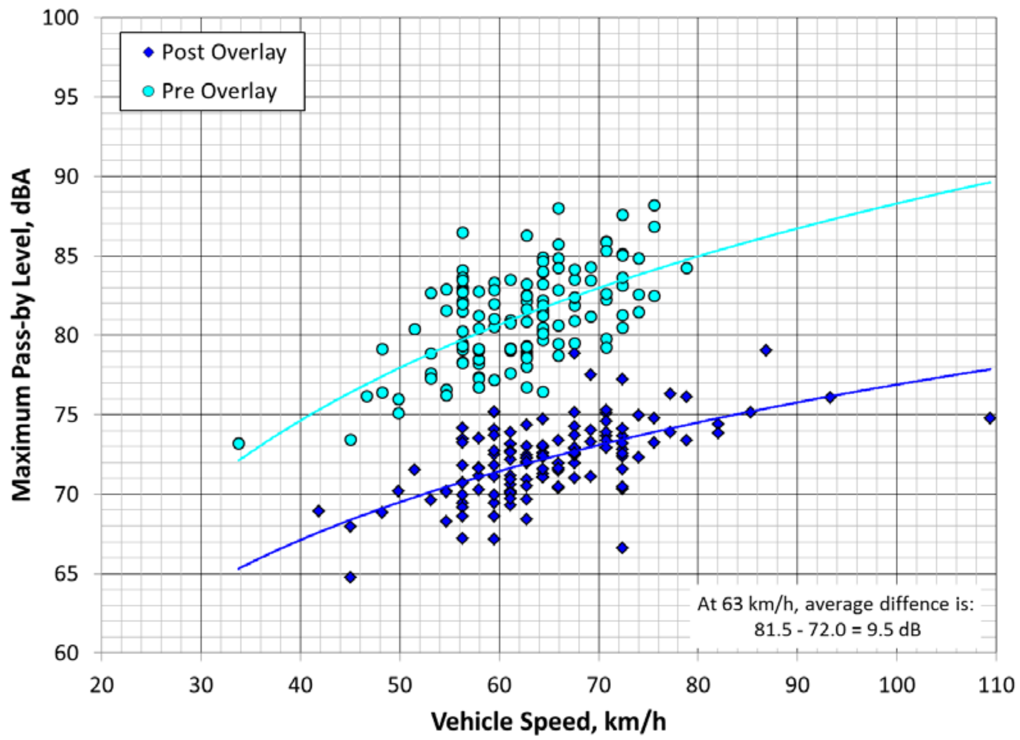

Figure 6: Pass-by results for light vehicles in the westbound direction measured at 7.5 m

