National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science

Quieter Pavement Project - Death Valley National Park

Interim report for post-treatment conditions, 1-month age

Natural Resource Report NPS/DEVA/NRR—2020/2079

Volpe The National Transportation Systems Center

ON THE COVER
View of Badwater Road, Death Valley National Park
VOLPE CENTER

Quieter Pavement Project - Death Valley National Park

Interim report for post-treatment conditions (1-month)

Natural Resource Report NPS/DEVA/NRR—2020/2079

Aaron L Hastings, Amanda S Rapoza, William L Chupp, Sophie Kaye, and Daniel Flynn

U.S. Department of Transportation
Office of the Assistant Secretary for Research and Technology
John A. Volpe National Transportation Systems Center
Cambridge, MA 02142-1093

February 2020

U.S. Department of the Interior
National Park Service
Natural Resource Stewardship and Science
Fort Collins, Colorado

The National Park Service, Natural Resource Stewardship and Science office in Fort Collins, Colorado, publishes a range of reports that address natural resource topics. These reports are of interest and applicability to a broad audience in the National Park Service and others in natural resource management, including scientists, conservation and environmental constituencies, and the public.

The Natural Resource Report Series is used to disseminate comprehensive information and analysis about natural resources and related topics concerning lands managed by the National Park Service. The series supports the advancement of science, informed decision-making, and the achievement of the National Park Service mission. The series also provides a forum for presenting more lengthy results that may not be accepted by publications with page limitations.

All manuscripts in the series receive the appropriate level of peer review to ensure that the information is scientifically credible, technically accurate, appropriately written for the intended audience, and designed and published in a professional manner.

Data in this report were collected and analyzed using methods based on established, peer-reviewed protocols and were analyzed and interpreted within the guidelines of the protocols.

Views, statements, findings, conclusions, recommendations, and data in this report do not necessarily reflect views and policies of the National Park Service, U.S. Department of the Interior. Mention of trade names or commercial products does not constitute endorsement or recommendation for use by the U.S. Government.

This report is available in digital format from the Natural Resource Publications Management website. If you have difficulty accessing information in this publication, particularly if using assistive technology, please email irma@nps.gov.

Please cite this publication as:

Hastings, A. L., A. S. Rapoza, W. L. Chupp, S. Kaye, and D. Flynn. 2020. Quieter Pavement Project - Death Valley National Park: Interim report for post-treatment conditions, 1-month age. Natural Resource Report NPS/DEVA/NRR—2020/2079. National Park Service, Fort Collins, Colorado.

NPS 143/166876, February 2020

REPORT DOCUMENTATION PAGE			*Form Approved* *OMB No. 0704-0188*
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.			
1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE December 2019		3. REPORT TYPE AND DATES COVERED Final Report
4. TITLE AND SUBTITLE Quieter Pavement Project – Death Valley National Park: Interim report for post-treatment conditions, 1-month age			5. FUNDING NUMBERS VXAEA1 / SG341
6. AUTHOR(S) Aaron L Hastings, Amanda S Rapoza, William L Chupp, Sophie Kaye, Daniel Flynn			
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) U.S. Department of Transportation Office of the Assistant Secretary for Research and Technology John A. Volpe National Transportation Systems Center Environmental Measurement and Modeling Division, V324 Cambridge, MA 02142-1093			8. PERFORMING ORGANIZATION REPORT NUMBER DOT-VNTSC-NPS-20-02
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) U.S. Department of the Interior National Park Service Natural Resource Program Center Natural Sounds and Night Skies Division 1201 Oakridge Drive Fort Collins, CO 80525			10. SPONSORING/MONITORING AGENCY REPORT NUMBER
11. SUPPLEMENTARY NOTES NPS Program Manager: Frank Turina			
12a. DISTRIBUTION/AVAILABILITY STATEMENT			12b. DISTRIBUTION CODE
13. ABSTRACT (Maximum 200 words) The U.S. Department of Transportation, John A. Volpe National Transportation Systems Center is assisting the National Park Service, Natural Sounds and Night Skies Division in the study of practical noise reduction benefits of common surface treatments used by the Parks for pavement preservation. The goal of this study is to provide park administrators and planners with paving options using the standard surface treatments that alone, or in conjunction with other strategies, can help reduce noise in sensitive park areas. Acoustic data for the pre-treatment conditions, before application of the surface treatments, were collected on November 7 and 8, 2016. Acoustic data for immediate post-treatment conditions, one month after treatments were applied, were collected May 23 and 24, 2018. This document summarizes these interim data collected and results of the noise measurements. As the pavements age and additional measurements are made, these data and analyses will be updated in future reports.			
14. SUBJECT TERMS Quieter pavements, traffic noise, noise, Death Valley, National Park, soundscape			15. NUMBER OF PAGES 56 16. PRICE CODE
17. SECURITY CLASSIFICATION OF REPORT Unclassified	18. SECURITY CLASSIFICATION OF THIS PAGE Unclassified	19. SECURITY CLASSIFICATION OF ABSTRACT Unclassified	20. LIMITATION OF ABSTRACT

Above is a screenshot of the internal *NPS Report Documentation Page Form* that was added to this document at the insistence of the authors. This form is not required for publishing in the NPS Natural Resource Publications Series. A full transcription of all language displayed in this form can be found in Appendix A.

Contents

Figures

Tables

Page

Abstract

The U.S. Department of Transportation, John A. Volpe National Transportation Systems Center is assisting the National Park Service, Natural Sounds and Night Skies Division in the study of practical noise reduction benefits of common surface treatments used by the Parks for pavement preservation. The goal of this study is to provide park administrators and planners with paving options using the standard surface treatments that alone, or in conjunction with other strategies, can help reduce noise in sensitive park areas. Acoustic data for the pre-treatment conditions, before application of the surface treatments, were collected on November 7 and 8, 2016. Acoustic data for immediate post-treatment conditions, one month after treatments were applied, were collected May 23 and 24, 2018. This document summarizes these interim data collected and results of the noise measurements. As the pavements age and additional measurements are made, these data and analyses will be updated in future reports.

Acknowledgments

The authors thank Frank Turina and Ashley Pipkin of the National Park Service, Natural Sounds and Night Skies Division, and Death Valley National Park Superintendent Mike Reynolds for their vision and support of this study, as well as Kevin Gray and Sean Wheeler of the Federal Highway Administration. The authors also thank all the NPS Pacific West Region and Death Valley National Park personnel who helped our team with permitting, site selection, and traffic control including: Justin DeSantis, Sarah Raube, Kevin Green, Josh Hoines, and Ainsley Holeso. In addition, the authors thank the other members of the Volpe team for their support in the planning and execution of this effort: Cynthia Lee, Trevor May, John MacDonald and David Read. We would also like to thank the peer reviewers for this document – Kurt Fristrup, Cynthia Lee and Ashley Pipkin.

1. Introduction

The U.S. Department of Transportation, John A. Volpe National Transportation Systems Center (Volpe Center) is assisting the National Park Service (NPS), Natural Sounds and Night Skies Division (NSNSD), in their investigation of the use of quieter pavement as a noise abatement measure. This document details the initial two sets in a series of measurements in Death Valley National Park (DEVA) to track the sound level characteristics of the common park pavement surface treatments over time. Data for the pre-treatment condition were collected in November 2016, prior to resurfacing, while data for the immediate post-treatment condition were collected in May 2018, 1-month after treatments were applied. Post-treatment data regarding the four surface treatments under investigation will be collected and documented at regular intervals over the duration of this study (2016-2022). This study is being conducted in cooperation with DEVA NPS staff and the Federal Highway Administration (FHWA).

Quieter pavements have been studied and used successfully in highway applications in the US and abroad for several years. Sohaney (2013) published a synthesis of quieter pavements research and applications, "Quieter Pavements Guidance Document" for the National Park Service in June of 2013. An addendum to this document was prepared in 2018 (Hastings, 2018), which includes a summary of recent findings and an annotated bibliography.

Although numerous types of quieter pavements have been successfully used and studied in highway applications, the cost-benefit of these pavements is not conducive to use in many NPS units. Roadways in parks have a longer service life, requiring repairs and often resurfacing before a full replacement. Traffic on these roadways is also generally lower in speed, and parks are concerned about sound propagation at large distances, whereas highway planners often only consider effects up to 1000 ft from the roadway. In addition, the availability and maintenance requirements for traditional 'quieter pavement' technologies such as open-graded asphalt and rubberized asphalt can sometimes make them infeasible in remote parks.

As a result, the NSNSD and the Volpe Center are studying the noise reduction benefits of common surface treatments used by NPS units for pavement preservation. Based on discussions with FHWA and NPS, chip seal (with 3/8" and 1/4" aggregate), and microsurfacing type II and type III are common park pavement surfaces. The goal of this study is to provide park administrators and planners with paving options using the standard surface treatments that alone, or in conjunction with other strategies, can help reduce noise in sensitive park areas.

Measurement data for the pre-treatment condition provides a baseline/reference by which the surface treatments can be compared. For instance, chip seal is a common surface treatment but is known to have high noise levels at the beginning of its lifetime (Lodico & Donovan), then gradually becomes quieter over time; however, there are no known studies that provide quantitative measures of how chip seal noise levels change over time. The purpose of this study is to address said gaps in existing literature. Quantifying the initial change in noise as well as the rate of change (whether quieter or louder) for two aggregate sizes of chip seal will provide needed input when considering cost/benefits of using that particular surface treatment. Of the microsurfacing treatments, type II microsurfacing has a superior texture, but type III is most typically used for roadways due to improved durability. Quantifying the differences in noise levels as a function of surface treatment and time will again provide needed input when considering cost/benefits of using a particular surface treatment.

This research builds upon previous survey work conducted in DEVA (Rochat and Lau 2013) and several other NPS units in Pennsylvania and Virginia (Gettysburg National Military Park, Valley Forge National Historic Park, Shenandoah National Park, and Delaware Water Gap National Recreation Area) (Wayson and MacDonald 2014) where the goal was to demonstrate the potential benefits and limitations of various pavement types and surfaces (including quieter pavement) for NPS units.

2. Measurement Locations

Death Valley National Park is located northeast of Los Angeles, California along the border with the State of Nevada. The park was established in February 1933 and encompasses 3.3 million acres. Located in the arid Mojave Desert, Death Valley National Park is the largest National Park System in the contiguous 48 states and contains the lowest point in the Western Hemisphere. Over 800,000 people visit the park annually. Death Valley is an ideal candidate for this type of study, as it contains roadways where vehicle speed is typically greater than 45 mph, where tire-pavement noise dominates, and quieter pavements can be of most benefit. In addition, the park has very low natural ambient sound conditions (Lee & MacDonald 2016). Climatic conditions also allow for a relatively long window for acoustic sampling, typically from October to May.

The specific measurement sites within Death Valley were chosen within the area where pavement rehabilitation projects were scheduled to commence in 2017 or 2018. Site selection within this area was based on proximity to acoustically sensitive areas: those frequented by park visitors and/or sensitive fauna. All sites had a region of flat ground adjacent to and extending at least 400 feet perpendicular to and along the roadway so that wayside acoustic measurements could be conducted.

Based on these criteria, Badwater Road was identified as the best candidate for this study. Badwater Rd. received pavement surface rehabilitation treatments in early 2018, and has a number of areas conducive to acoustic measurements. Badwater Road is a 72-mile stretch of roadway in a heavily visited area of the park. It extends from the Furnace Creek visitor area southward to Badwater basin and Ashford Mill turning eastward through Jubilee Pass toward the park boundary and the town of Shoshone, CA (See Figure 1).

The locations for the test-strip surface-treatment paving and acoustic measurement were finalized during an on-site meeting and location scoping between FHWA, NPS and Volpe personnel on November 2-3, 2016. A total of eight locations were selected around two geographical areas, creating a northern and a southern group. The pavement treatments were each applied twice, once in each group of sites. The northern group of sites (S01-S04) has more traffic and higher visitation where measures of visitor perception are of interest. The northern group is located nearest to the Furnace Creek visitor center and lodging area and is also near several visitor points-of-interest. The southern group of sites (S05-S08), located near Jubilee Pass has less visitation (less traffic and wear-and-tear on the roadway), where measures of wildlife-related influences may be of interest. Additionally, the southern group is at a higher altitude (where average temperatures are a bit lower) and in a section of roadway that had previously seen damage due to flash flooding.