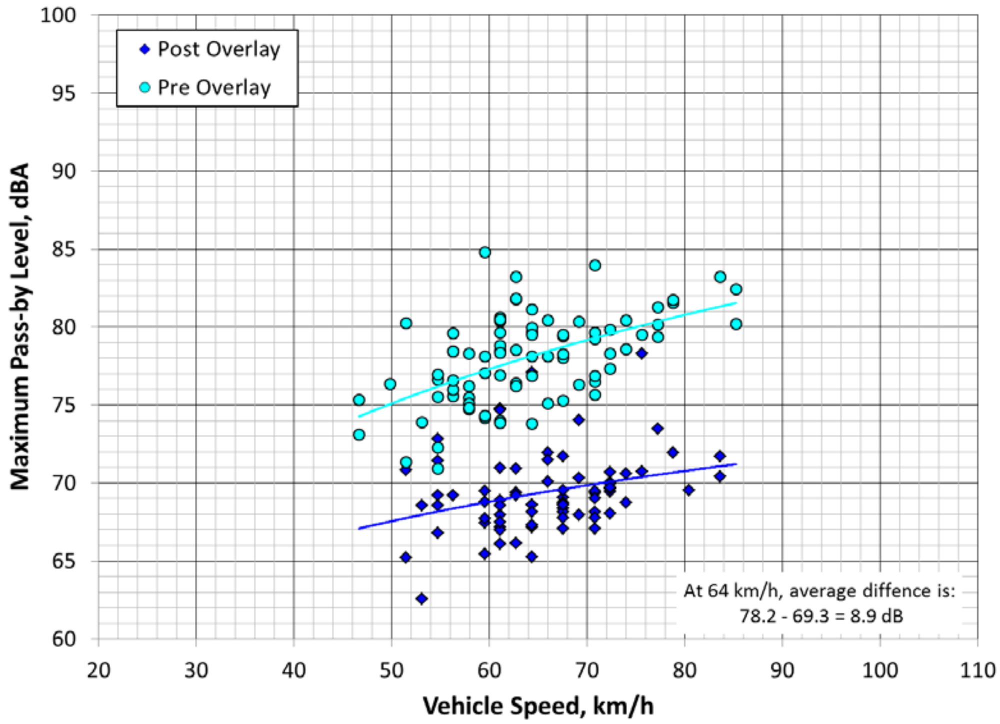

Figure 7: Pass-by results for light vehicles in the eastbound direction measured at 11.3 m

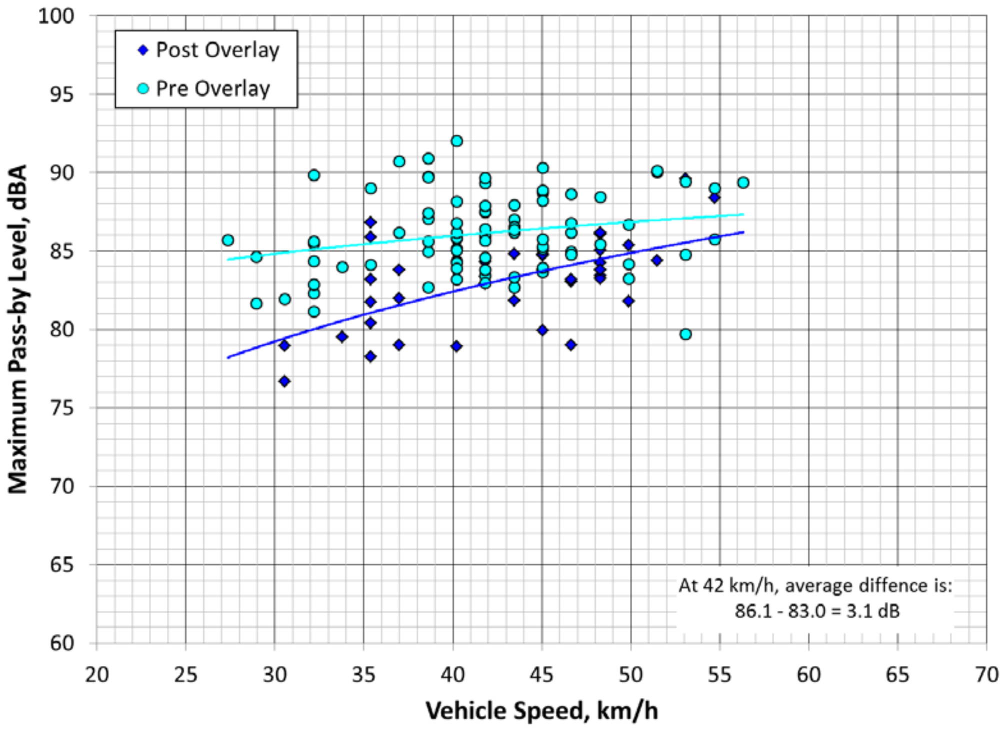

Figure 8: Pass-by results for heavy trucks in the westbound direction measured at 7.5 m

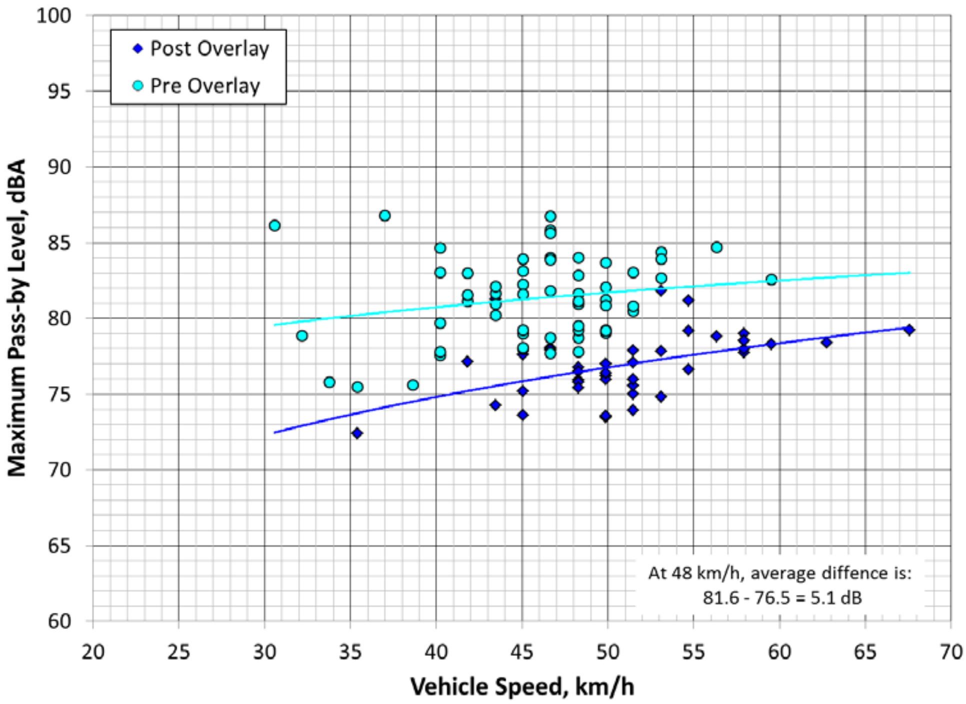

Figure 9: Pass-by results for heavy trucks in the eastbound direction measured at 11.3 m

during which engine and exhaust noise are thought to be the major sources of noise (1). With the overlay, the levels are also about 4 dB lower than the REMELS data base for average pavement at 42 km/h for accelerating trucks. Before the overlay, the levels were almost equal to the REMELS value. For the trucks in the eastbound direction under cruise or decelerating conditions (Figure 9), in which powertrain related noise sources are not so dominant compared to tire-pavement noise, the reduction at the average speed of 48 km/h is even greater with a difference of 5.1 dB. Compared to the REMELS data base for cruise conditions, the overlay was about 4 dB quieter while the pre overlay levels were about 1 dB noisier.

The pass-by results for medium trucks are shown in Figure 10 and 11 for the westbound and eastbound directions, respectively. For the westbound direction (Figure 10), the results coalesce into two groupings for the pre and post overlay cases; although, the data is limited. At the average speed of 51 km/h, the reduction is 5.1 dB in the westbound direction. For the eastbound case, there are fewer data points and the scatter is greater. However, the 5.2 dB reduction determined at 55 km/h was virtually the same as the westbound direction. Compared in the REMELS data base levels for medium trucks, the levels for average pavement fall in between the higher pre-overlay levels and the lower post-overlay levels.

The average reduction of tire-pavement source noise levels was 3.5 dB on an overall A-weighted basis. This is less than may be expected in comparison to the traffic Leq and cruise pass-by reductions. In examining the results shown in Figure 12, the spectral reduction is generally greater than what the overall reduction indicates. In every band except 630 Hz, the reductions averaged 6 dB with a maximum difference of 8.2 dB. For most pavements, one-to-one relationship exists between OBSI reductions and light vehicle pass-by reductions. The exceptions to this are cases where the pavement is porous (7). In these cases, pass-by and wayside sound levels are reduced further than that due to the reduction in tire-pavement source strength because of losses during propagation over an absorptive surface. For the pavement rehabilitation on US 101, this effect was found to produce an additional reduction of 3 to 4 dB[5].