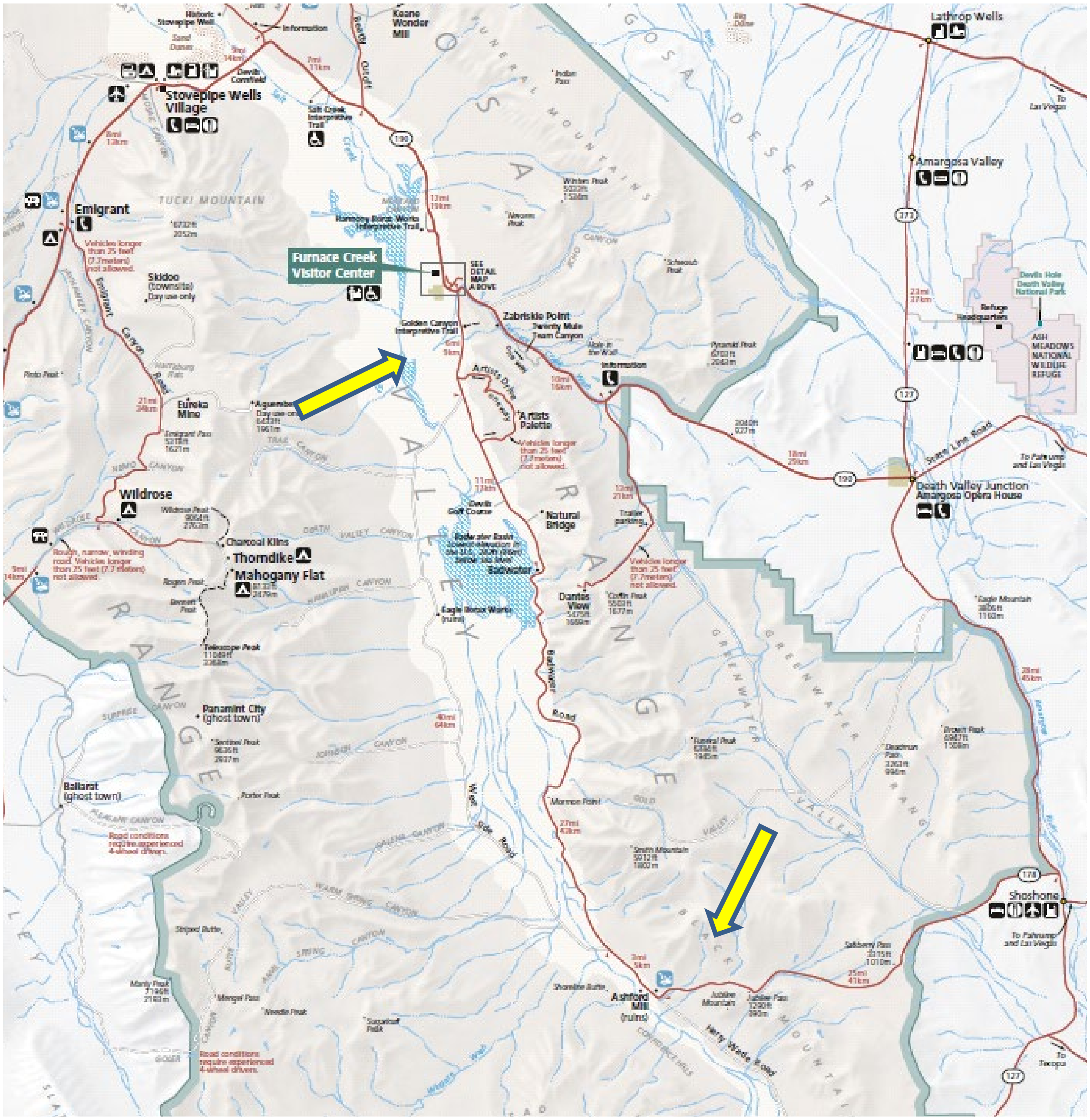

Figure 1. Park map showing Badwater / Furnace Creek area. Yellow arrows point to the geographical areas along Badwater Road for measurements.

The Badwater Road resurfacing project took place during March and April 2018 with coordination and oversight from the Federal Highway Administration's Office of Federal Lands Highway. The resurfacing was part of a larger project in Death Valley, where numerous sections of park roadways were resurfaced. The 3/8" chip seal treatment was the standard treatment, applied to the majority of Badwater Road (with the exception of the test sections). The other three types of treatment (1/4" chip seal and types II and III microsurfacing) were each applied in test sections, approximately one-half mile in length at the locations identified by the Volpe/NPS/FHWA team during the November 2016 site scoping. Test section lengths and spacing between sections were such that treatments on one section would not affect the noise levels at nearby measurement sites. Specifically, measurement sites are at least 2000 ft from the nearest change in surface treatment. Figure 2 through Figure 6 show photographic examples of the pre- and post-treatment pavements applied in early 2018 to the sections of roadway on Badwater Road.

Figure 2. Example of pre-treatment pavement at Site S02 (VOLPE CENTER).

Figure 3. 3/8-inch chip seal treatment at Site S01 (VOLPE CENTER).

Figure 4. ¼-inch chip seal treatment at Site S02 (VOLPE CENTER).

Figure 5. Type II microsurfacing treatment at site S03 (VOLPE CENTER).

Figure 6. Type III microsurfacing treatment at Site S06 (VOLPE CENTER).

In addition to the eight measurement locations along Badwater Road, a ninth measurement location at the Golden Canyon Parking Lot (nearby S01) was added in 2018. This parking lot was treated with the type II microsurfacing, but would not receive the same amount of moving vehicle traffic as the roadway itself. As this site is nearby the S01 location with easy access, it provided a convenient location to examine repeatability of EFR tests between two locations with the same type of pavement but different amounts of traffic.

During visual inspection of the test strips in May 2018, the type III microsurfacing sections were less even and smooth than specified. This pavement quality can affect the overall sound level results for this pavement type.

Figure 7 provides a map showing the site locations on Badwater Road, labeled S01 through S08. Table 1 lists the surface treatments applied, latitude, longitude, and altitude at each of these locations. The coordinates for the locations listed below represent the center point of the test section.

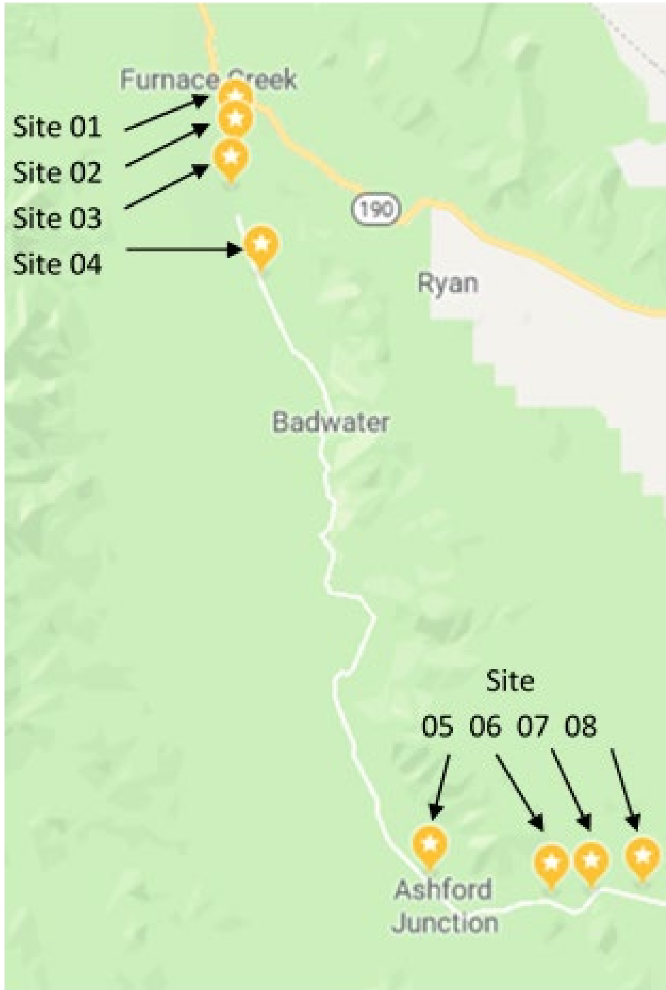

Figure 7. Map of Death Valley, Badwater Road, showing site locations.

Table 1. Death Valley measurement locations.

Site	Pavement Type (Post-paving, May 2018)	Latitude	Longitude	Roadway Mile Post of test strips	Altitude (ft, MSL)
S01	3/8" chip seal (default)	36.41783	116.84708	2.0 to 2.5	-187
S02	¼" chip seal	36.40432	116.84638	3.0 to 3.5	-203
S03	Type II microsurfacing	36.37843	116.84988	4.74 to 5.24	-173
S04	Type III microsurfacing	36.32172	116.82523	9.0 to 9.5	-176
S05	3/8" chip seal (default)	35.9231	116.68435	43.5 to 44.0	-65
S06	Type III microsurfacing	35.91185	116.58432	50.0 to 50.5	1230
S07	Type II microsurfacing	35.91285	116.55295	52.25 to 52.75	1270

Table 1 (continued). Death Valley measurement locations.

Site	Pavement Type (Post-paving, May 2018)	Latitude	Longitude	Roadway Mile Post of test strips	Altitude (ft, MSL)
S08	¼” chip seal	35.9167	116.51065	55.0 to 55.5	1957
Golden Canyon Lot (near S01)	Type II microsurfacing	36.42063	116.84711	2.0	-187

3. Methods

Data for pre-treatment conditions were collected during November 7-8, 2016. Data for the post-treatment conditions at nominally 1-month were collected over the course of two days; May 23 and 24, 2018. Data were collected using three acoustic measurement techniques, detailed further in Sections 3.1 through 3.3.

1) On-board sound intensity (OBSI): A measure of the tire/pavement generated noise at the source using an intensity probe that is mounted on a test vehicle.
2) Wayside vehicle noise emission level measurements: Vehicle noise emission levels are measured using standard FHWA procedures (Lee 1996), using a microphone at 50 feet from the centerline of the near traffic lane, 5 feet above the pavement surface. In addition to standard wayside measurements, wayside binaural recordings were obtained using two microphones and a model of a human head, placed 25 feet from the centerline of the near traffic lane.
3) Effective flow resistivity (EFR): EFR is a measure of acoustic flow resistivity, which includes the influence of material characteristics such as tortuosity, porosity, shape of ground surface, etc. The EFR of ground affects how a sound wave will reflect off the pavement. An acoustic point source (compression driver with tube) is used to generate tones that are measured by two microphones.

In addition to the acoustic data, qualitative and quantitative measures of the pavement characteristics were also collected:

1) Photogrammetry: Beginning in 2018, digital photographs of the pavement surface were collected in a specific manner such that they can be used to create a standard digital model through a technique called photogrammetry. These digital models provide a 3-dimensional picture of the pavement surface and can be used to compute texture metrics such as porosity and roughness. This analysis will be summarized in the final report upon completion of all five years of post-treatment monitoring.
2) Pavement temperature: Pavement temperature can affect the performance of the pavement and can thus affect the noise generated by the tire/pavement interaction.

Ideally, all three types of acoustic measurements would be conducted concurrently for each location to form matched datasets. This permits the noise to be measured along the roadway as well as the noise at the tire/pavement interface and allows propagation effects to be analyzed. This is important since not only does the pavement surface texture affect the noise created at the tire/pavement interface (source), but it also affects the sound wave as it propagates over the surface (path) before it is heard along the road (receiver).

However, due to logistical constraints all measurement types were not collected at all sites. Instead, measurement effort was apportioned to maximize the amount of data for the three measurement types across all pavement types. OBSI measurement data were collected at all eight sites for both the pre-treatment and 1-month post-treatment conditions. Wayside and EFR measurements for the pre-treatment condition were limited to sites S02, S07 and S08, as the pre-treatment pavement surface did not vary from site-to-site. Wayside and EFR measurement data for the 1-month post-treatment condition were collected for each of the four pavement treatment types in the northern section (S01, S02, S03 and S04), as well as the Golden Canyon Parking Lot. Because the treatments in the northern group of measurement locations were repeated in the southern group, it was reasonable to limit these more time-consuming test types to one location grouping. The northern sites were considered more demonstrative of realistic road condition changes over time as they are more heavily trafficked throughout the year, and therefore are subjected to more wear and tear.

Figure 8 shows the approximate locations of the OBSI and EFR measurements relative to the wayside location at a single site.

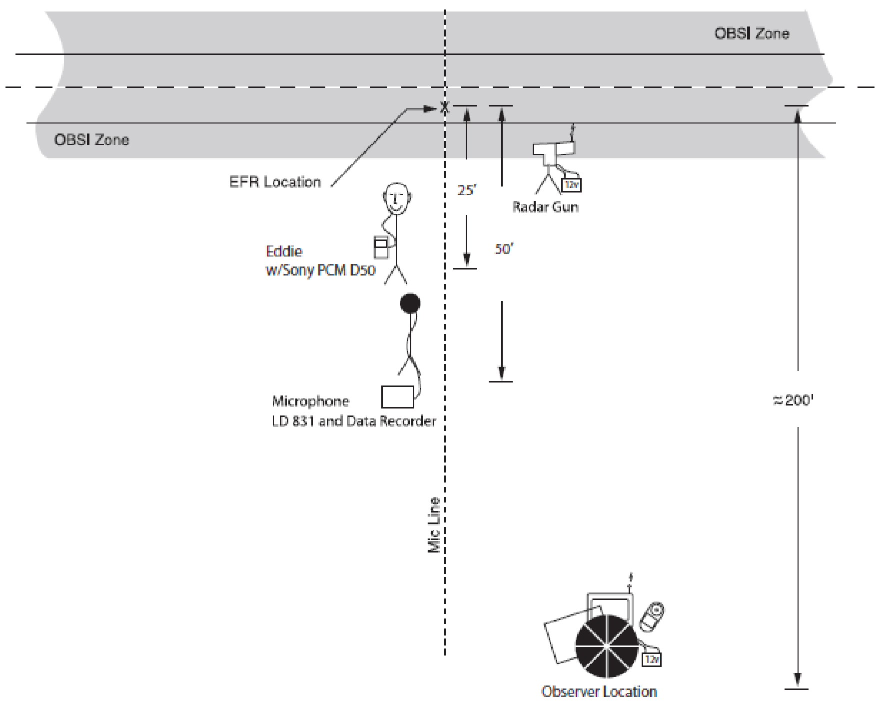

Figure 8. Approximate instrumentation and test locations for OBSI, Wayside, Binaural and EFR measurements.