An average of the ⅓ octave band spectra for light vehicle pass-by events at a speed of 64 km/h are shown in Figure 13 for the pre- and post-overlay conditions, along with the similar results from the OBSI measurements. The spectral characteristics of the pre and post measurements for the two data types are somewhat similar, except the differences are greater as measured with the pass-by data. Both data types also have a relative “dip” in level in the 1600, 2000, and 2500 Hz bands which is

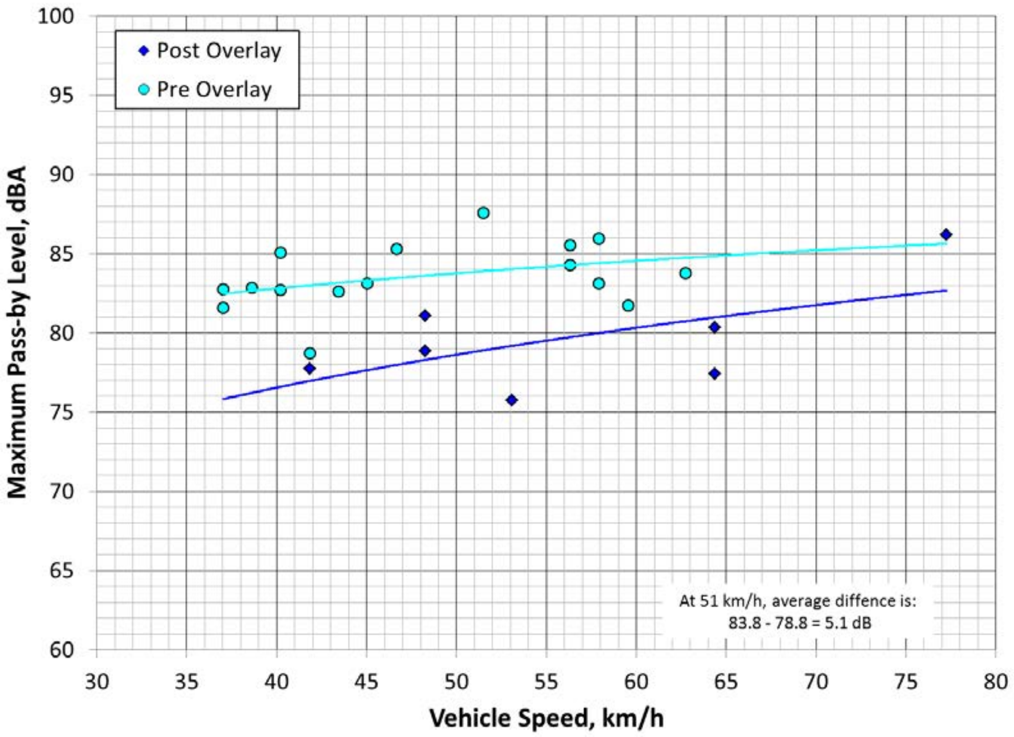

Figure 10 - Pass-by results for medium trucks in the westbound direction measured at 7.5 m

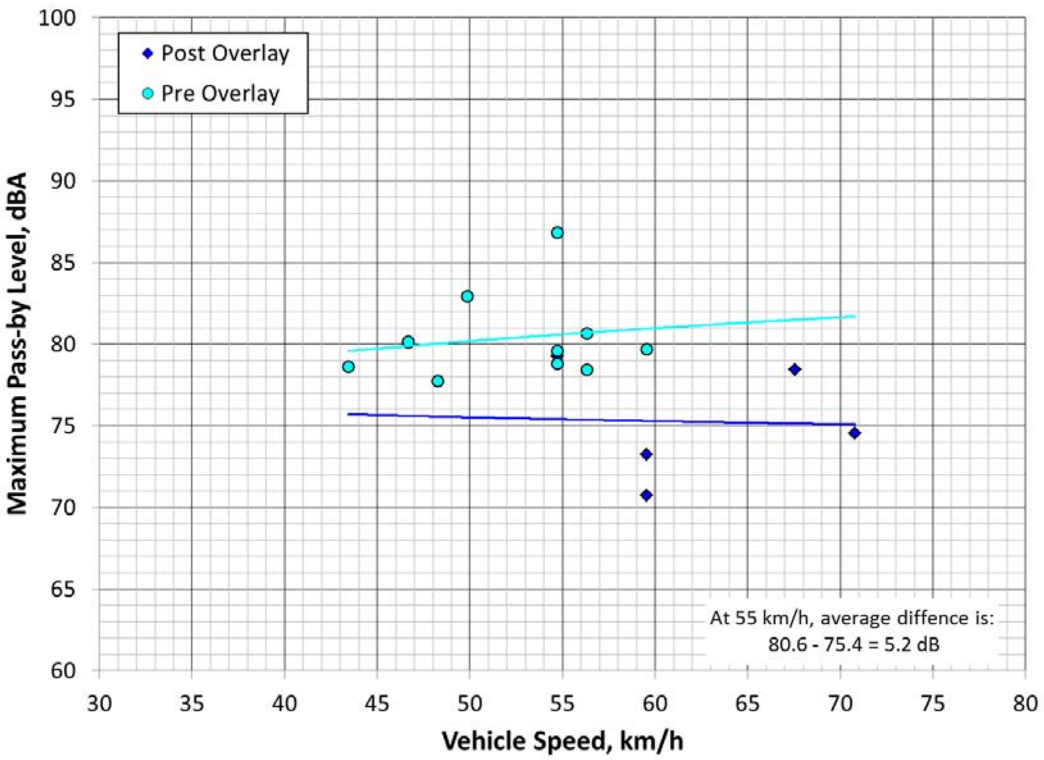

Figure 11 - Pass-by results for medium trucks in the eastbound direction measured at 11.3 m