3.1. Tire/Pavement Sound Intensity Levels (OBSI Measurements)

On-Board Sound Intensity (OBSI) is a measure of the tire/pavement generated noise at the source. The standard test method (AASHTO TP76-10) was used, whereby two intensity probes are placed 3-inches from the pavement/tire interface Each intensity probe consisted of a phase-matched pair of microphones. These probes were positioned at the leading or trailing edges of the tire/pavement interface (see Figure 9). In this way the tire/pavement generated noise was measured as sound intensity at the two locations. The OBSI measurement method was not significantly affected by sounds outside the vicinity of the pavement/tire interface. Therefore, measurement accuracy was unaffected by the presence of other vehicles and natural or other anthropogenic sounds. In addition, a standard reference test tire was used to minimize any differences in the tire 'source' from location to location and year to year.

Figure 9. Example of OBSI microphone array mounted on a passenger car (VOLPE CENTER).

The OBSI test data were collected as the test vehicle traversed each measurement site. The test was run over a 6.7-second data collection interval while the vehicle maintained a fixed speed of 45 mph, resulting in a test section of pavement 440 feet in length. Multiple pass-bys were performed in each location to get an accurate representation of the noise levels associated with the pavement.

The intensity probes were mounted on a passenger car as illustrated in Figure 9, with cables carrying the electrical signal from the probes at the wheel to the data analyzer and laptop computer inside the car. The sound intensity measured at each probe was recorded via software on a laptop computer. Data collected for each test run consisted of the overall sound intensity level and the sound intensity level in 1/3 octave bands between 250 and 5000 Hz. Multiple passes were run on each test section and averaged to obtain a single OBSI level for each. After each test run, the data were reviewed for quality control and stored. Post-test, the data were processed according to the standard method in AASHTO TTP76-10.

3.2. Wayside Sound Level Measurement

The wayside measurement is a standard method to measure the noise generated by vehicles near a roadway. Measurements were conducted in conformance with standard FHWA procedures[1], where the goal is to collect maximum sound level data for individual pass-by events. During the pre-

---

[1] These procedures are consistent with the methods used during the development of the Reference Energy Mean Emission Level (REMEL) database for the FHWA TNM (Lau et.al, 2004).

treatment measurements, data were collected for 4-6 hours each at sites S02 and S07. During the 1-month post-treatment measurements, data were collected for 2-3 hours each at sites S01-S04.

The measurement microphone was located at a distance of 50 feet from the centerline of the near traffic lane, 5 feet above the pavement surface (see Figure 10). A Class 1 sound level meter according to IEC 61672-1:2002 measured A-weighted maximum sound level using fast response,[2] as well as 1/3 octave-band one-half second equivalent sound levels. Meteorological data (air temperature, relative humidity, wind speed, and wind direction) and pavement temperature were recorded at hourly intervals.

Figure 10. Example wayside measurement setup at Site S03 (VOLPE CENTER).

During measurements, field personnel monitored pass-by events and recorded the event time, vehicle speed (measured by radar), vehicle type (auto, RV or medium truck, motorcycle, bus, etc.) and any interfering noises such as an aircraft flyover. Personnel also evaluated event quality in the field. A clean event occurred when no other vehicles were nearby, allowing for the sound level to rise and fall 10 dB from the maximum during the approach and departure. In general, this 10 dB rise-and-fall will

[2] Fast response is typically used for measuring individual vehicle pass-bys (see Lee 1996 and RSG 2018).

occur when the vehicle is clear of other vehicles by 150 ft on each side of the microphone (for multiple automobiles) or 500 ft for automobiles with motorcycles nearby.

Post-test, wayside data were processed to produce a database of vehicle-pass-by information, one record per vehicle. Each record contains:

- Vehicle speed and type identification (auto, motorcycle, medium truck/RV, bus)
- Meteorological data: temperature, humidity, wind speed
- Acoustical data: A-weighted maximum sound level, fast response, and corresponding one-third octave-band sound levels.

The ½-second sound level time-history records for each vehicle pass-by were also identified within the dataset, examined to ensure a 10 dB rise and fall (no contamination from other sources) and stored for later analysis.

In addition to traditional wayside data collection, binaural audio recordings were obtained using a two-microphone dummy head recorder. This device takes the form of a full-sized human head model, with one microphone in each ear. Recordings using two microphones along with the physical representation of a human head replicates the acoustic conditions in which humans experience sound. Listening to these recordings through high quality headphones produces a simulation of the audio environment in which the recordings were obtained, thus providing a 3-dimensional listening experience. Binaural audio recordings can be helpful for education and laboratory 'audio clip' studies where subjects wish to differentiate between the pass-by sounds produced by different pavement types. Because binaural recordings alter the frequency content of the signal, these recordings are not usually used as raw data sets for measuring or modeling traffic noise on roadways.

During the wayside measurements, the binaural head and microphones were positioned 25 feet from the centerline of the near traffic lane, 5 feet above the pavement surface. Figure 11 shows the setup of the binaural head recording system along Badwater road at site S03.

Figure 11. Example of binaural recording, binaural head setup at S03 (VOLPE CENTER).

3.3. Effective Flow Resistivity (EFR) Measurement

EFR is a measure of flow resistivity, which includes the influence of material characteristics such as tortuosity, porosity, shape of ground surface, etc. EFR is a parameter used in various acoustic propagation algorithms to determine the amount of sound absorbed / reflected by the pavement when propagating outwards into the park or a community.

In the FHWA TNM® version 2.5, a single EFR value of 20,000 cgs rayls is the default value applied to pavements. Studies have shown that pavement EFR values can range from about 2,000 to 30,000 cgs rayls, depending on pavement type and age (a review of the studies can be found in Rochat et al. 2012). For EFR, low values represent a sound absorbing material, and high values represent a sound reflecting material. EFR is on a proportional scale in the sense that, for example, a difference of 1,000 cgs rayls in the low range (0-1,000 cgs rayls) represents a significant difference between very sound absorbent powder snow and roadside dirt, whereas in a higher range (10,000-30,000 cgs rayls), a 1,000 cgs rayls difference represents slight differences in, for example, the EFR of two different dense-graded asphalt pavements. Table 2 displays EFR values for common ground types.

EFR measurements at DEVA were conducted in conformance with ANSI S1.18, *Template Method for Ground Impedance*, using "Geometry A". The instrumentation set-up consists of an acoustic point source (compression driver with tube) and two microphones a set distance away and two different heights above the ground (see Figure 12 and Figure 13). Samples are collected 4 times at each test section, one in the direction of travel, and then at 90, 180, and 270 degrees of rotation from the direction of travel.

Table 2. Effective Flow Resistivity Data for Ground Types.

	Effective Flow Resistivity (x 10^3 Pa-s/m^2)	
Ground Type	**Range**	**Average**
Upper limit	2.5 x 10^5 – 25 x 10^5	800,000
Concrete, painted	200,000	200,000
Concrete, depends on finish	30,000-100,000	65,000
Asphalt, old, sealed with dust	25,000-30,000	27,000
Quarry dust, hard packed	5000-20,000	12,500
Asphalt, new, varies with particle size	5,000-15,000	10,000
Dirt, exposed, main-packed	4,000-8,000	6,000
Dirt, old road, filled mesh	2,000-4,000	3,000
Limestone chips, 1.25-2.5 cm mesh	1,500-4,000	2,750
Dirt, roadside with < 10 cm rocks	300-800	550
Sand, various types	40-906	317
Soil, various types	106-450	200
Grass, lawn or grass field	125-300	200
Clay, dry, (wheeled/unwheeled)	92-168	130
Grass field, 16.5% moisture content	75	75
Forest floor (pine/hemlock)	20-80	50
Grass field, 11.9% moisture content	41	41
Snow, various types	1.3-50	29

Figure 12. EFR data collection instrumentation (VOLPE CENTER).

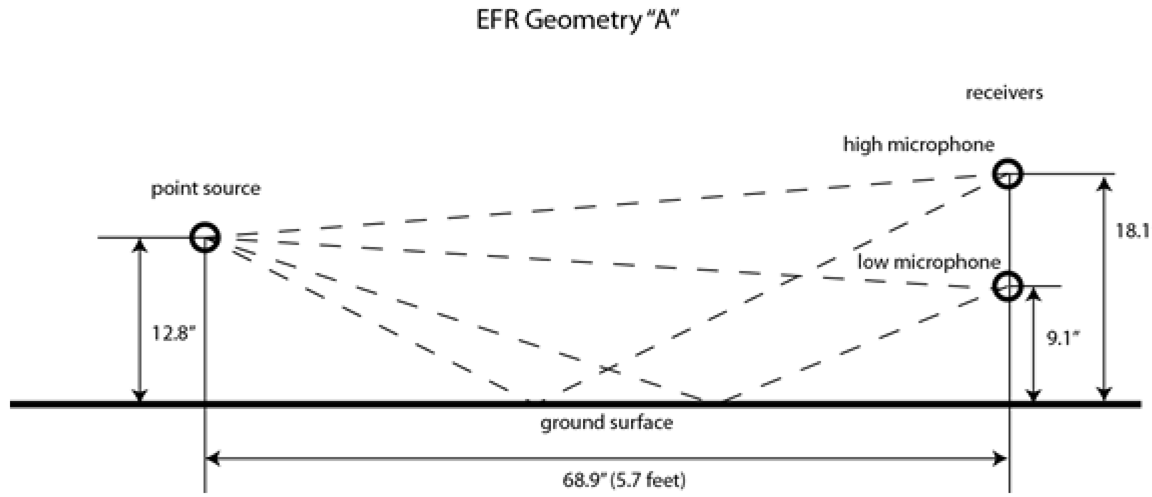

Figure 13. Diagram of EFR set-up.

The method generally consists of using a signal generator to generate tones at 1/3-octave band center frequencies between 250 and 4000 Hz, noting the difference in sound level between the two microphones for each frequency. This general method was used during the pre-treatment measurements in 2016. Based on these data, it was determined that more accurate EFR estimates might be obtained for the test pavement surfaces by increasing the number of data points collected between 2000 Hz and 2250 kHz, where the EFR values for hard surfaces varied the most. In 2018, additional data were collected for frequencies at 62 Hz intervals between 2000 Hz and 2250 Hz, as well as frequencies at 1000 Hz, 2500 Hz, and 3150 Hz.

4. Results and Analyses

Sections 4.1 through 4.3 summarize the measured data and analyses of both pre-treatment measurements (November 2016) and post-treatment measurements at 1-month (May 2018).

4.1. On-Board Sound Intensity Data

Table 3 shows the overall sound intensity level measured with OBSI techniques by location for both pre- and post-treatment pavements; Table 4 and Figure 14 show the overall sound intensity level by pavement type. In all cases, the reported overall sound intensity level is the arithmetic average of at least three good ‘runs’ on each surface. The range of sound levels matches closely with the typical range for dense graded asphalts. Microsurfacing treatments have the lowest overall sound intensity levels. As expected, the newly-treated chip seal pavements generally have greater sound intensity levels than did the pre-treatment pavement. There is no discernable trend between pavements of the same type in the northern and southern site groupings. The changes in overall sound levels between pre-treatment (2016) and 1-month post-treatment (2018) measurements are generally in the expected directions. All the post-treatment levels are within 2.5 dB of the pre-treatment level at each site. The range of OBSI levels between pre- and post-treatment remain fairly similar despite the post-treatment measurements encompassing multiple pavement types compared to the pre-treatment measurements, which encompass many samples of the same pavement type. The variability between pre-treatment measurements is due to deterioration from age and usage, which results in erosion and cracks, whereas the variability between post-treatment measurements is attributed to the different pavement materials themselves, as all samples are of one-month age, and therefore have been subject to minimal wear and tear. Temperature differences between each measurement have not been taken into account for either pre- or post-treatment results.

Table 3. Measured overall sound intensity levels, pre-treatment and post-treatment (1-month), 45 mph speed.

Location	Pavement Treatment	Pre-treatment Overall Sound Intensity Level (dB)	Post-treatment 1-month age Overall Sound Intensity Level, (dB)	Delta (Post – Pre, dB)
S01	3/8” chip seal	99.7	100.6	+0.9
S02	1/4” chip seal	100.1	99.3	-0.8
S03	Type II Microsurfacing	98.4	97.4	-1.0
S04	Type III Microsurfacing	101.1	98.9	-2.2
S05	3/8” chip seal	98.3	100.1	+1.8
S06	Type III Microsurfacing	100.8	99.7	-1.1
S07	Type II Microsurfacing	100.2	97.7	-2.5
S08	1/4” chip seal	99.7	100.2	+0.5

Table 4. Range of measured OBSI levels by pavement type.