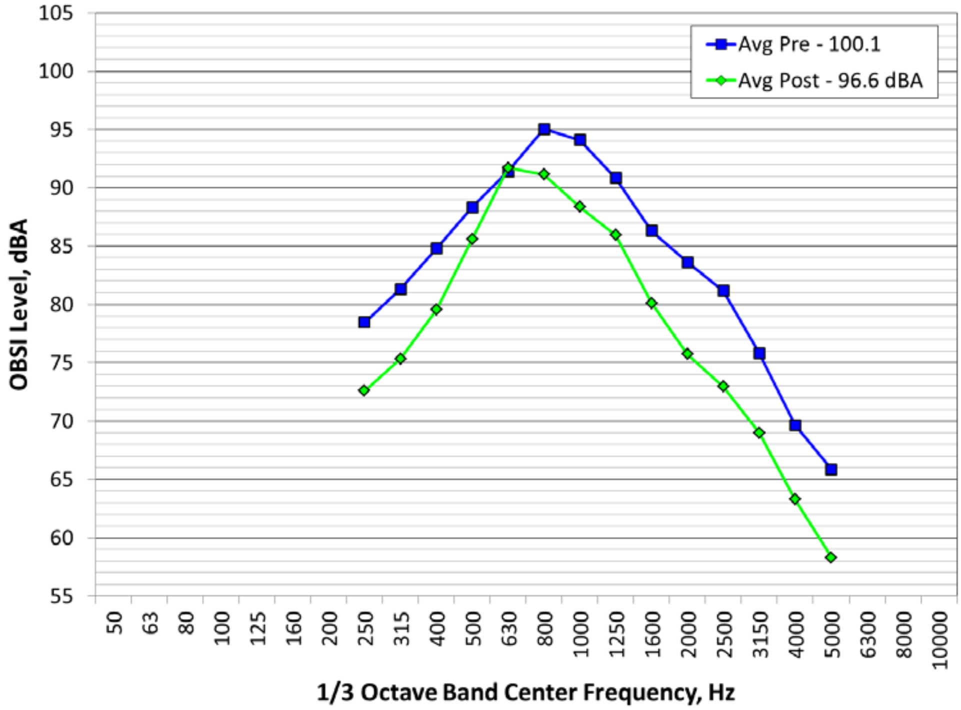

Figure 12: ⅓ Octave band OBSI levels pre and post pavement overlay

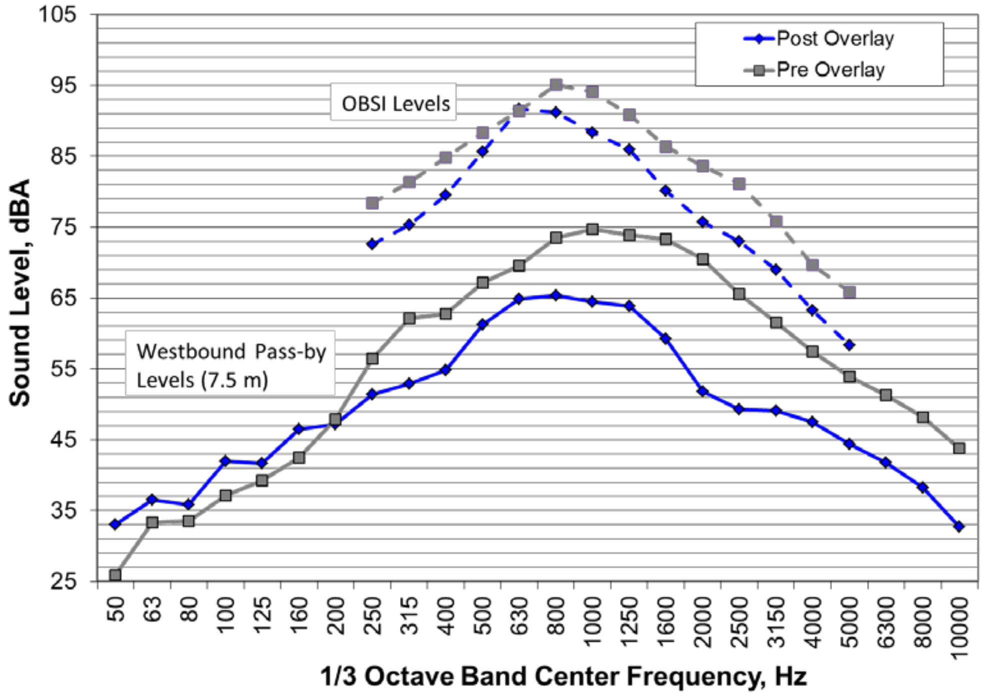

Figure 13: Light vehicle pass-by spectra at 64 km/h westbound with OBSI spectra

characteristic of porous, absorptive pavements (5). Pass-by spectra for the eastbound direction, along with the OBSI results, are shown in Figure 14, giving results similar to the westbound direction.

Average ⅓ octave band pass-by spectra for heavy trucks accelerating away from the quarry at 42 km/h are shown in Figure 15 along, with the OBSI results. For the trucks operating in this condition, the reductions occur in the bands from 800 to 10,000 Hz. In the higher frequencies, the reduction in

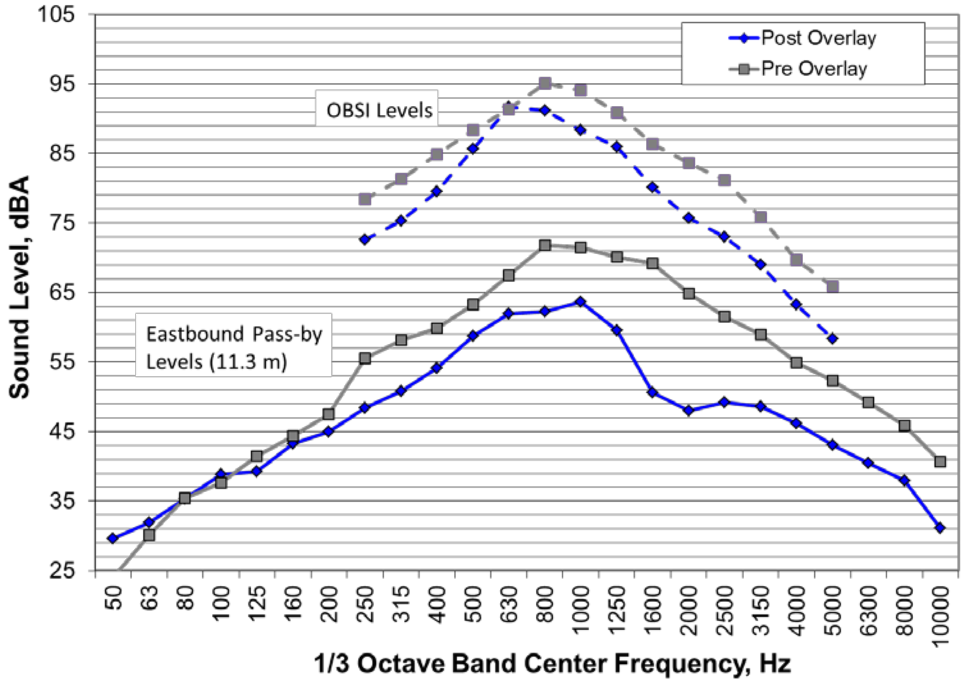

Figure 14: Light vehicle pass-by spectra at 64 km/h eastbound with OBSI spectra

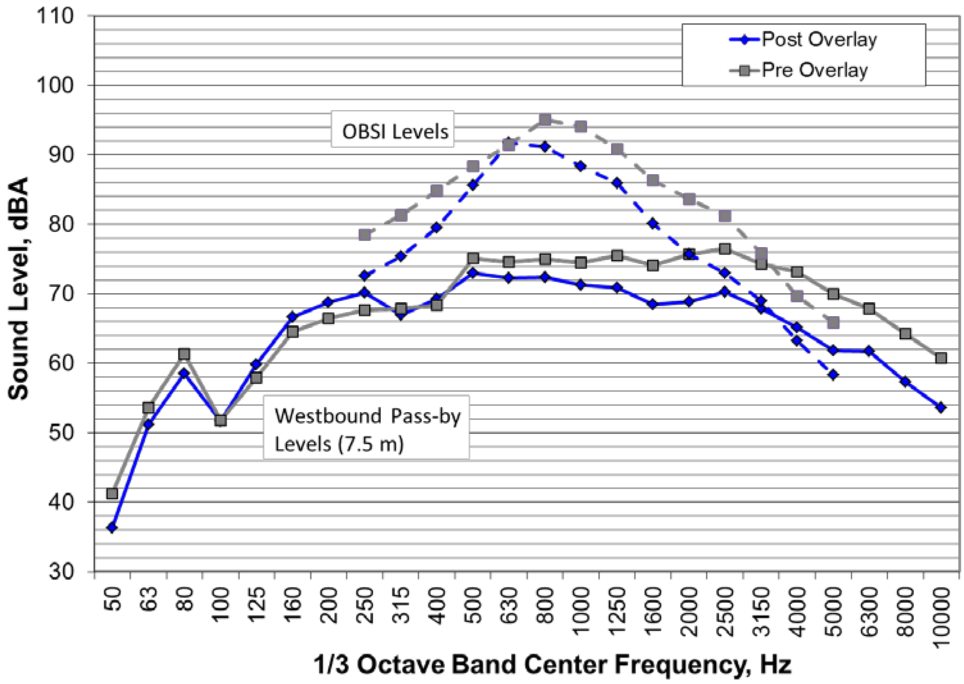

Figure 15: Heavy truck pass-by spectra at 42 km/h westbound with OBSI spectra

pass-by level are similar to the OBSI reduction while in the bands below 800 Hz, there is little difference produced by the pavement. These lower frequencies are likely dominated by powertrain related noise sources of the trucks. For the heavy truck cruise conditions in the eastbound direction, most of the reduction again falls in the higher frequency bands beginning at about 500 Hz as shown in Figure 16. For this cruise condition, the trucks are operating at a higher speed (48 vs. 42 km/h) so tire noise may be slightly more of a factor. Based on acoustic beaming forming measurements to localize noise sources during actual truck pass-by events, it has also been found that engine noise is often reflected from the pavement, particularly in the higher frequencies (8). A portion of the reduction seen in both the westbound and eastbound directions could be due to the porous pavement reducing the