Pavement Type	Range	Average
Pre-treatment	98.3-101.1	99.2
3/8” chip seal	100.1 – 100.6	100.4
1/4” chip seal	99.3-100.2	99.8
Type II Microsurfacing	97.4-97.7	97.6
Type III Microsurfacing	98.9-99.7	99.3

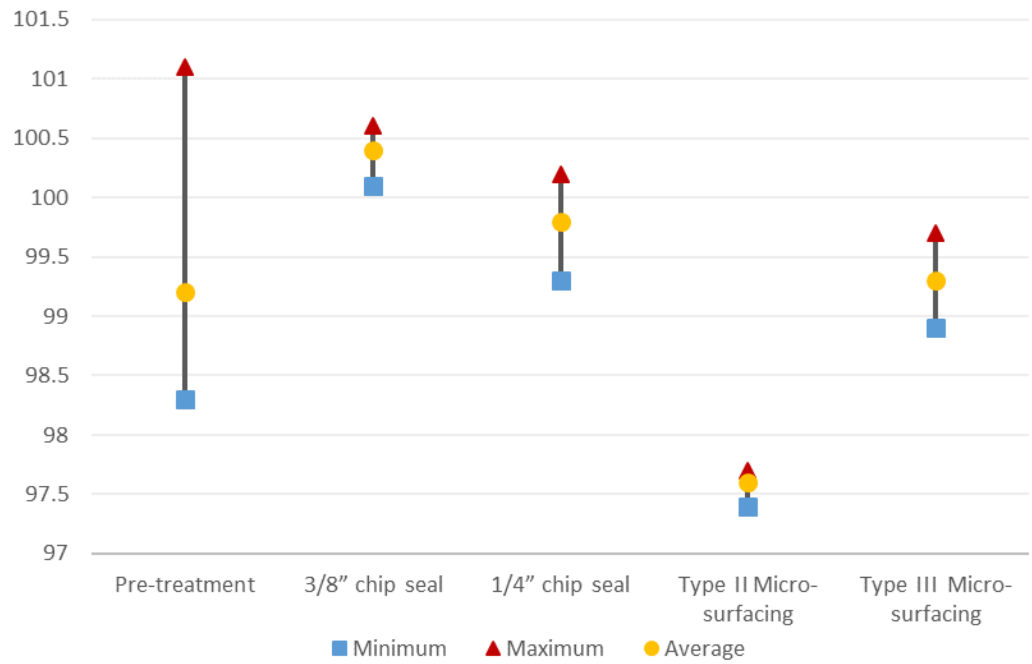

Figure 14. Range of measured OBSI levels by pavement type.

Figure 15 shows the 1/3 octave band sound intensity levels measured at each site, corresponding to the overall sound intensity levels shown in Table 3. Visible trends include:

- The type II microsurfacing pavement produces the least low-frequency energy, and less high-frequency energy than the chip seal pavements.
- The type III microsurfacing pavement produces more low-frequency energy and less high-frequency energy than other pavement types.
- The 3/8” chip seal produces the highest overall sound intensity levels.
- Compared to the pre-treatment data, new pavement treatments generally produce more low-frequency energy and less high-frequency energy.

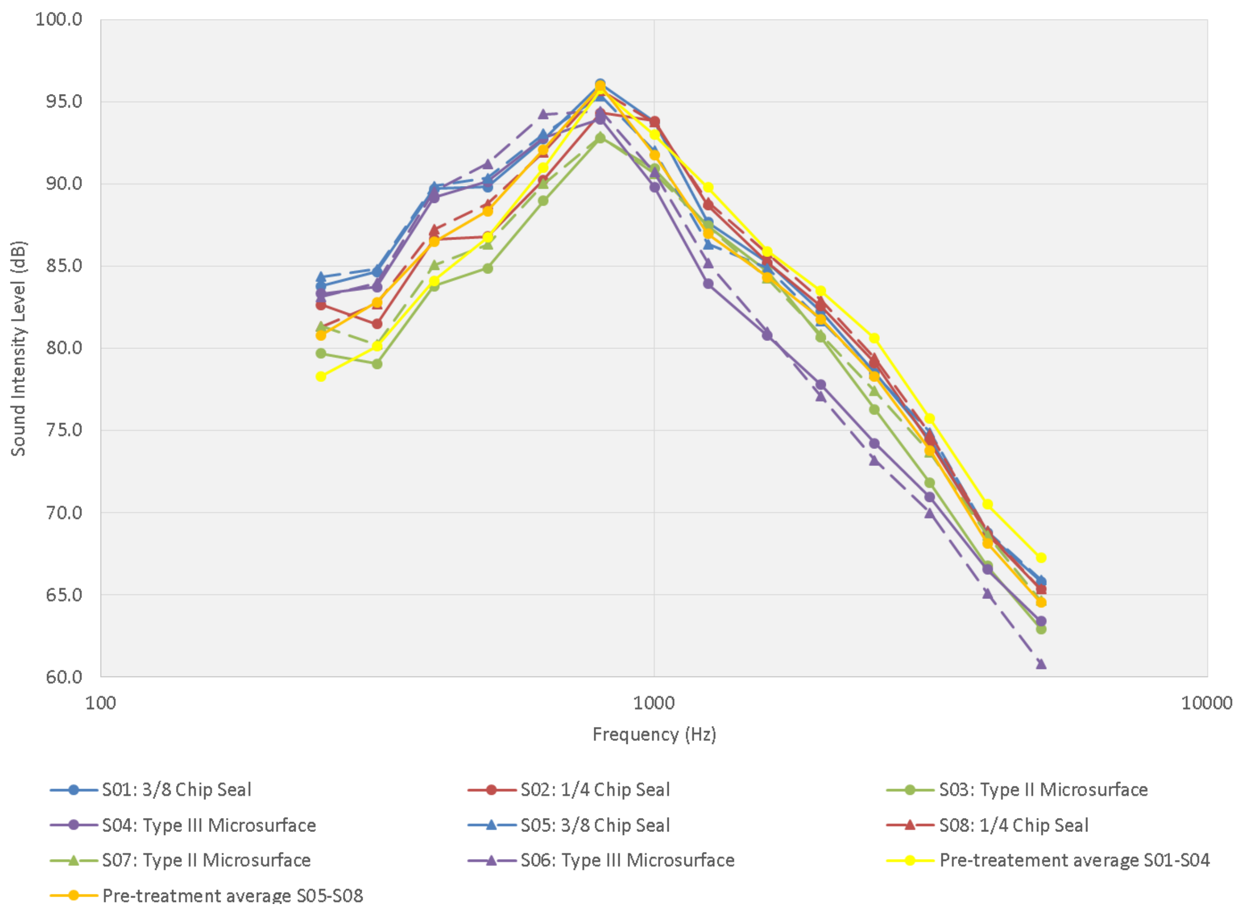

Figure 15. Measured 1/3 octave-band sound intensity levels. Post-treatment, 1-month and pre-treatment. 45 mph speed.

4.2. Wayside Sound Level Data

Pre-treatment wayside data for vehicle pass-bys were collected at two of the eight measurement locations. Site S02 was chosen to be representative of the northern section, and site S07 was chosen to be representative of the southern section. For post-treatment conditions, wayside vehicle pass-by data were collected for each of the four treatment types at locations S01 through S04. Table 5 summarizes the wayside maximum sound level pass-by data obtained.

Figure 16 depicts the wayside maximum sound level data for the pre-treatment conditions, while Figure 17 depicts the data for post-treatment conditions. These figures contain the measured maximum sound pressure level data (A-weighted, fast response) as a function of vehicle speed for each vehicle pass-by. Overlaid on these charts is the reference energy mean emission level (REMEL) curve for automobiles, average pavement, as developed for FHWAs TNM (Lau et al. 2004) and measured with similar procedures, thus allowing for direct comparison. Both pre- and post-treatment data are in good agreement with the REMEL relationship, scattered above/below the REMEL automobile curve for average pavement.

Table 5. Summary of Wayside Pass-by Measurements.

Location	Pavement Type	Number of Clean Vehicle Pass-bys	Speed Range (mph)	Speed Average (mph)	L_{AFmx} Sound Level Range (dB(A))	L_{AFmx} Sound Level Average (dB(A))
S02	Pre-treatment	69	41-80	55.0	66 – 77.9	71.5
S07	Pre-treatment	26	39-61	51.0	63.2-75.0	69.8
S01	3/8” chip seal	31	29-59	45.8	60.5-75.4	68.3
S02	1/4” chip Seal	16	37-67	53.3	67.4-74.1	71.6
S03	Type II microsurfacing	30	37-58	45.4	61.9-73.5	67.5
S04	Type III microsurfacing	17	34-67	51.2	60.7-75.8	70.4

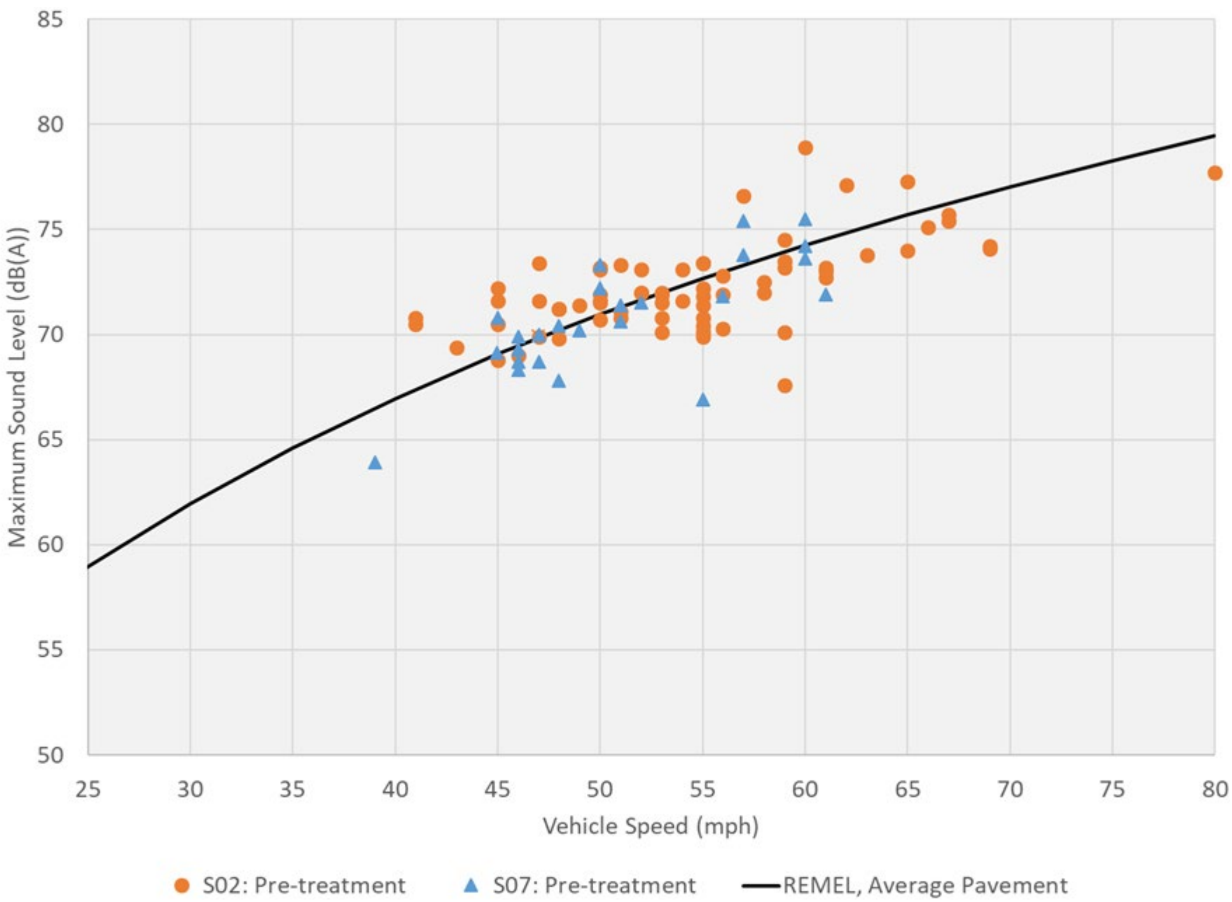

Figure 16. Measured wayside (50 ft) A-weighted maximum sound level data, pre-treatment conditions, sites S02 and S07. The REMEL relationship for automobiles is overlaid for comparison.

Measured data can be affected by vehicle speed, pavement type, pavement temperature, and the interactions between these main effects. In order to further isolate the effect of pavement type, a Multiple Analysis of Variance (MANOVA) was conducted using measurements from the pre-treatment and post-treatment conditions. The predictors in the MANOVA include the treatment type, vehicle speed, and pavement temperature. The response variables are the one-third octave band levels associated with the pass-by for each event. In contrast to an ANOVA model, the response in the statistical model is a matrix (number of observations × number of 1/3 octave bands as response variables) rather than a single vector (number of observations × 1 response variable). This analysis allows the greatest amount of data to be utilized to systematically estimate the contribution of pavement type on the difference in measured levels.