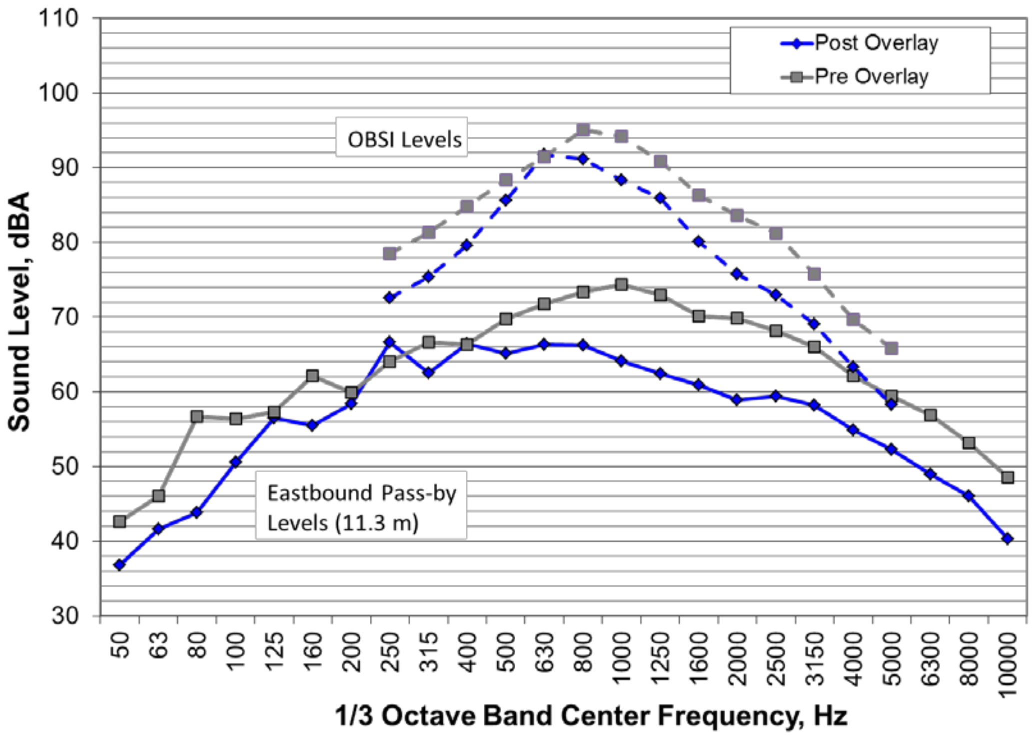

Figure 16: Heavy truck pass-by spectra at 48 km/h eastbound with OBSI spectra

strength of these reflections along with reducing tire-pavement noise.

4. CONCLUSIONS

The relatively thin (25 mm) OGAC overlay produced larger than expected reduction in pass-by noise levels for light vehicles, medium and heavy duty trucks. For the heavy trucks under acceleration at low speed, it is likely that the reduction was due to a combination of the reduced tire-pavement source levels and reduction in powertrain noise due to the absorptive, porous pavement. For accelerating and cruising trucks, most of the reduction occurred in the frequencies above 500 Hz in the same regions where tire-pavement source reductions were measured. However, the absorptive effect of the pavement would also be greater in these frequencies. For light vehicles at higher speeds, the reduction was much greater. Comparisons of the OBSI and pass-by spectra indicate that much of the light vehicle reduction can be attributed to tire-pavement noise reduction. However, the reduction in pass-by levels was greater than the source reductions alone, suggesting that sound propagation over the porous pavement also contributed to the wayside noise reductions. Overall, it was found that the overlay produced a noticeable reduction in overall traffic noise of about 5 dB.

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