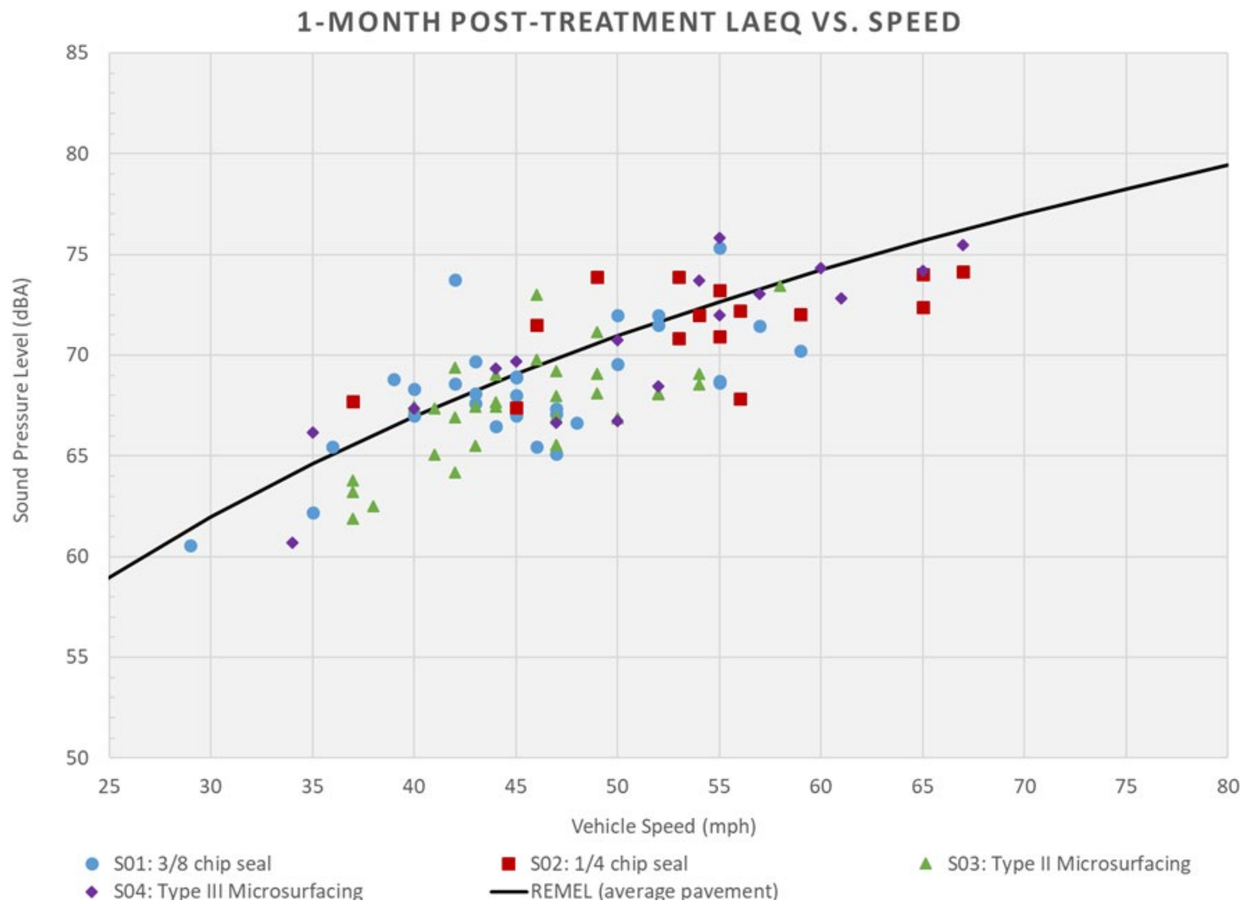

Figure 17. Measured wayside (50 ft) A-weighted maximum sound level, 1-month post-treatment conditions, sites S01 through S04. The solid line represents the REMEL relationship for automobiles, which is overlaid for comparison.

The results of the MANOVA are shown in Table 6. The first column describes the effect under consideration, either a main effect (pavement type (treatment), pavement temperature, vehicle speed) or an interaction effect (interaction between pavement temperature and vehicle speed, interaction between pavement type and vehicle speed). The second column is the number of degrees of freedom associated with each effect. The third column is an estimate of Pillai's trace, which is a test statistic used in multivariate analyses. Pillai's trace is based on the eigenvalues associated with each predictor, across all the sound intensity frequencies. A larger value indicates that this predictor explains more of the difference in the response data (the matrix of all the sound levels across frequencies). The next three values give the approximate F-statistic, which is used for evaluating statistical significance and the degrees of freedom for the numerator and denominator in the F-statistics. The final column gives the p-value. A p-value less than 0.05 is typically considered statistically significant.

Table 6. Multiple Analysis of Variance of Wayside Pass-by Sound Pressure Levels.

Category	Df	Pillai	approx F	num Df	den Df	Pr(>F)
Treatment	4	2.849	13.748	108	600	< 0.001
Pavement Temperature	1	0.287	2.197	27	147	0.002
Speed	1	0.683	11.755	27	147	< 0.001
Pavement Temperature : Speed	1	0.245	1.762	27	147	0.018
Treatment : Speed	4	1.058	1.998	108	600	< 0.001
Residuals	173	n/a	n/a	n/a	n/a	n/a

The MANOVA indicates that there are strong, statistically significant effects for all predictors included in the MANOVA across the range of one-third octave bands analyzed. Once this was established it was appropriate to conduct single Analyses of Variance (ANOVAs) for each one-third octave band frequency using this model to determine the effects of pavement type (along with the other factors) on sound level.

Figure 18 to Figure 21 show the differences in sound level according to the ANOVA statistical model between each new pavement type and an average of the two pre-treatment locations for which wayside data was collected (S02 and S07). Note that in these figures the error bars are based on ±1 standard error, which provides a confidence interval of 68.3%, rather than the typical ±1.96 standard errors, which provides a 95% confidence interval. This was done to help highlight potential differences. Because this interval is less conservative, as new data are added, some trends may change. From these figures, the following conclusions can be drawn:

- 3/8” chip seal and type II microsurfacing pavements produce less low frequency content than the pre-treatment pavement
- Type III microsurfacing pavement produces more low frequency content and less high frequency content than the pre-treatment pavement
- ¼” chip seal pavement is generally slightly louder than the pre-treatment pavement

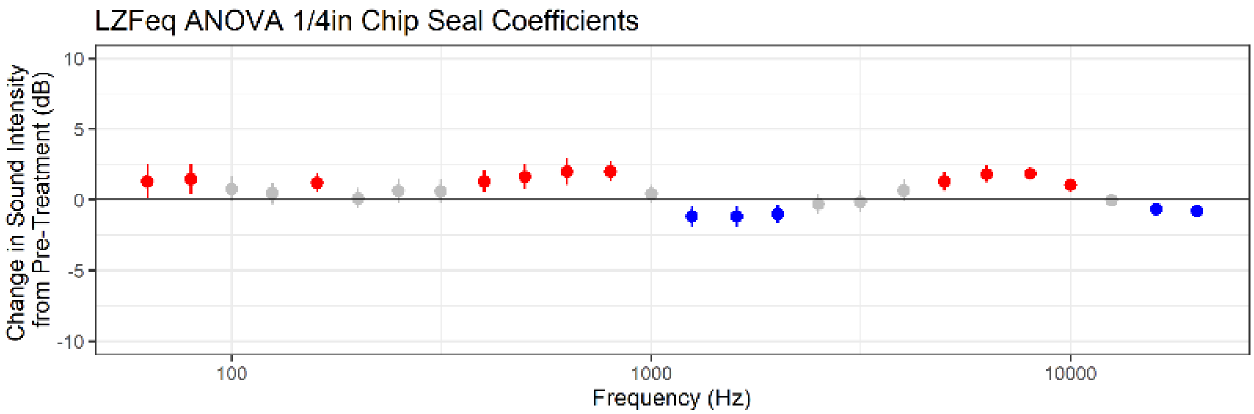

Figure 18. Spectral sound intensity difference between pre-treatment and ¼” chip seal pavement. ANOVA analysis adjusting for average parameters: 50 mph average speed and 90° F pavement temperature.

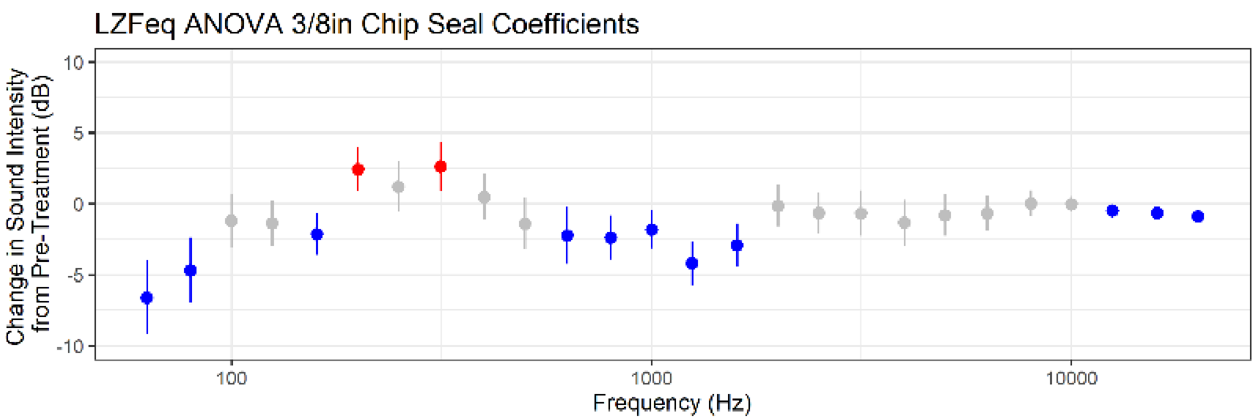

Figure 19. Spectral sound intensity difference between pre-treatment and 3/8” chip seal pavement. ANOVA analysis adjusting for average parameters: 50 mph average speed and 90° F pavement temperature.

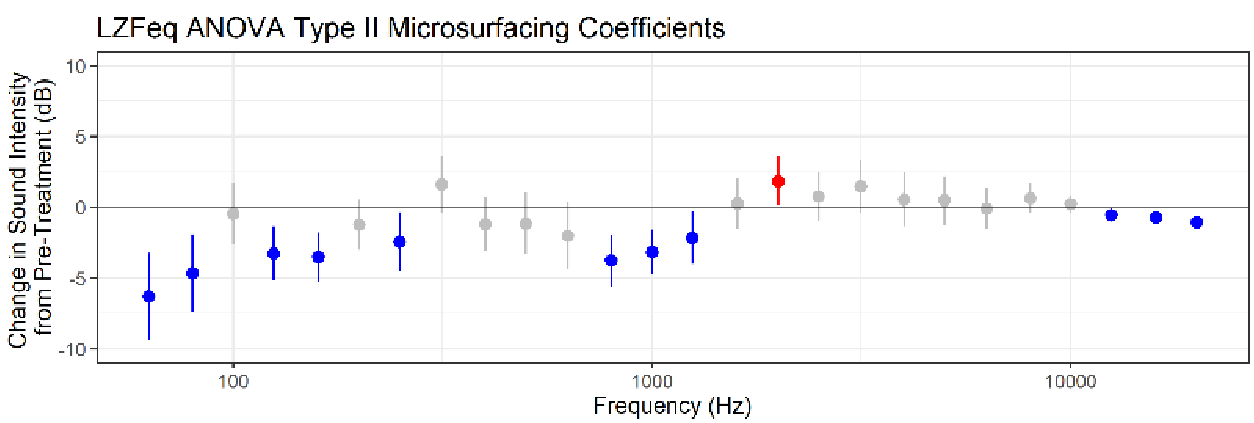

Figure 20. Spectral sound intensity difference between pre-treatment and type II microsurfacing pavement. ANOVA analysis adjusting for average parameters: 50 mph average speed and 90° F pavement temperature.

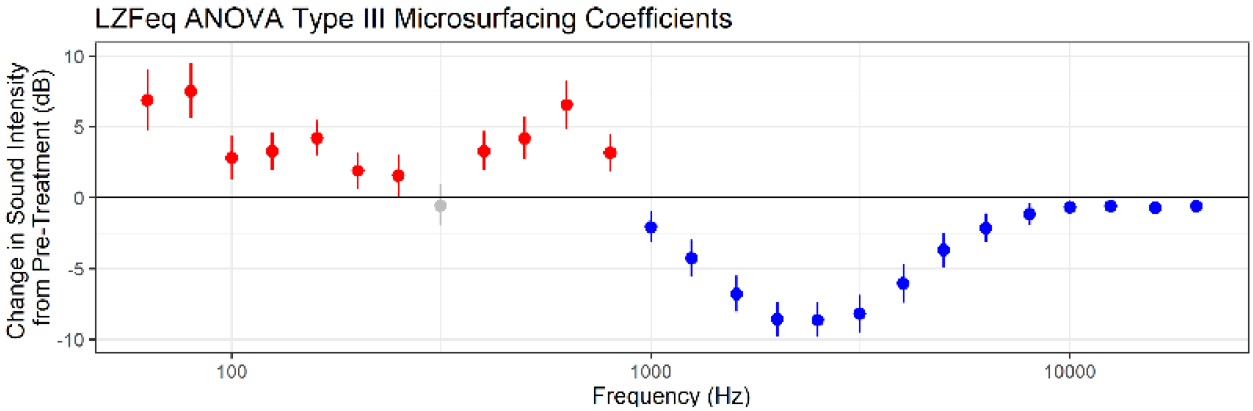

Figure 21. Spectral sound intensity difference between pre-treatment and type III microsurfacing pavement. ANOVA analysis adjusting for average parameters: 50 mph average speed and 90° F pavement temperature.

Figure 22 shows the REMEL curve for automobiles on average pavement as well as the trend lines developed using the results from the ANOVAs. Note, that the trend lines are linear while the REMEL curve has a logarithmic form. For limited speed ranges, comparison between the two forms are useful and the following observations are noted for the pre-treatment and 1-month post-treatment pavements:

- The pre-treatment trendline (yellow) is a in good agreement with the REMEL relationship, thus characterizing average pavement, as expected.
- The trend lines for both the 1/4" chip seal and type III microsurfacing pavements have a more shallow slope than the REMEL relationship – with sound levels at lower speeds (40-55 mph) being higher than average while sound levels at higher speeds (55-65 mph) being lower than for the average pavement.
- The trend lines for both the 3/8" chip seal and type II microsurfacing pavements are by contrast, slightly steeper than the REMEL relationship – with lower speeds being significantly quieter than expected for average pavement and faster speeds only approaching the levels expected for average pavement.
- At speeds less than 55 mph, which are typical of most park roadways, 1/4" chip seal and type III microsurfacing are loudest. Type II microsurfacing and 3/8" chip seal are quietest below 55 mph.

Having completed the ANOVA, the sound levels for each pavement type can be normalized to account for the site-to-site variability of the other significant factors. This allows for a simple comparison of the pavement types as shown in Table 7, where the predicted sound level for each pavement type is given, for vehicles traveling at 50 mph and with a pavement temperature of 90 degrees Fahrenheit.

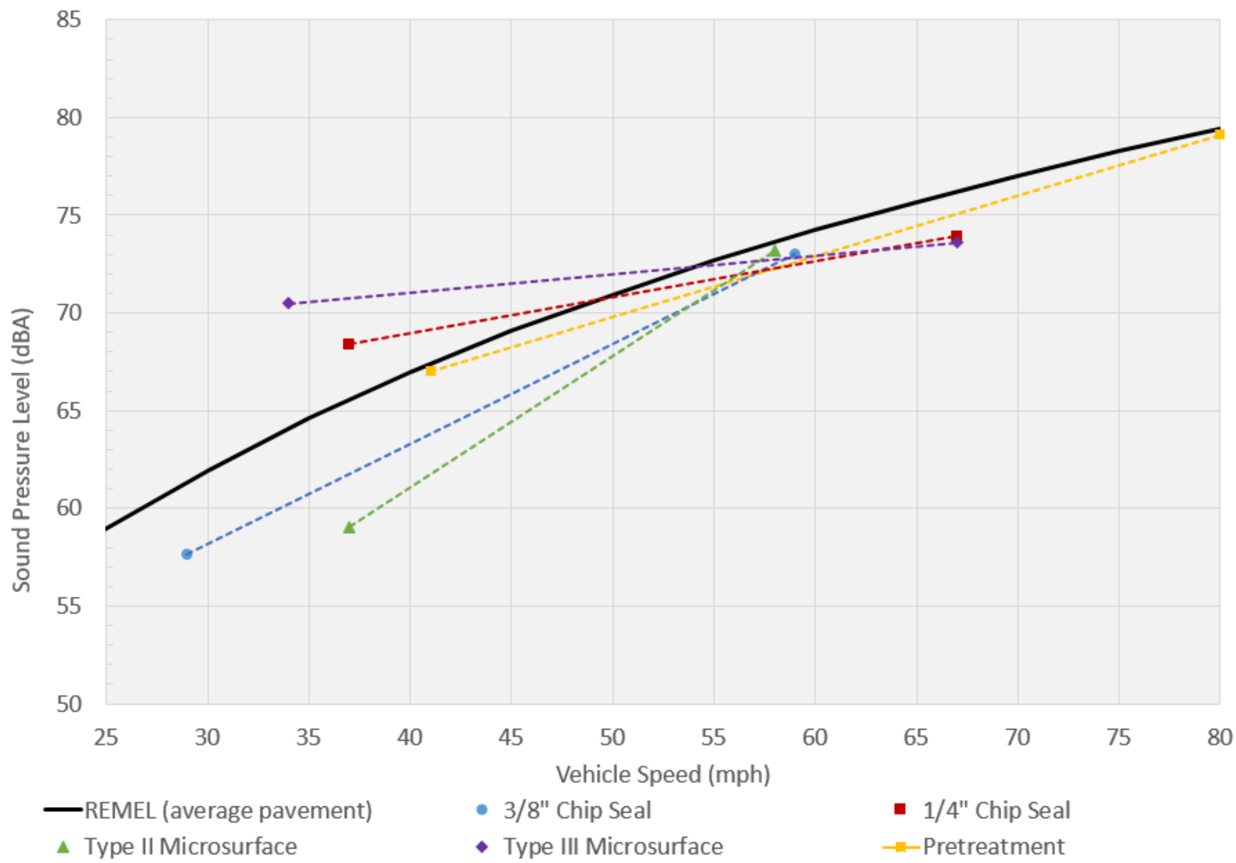

Figure 22: Comparison of standard REMELs and linear models of pavement treatments, pre-treatment and 1-month post-treatment.

Table 7. Overall A-weighted ANOVA predicted wayside data at 50 mph speed, 90 degree Fahrenheit pavement temperature.

Location	Pavement Type	Sound Pressure Level (dBA)
S02	Pre-treatment	69.6
S01	3/8” chip seal	67.9
S02	1/4” chip Seal	70.6
S03	Type II microsurfacing	67.5
S04	Type III microsurfacing	71.6
National Average REMEL, Automobiles	Average pavement	71.0

Similarly, Figure 23 show predicted spectra associated with the wayside measurement locations for all sites for the pre- and 1-month post-treatment conditions. These spectra are normalized for vehicles traveling at 50 mph and with a pavement temperature of 90 degrees Fahrenheit in order to facilitate an accurate comparison (as shown in Table 7). The same observations as were made from Figure 18 to Figure 21.

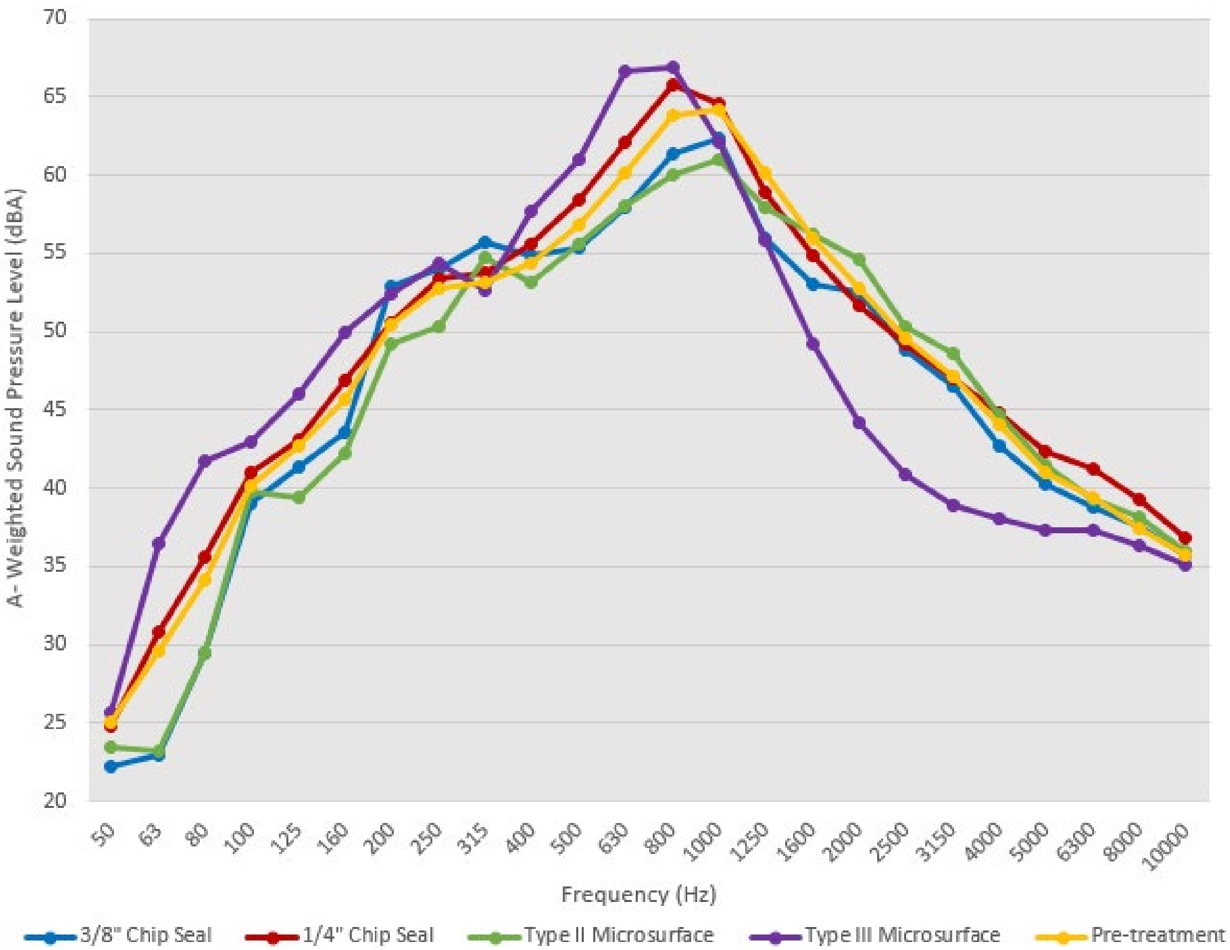

Figure 23. Measured wayside (50 ft) A-weighted spectral data, pre- and 1-month post-treatment conditions. ANOVA analysis adjusting for average parameters: 50 mph average speed and 90° F pavement temperature.

4.3. Effective Flow Resistivity Data

Pre-treatment EFR data were collected at three of the eight measurement sites: S02, S07 and S08, while the 1-month post-treatment data were collected at four of the eight measurement sites: S01, S02, S03, and S04. In addition, a fifth measurement location was included at Golden Canyon Parking Lot, chosen because the parking lot was treated with the same pavement as site S03, but does not receive the same high speed traffic as the roadway. This offers an opportunity to perform repeatability tests and compare how different types of wear affect the flow resistivity characteristics of these materials.

EFR data were measured and analyzed in conformance with the ANSI S1.18 standard. Figure 24 through Figure 31 illustrate the process of comparing mean measured differences (red dots) with known EFR curves for EFR values between 10 and 32,000 cgs/rayls, displayed as thin colored curves in the following figures. The solid black line on these figures indicates the EFR curve which best fits the data.

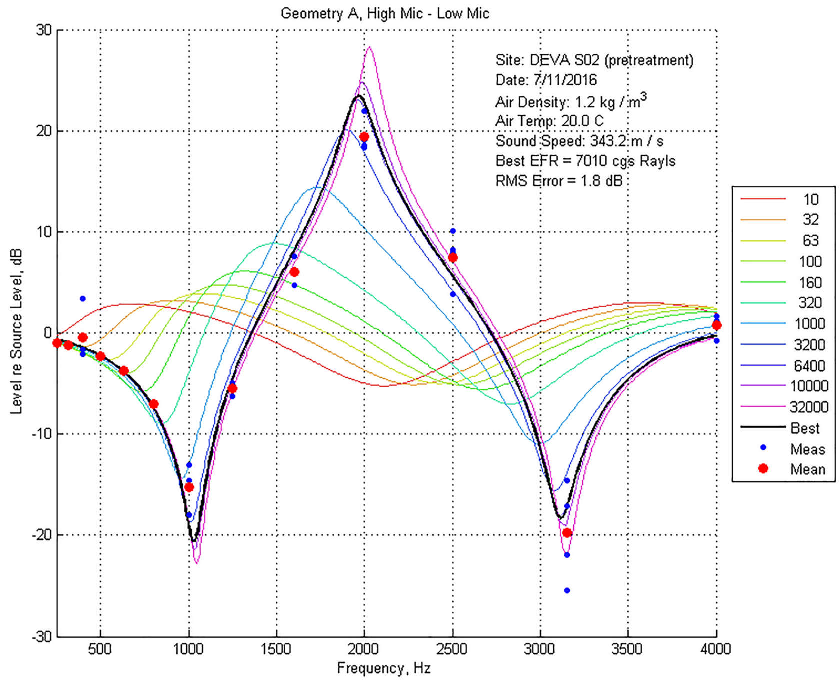

Figure 24. Comparison of measured (blue dots), average measured (red dots) and computed best fit (solid lines) sound level differences by frequency at site S02, pre-treatment conditions. A black line indicates the differences computed for the EFR value that best fits the measured data (7010 cgs rayls).

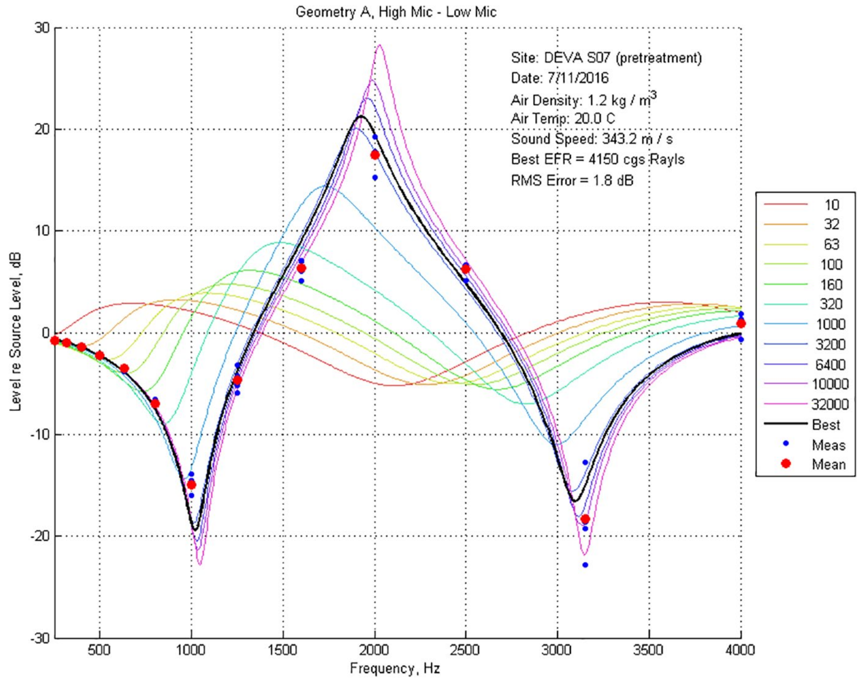

Figure 25. Comparison of measured (blue dots), average measured (red dots) and computed best fit (solid lines) sound level differences by frequency at site S07, pre-treatment conditions. A black line indicates the differences computed for the EFR value that best fits the measured data (4150 cgs rayls).

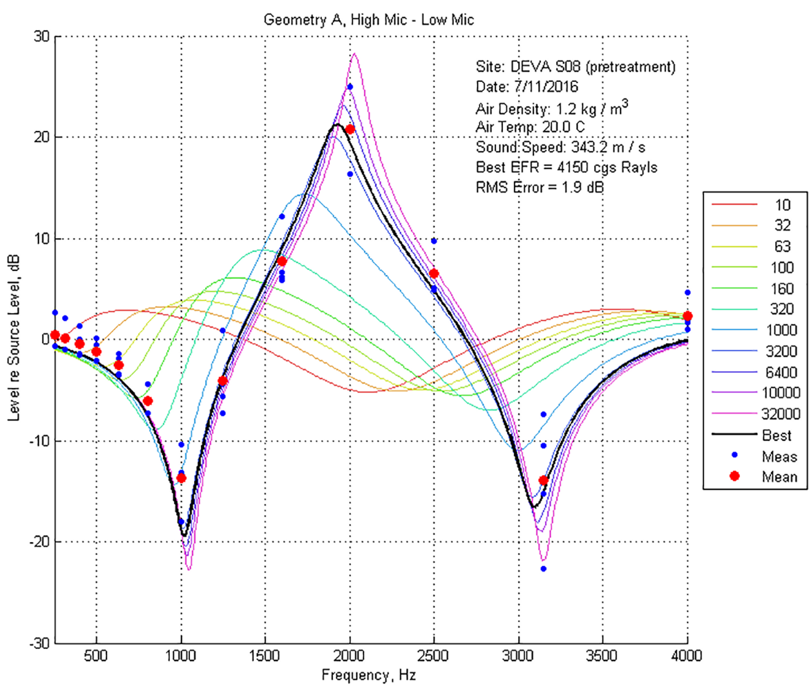

Figure 26. Comparison of measured (blue dots), average measured (red dots) and computed best fit (solid lines) sound level differences by frequency at site S08, pre-treatment conditions. A black line indicates the differences computed for the EFR value that best fits the measured data (4150 cgs rayls).

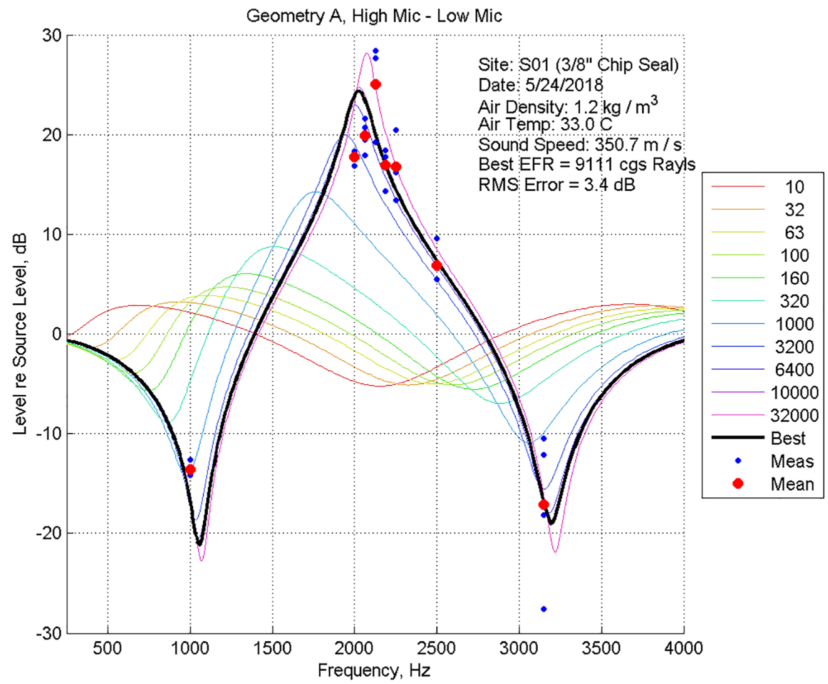

Figure 27. Comparison of measured (blue dots), average measured (red dots) and computed best fit (solid lines) sound level differences by frequency at site S01, 1-month post-treatment condition, 3/8" chip seal. The black line indicates the differences computed for the EFR value that best fits the measured data (9111 cgs rayls).

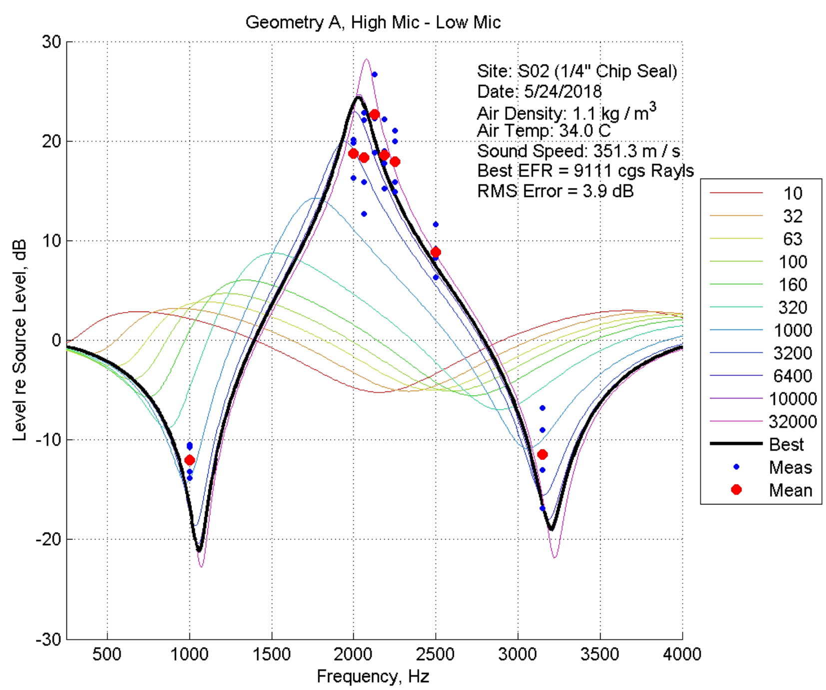

Figure 28. Comparison of measured (blue dots), average measured (red dots) and computed best fit (solid lines) sound level differences by frequency at site S02, 1-month post-treatment condition, ¼" chip seal. The black line indicates the differences computed for the EFR value that best fits the measured data (9111 cgs rayls).

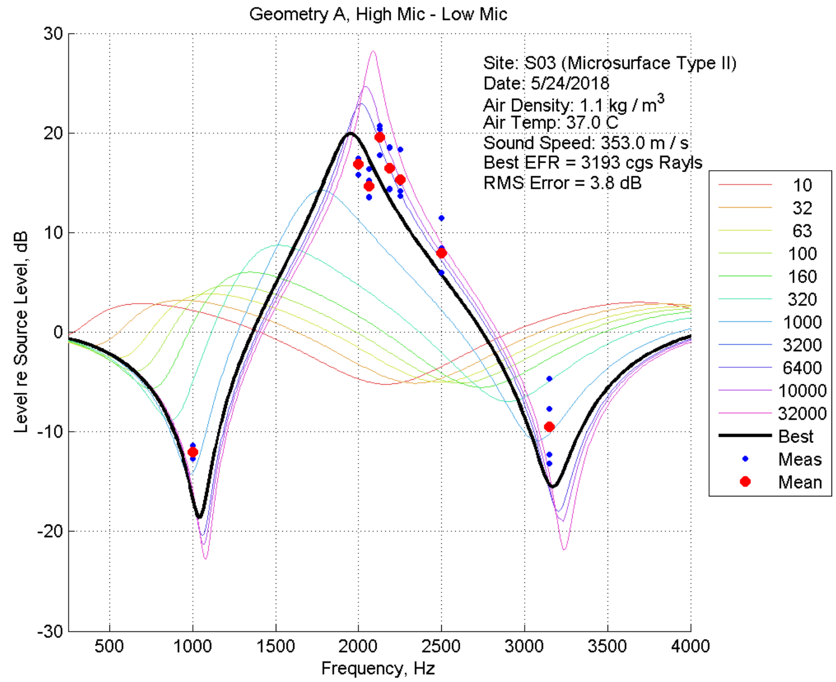

Figure 29. Comparison of measured (blue dots), average measured (red dots) and computed best fit (solid lines) sound level differences by frequency at site S03, 1-month post-treatment condition, type II microsurfacing treatment. The black line indicates the differences computed for the EFR value that best fits the measured data (3193 cgs rayls).

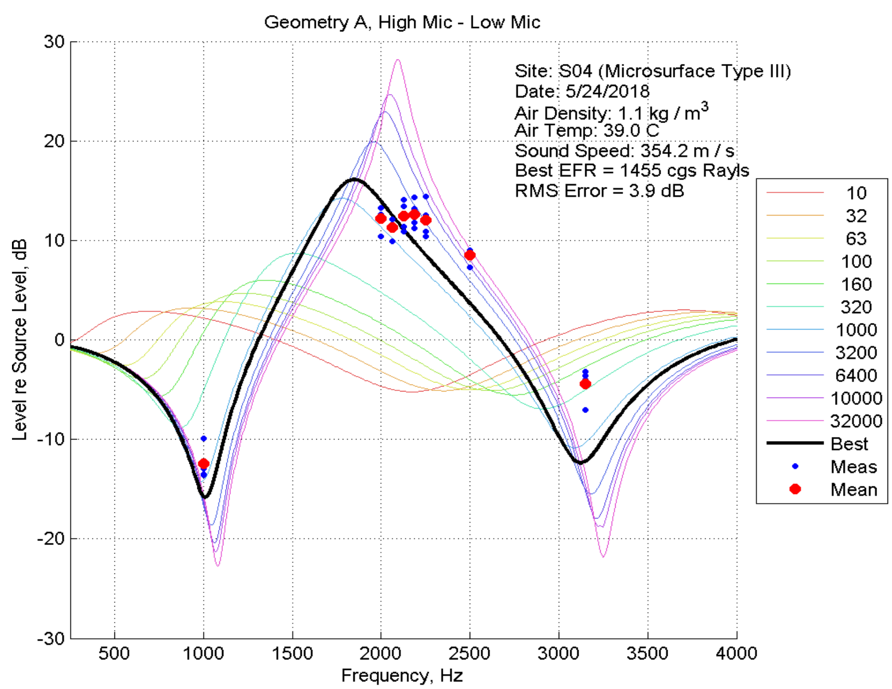

Figure 30. Comparison of measured (blue dots), average measured (red dots) and computed best fit (solid lines) sound level differences by frequency at site S04, 1-month post-treatment condition, type III microsurfacing treatment. The black line indicates the differences computed for the EFR value that best fits the measured data (1455 cgs rayls).

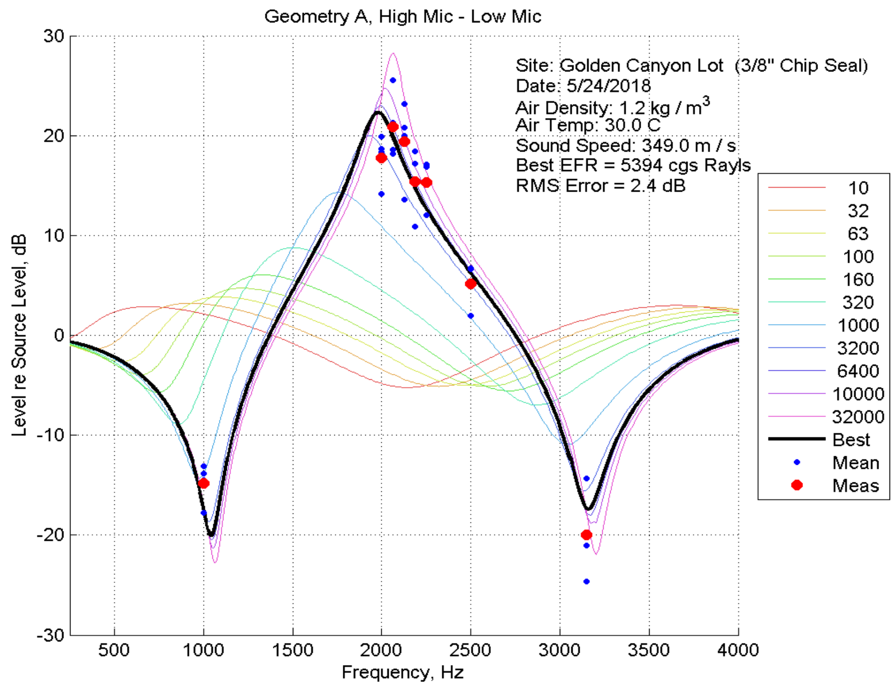

Figure 31. Comparison of measured (blue dots), average measured (red dots) and computed best fit (solid lines) sound level differences by frequency at Golden Canyon Parking Lot, 1-month post-treatment condition, type II microsurfacing treatment. The black line indicates the differences computed for the EFR value that best fits the measured data (5394 cgs rayls).

In these measurements, EFR data were measured with more data collected between the 2000-2500 Hz, 1/3 octave band center frequencies (as indicated with a greater concentration of blue data points at those frequency bands in Figures 24 through 31). The intent was to obtain more accurate estimates of the EFR since the range of 2000-2500 Hz is where the differences between EFR values of different pavement types are expected to be greatest. By following this process there can be a greater spread for the individual samples. But on average, this helps to match a single EFR curve more robustly, since it helps to deemphasize minor differences in pavement and source and receiver geometries during the repetitions. In general this updated process achieved good results, making it is easier for the algorithm to identify the best fit line. In future measurements, additional frequencies may be measured to further increase the EFR estimate accuracy.

The best-fit EFR values for the pre- and 1-month post-treatment measurements are presented in Table 8. The values shown below fall within the range measured for pavements (2,000 to 30,000); with the exception of the type III microsurfacing. The chip seal pavement treatments have high EFR values, while the microsurfacing pavement treatments generally have the low EFR values; the pre-treatment pavements fall in between. Although S03 and the parking lot were both treated with type II microsurfacing, they have different EFR values as they have experienced different wear and tear, with the latter experiencing a month of foot traffic as well as vehicles traveling far below design speed. These results agree with results from the other measurement techniques (OBSI and wayside).

Table 8. Best-fit EFR values by measurement location.

Measurement Location	EFR (cgs/rayls)
S02: pre-treatment	7010
S07: pre-treatment	4150
S08: pre-treatment	4150
S01: 3/8” chip seal	9111
S02: 1/4” chip seal	9111
S03: type II microsurfacing	3193
S04: type III microsurfacing	1455
Golden Canyon Parking Lot: type II microsurfacing	5394

3 Discussion

Overall, the sound level data show that the wayside sound levels of the pavement treatments at 1-month age overlap the national average reference energy-mean emission level (REMEL) for average pavements, as the pre-treatment levels did in 2016. This is expected, as the national average category actually encompasses a wide range of dense-graded asphalt, DGAC pavements. The OBSI measurements also show that, at 1-month age, these pavement treatments fall within the typical range for dense-graded asphalts. However, EFR values for these pavements are about half to one tenth that of what is normally modeled for pavements. These low levels may partly be explained by the fact that the nominal value of 20,000 cgs rayls includes consideration of concrete pavements, which are acoustically harder than asphalt pavements. Other factors contributing to these levels include the asphalt mix, texture and potentially the age of the pavement.

There are discernable differences in overall sound level emissions from these pavement treatments. The type II microsurfacing has the lowest overall wayside and OBSI levels. The 3/8" chip seal produces the highest overall OBSI levels but had the second lowest wayside sound levels. The ¼" chip seal produces the second highest wayside sound levels and second highest OBSI levels. As expected, the chip seal pavements at 1-month age generally have greater sound intensity levels then did the pre-treatment pavement. Measurements over the remaining study years will help to indicate if these differences increase or decrease.

The pre-treatment trend line is a good approximation of the REMEL relationship, closely resembling average pavement, as expected. The trend lines for both the 1/4" chip seal and type III microsurfacing pavements have a more shallow slope than the REMEL relationship – with sound levels at typical park speeds (below 55 mph) being higher than average. The trend lines for both the 3/8" chip seal and type II microsurfacing pavements are by contrast, slightly steeper than the REMEL relationship – with lower speeds being significantly quieter than expected for average pavement at typical park speeds.

The overall sound levels, however, do not tell the whole story. It has been demonstrated that the frequency content of the emitted sound can vary substantially, even between two pavements having the same overall sound level. So much so, that even casual observers can hear and discern a difference between the sounds generated by each pavement type with similar overall levels.[3] The frequency content may be particularly important in park environments, where preservation of the natural sound environment is the goal, and therefore long-range sound propagation is of concern. Low-frequency sounds propagate longer distances than high-frequency sounds, as sounds with longer wavelengths are not as easily absorbed by ground surfaces and vegetation, and can more readily diffract around terrain features (e.g., hills, walls, etc.).

[3] A separate study is to be conducted to fully evaluate visitor responses to and ratings of the sounds of these different types of pavement.

Both the OBSI and wayside data characterize the frequency content of the emitted sounds. The microsurfacing type II pavement produces the least low-frequency energy of all the treatments, while the microsurfacing type III pavement produces more low and mid-frequency energy, but less high-frequency energy than all other pavement types. This causes the overall sound quality of the microsurfacing type III to sound ‘deeper’ or ‘boomier’ than other pavements. When propagation over long distances is of concern, it is generally advantageous to have the acoustic energy distributed in the higher frequency bands, which causes the overall levels to attenuate more quickly with distance. As the textures change over time, the frequency content of these pavements may change, so it will be important to monitor these spectra over time. Supplemental acoustic modeling using FHWA’s TNM shows that at 1-month post-treatment, at 50 ft distance, use of the type II microsurfacing treatment would result in a reduction in sound level equivalent to a 40% *decrease* in daily traffic, whereas the type III microsurfacing treatment would result in an increase in sound level equivalent to a 70% *increase* in daily traffic. At a distance of one mile, use of the type II microsurfacing would result in a reduction in sound level equivalent to a 30% *decrease* in daily traffic, whereas the type III microsurfacing would result in an increase in sound level equivalent to a 140% *increase* in daily traffic. This increase in sound level compared to the pre-treatment pavement is due to the prevalence of low-frequency energy from the type III microsurfacing pavement, which propagates long distances.

The measured EFR data show that the new chip seal pavement (both 3/8” and ¼” aggregates) have the highest EFR values, while the new microsurfacing pavements have the lowest EFR values. In the 2018, post-treatment, EFR data were measured with additional data points collected between the 2000-2500 Hz. The intent was to obtain more accurate estimates of the EFR, as this frequency range is where the differences between EFR values of different pavement types are expected to be greatest. By following this process there can be a greater spread for the individual samples. But on average, this helps to match a single EFR curve more robustly, since it helps to deemphasize minor differences in pavement, source and receiver geometries during the repetitions. In general, this updated process achieved good results, making it is easier for the algorithm to identify the best fit line. In future measurements, additional frequencies may be measured to further increase the EFR estimate accuracy.

5. Next Steps

This document reports the results of noise measurements for the pre-treatment conditions as well as the initial post-treatment conditions at Death Valley National Park (DEVA). Pre-treatment data, consisting of 6 year old 3/8” chip seal pavement, were collected in November 2016, while data were collected 1-month post-treatment in May 2018. Continued tracking of the acoustic performance of these pavement treatments over the course of the study will expand our understanding of how these pavement treatments age, as well as understanding which treatment may be most beneficial in terms of both (1) sound levels nearby the roadway and at greater distances, (2) and practicality in terms of durability and cost.

Future work may include expanding this type of study to additional parks – those that may have access to or preference for different pavement types, which would occur for parks nearer population centers, as well as those which may have different maintenance and durability challenges due to climate (for example climates with 4 seasons). It is expected that through this work park managers will have more choices on the type of pavement that is best suited to their particular park environment.

6. Literature Cited

American Association of State and Highway Transportation Officials, 2010. Standard Method of Test for Measurement of Tire/Pavement Noise Using the On-Board Sound Intensity (OBSI) Method, AASHTO TP 76-10.

American National Standards Institute and Acoustical Society of America Standards, 1999. Template Method for Ground Impedance, ANSI S1.18-1999, Acoustical Society of America, New York.

Dana Lodico and Paul Donavan, “Quieter Pavement - Acoustic Measurement and Performance”, California Department of Transportation Division of Environmental Analysis, February 2018.

Hastings, Aaron, 2018. Quieter Pavements Guidance Document – Addendum for Years 2013 to 2018. Natural Resource Technical Report NPS/NSNS/NRTR—2018/XXX. (Draft)

Lau, Michael C., Cynthia S.Y. Lee, Judith L. Rochat, Eric R. Boeker, and Gregg G. Fleming. 2004. FHWA Traffic Noise Model® (FHWA TNM®) User’s Guide (Version 2.5 Addendum), Report No. FHWA-PD-96-009, Washington, D.C.: Federal Highway Administration.

Lee, Cynthia S.Y. and Gregg G. Fleming 1996. Measurement of Highway Related Noise, Report No. FHWA-PD-96-046, U.S. Department of Transportation, Volpe National Transportation Systems Center, Acoustics Facility, Cambridge, MA, USA.

Lee, Cynthia and MacDonald, John, Death Valley National Park: Baseline Ambient Sound Levels 2008, DOT-VNTSC-NPS-11-19, Cambridge, MA: John A. Volpe National Transportation Systems Center, 2016.

Richard Sohaney, Robert O. Rasmussen, Paul Donavan, and Judith L. Rochat, 2013. Quieter Pavements Guidance Document, Natural Resource Technical Report NPS/NSNS/NRTR—2013/760, June 2013.

Rochat, Judith L., Michael Lau. 2013. Demonstration of using quieter pavement in Death Valley National Park, February 2013, DOT-VNTSC-NPS-11-23, NPS/NSNS/NRTR—2013/759.

Rochat, Judith L., Aaron L. Hastings, David R. Read and Michael Lau, 2012. FHWA Traffic Noise Model (TNM) Pavement Effects Implementation Study: Progress Report 1, Report Nos. DOT-VNTSC-FHWA-12-01, U.S. Department of Transportation, Volpe National Transportation Systems Center.

RSG, 2018. Noise Measurement Field Guide, Report No. FHWA-HEP-188-066, U.S. Department of Transportation, Federal Highway Administration, Washington, DC.

Wayson, Roger and John MacDonald 2014. Measurement of Pavement Noise in the Northeast Region: On-Board Sound Intensity and Wayside Measurements (Unpublished).

Appendix A: Report Documentation

This appendix contains a text version of the Report Documentation Page, located on page iii of this document. The form, and the content below, were added to comply with requirements for DOT-authored publications, and are not required for publishing in the NPS Natural Resource Publication Series. The content below shows the numbered questions asked on the form, followed by the answers provided by the authors and appropriate NPS management that approved the publication of this document. For additional clarity, the words "No response" were added as the answer to a question when none was provided on the original form.

REPORT DOCUMENTATION PAGE

Form Approved

OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

1. AGENCY USE ONLY (Leave blank): No response.

2. REPORT DATE: December 2019

3. REPORT TYPE AND DATES COVERED: Final Report

4. TITLE AND SUBTITLE: Quieter Pavement Project - Death Valley National Park: Interim report for post-treatment conditions, 1-month age

5. FUNDING NUMBERS: VXAEA1 / SG341

6. AUTHOR(S): Aaron L Hastings, Amanda S Rapoza, William L Chupp, Sophie Kaye, Daniel Flynn

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES):

> U.S. Department of Transportation
> Office of the Assistant Secretary for Research and Technology
> John A. Volpe National Transportation Systems Center
> Environmental Measurement and Modeling Division, V324
> Cambridge, MA 02142-1093

8. PERFORMING ORGANIZATION REPORT NUMBER: DOT-VNTSC-NPS-20-02

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)10.SPONSORING/MONITORING AGENCY REPORT NUMBER:

U.S. Department of the Interior
National Park Service
Natural Resource Program Center
Natural Sounds and Night Skies Division
1201 Oakridge Drive
Fort Collins, CO 80525

11. SUPPLEMENTARY NOTES: NPS Program Manager: Frank Turina

12a. DISTRIBUTION/AVAILABILITY STATEMENT: No response.

12b. DISTRIBUTION CODE: No response.

13. ABSTRACT (Maximum 200 words):

The U.S. Department of Transportation, John A. Volpe National Transportation Systems Center is assisting the National Park Service, Natural Sounds and Night Skies Division in the study of practical noise reduction benefits of common surface treatments used by the Parks for pavement preservation. The goal of this study is to provide park administrators and planners with paving options using the standard surface treatments that alone, or in conjunction with other strategies, can help reduce noise in sensitive park areas. Acoustic data for the pre-treatment conditions, before application of the surface treatments, were collected on November 7 and 8, 2016. Acoustic data for immediate post-treatment conditions, one month after treatments were applied, were collected May 23 and 24, 2018. This document summarizes these interim data collected and results of the noise measurements. As the pavements age and additional measurements are made, these data and analyses will be updated in future reports.

14. SUBJECT TERMS: Quieter pavements, traffic noise, noise, Death Valley, National Park, soundscape

15. NUMBER OF PAGES: 56

16. PRICE CODE: No response.

17. SECURITY CLASSIFICATION OF REPORT: Unclassified

18. SECURITY CLASSIFICATION OF THIS PAGE: Unclassified

19. SECURITY CLASSIFICATION OF ABSTRACT: Unclassified

20. LIMITATION OF ABSTRACT: No response.

The Department of the Interior protects and manages the nation's natural resources and cultural heritage; provides scientific and other information about those resources; and honors its special responsibilities to American Indians, Alaska Natives, and affiliated Island Communities.

NPS 143/166876, February 2020

National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science
1201 Oakridge Drive, Suite 150
Fort Collins, CO 80525

EXPERIENCE YOUR AMERICA ™