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Quieter Pavement Project - Death Valley National Park

Interim Report for One-Year Post-Treatment Conditions

Natural Resource Report NPS/NRSS/NSNSD/NRR—2020/2143

U.S. Department of Transportation
Volpe Center

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

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U.S. Department of Transportation
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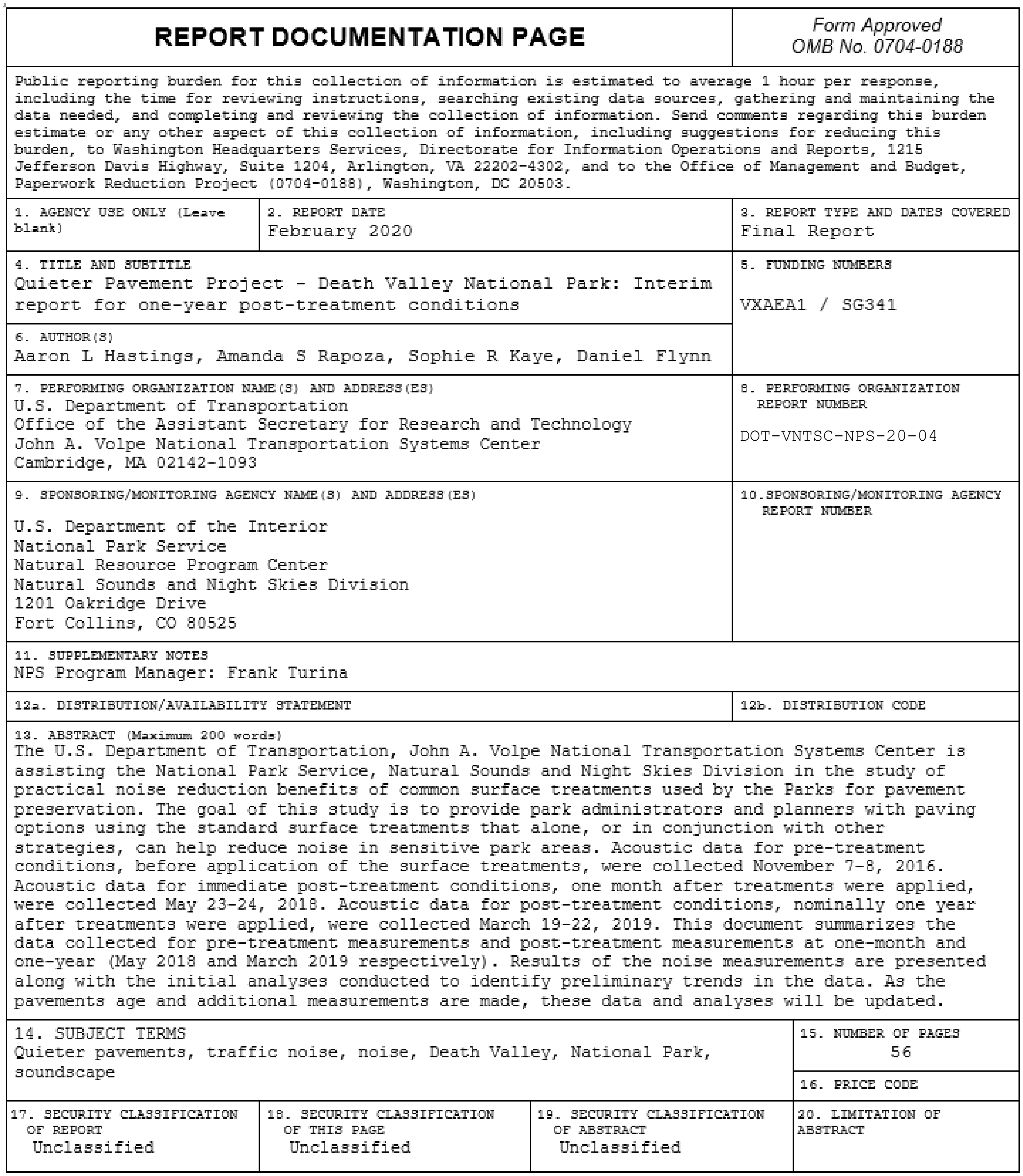

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The U.S. Department of Transportation, John A. Volpe National Transportation Systems Center is assisting the National Park Service, Natural Sounds and Night Skies Division in the study of practical noise reduction benefits of common surface treatments 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 pre-treatment conditions, before application of the surface treatments, were collected November 7-8, 2016. Acoustic data for immediate post-treatment conditions, one month after treatments were applied, were collected May 23-24, 2018. Acoustic data for post-treatment conditions, nominally one year after treatments were applied, were collected March 19-22, 2019. This document summarizes the data collected for pre-treatment measurements and post-treatment measurements at one-month and one-year (May 2018 and March 2019 respectively). Results of the noise measurements are presented along with the initial analyses conducted to identify preliminary trends in the data. As the pavements age and additional measurements are made, these data and analyses will be updated.

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Abstract

The U.S. Department of Transportation, John A. Volpe National Transportation Systems Center is assisting the National Park Service (NPS) 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 7–8, 2016. Acoustic data for immediate post-treatment conditions, one month after treatments were applied, were collected May 23–24, 2018. Acoustic data for post-treatment conditions, nominally one year after treatments were applied, were collected on March 19–22, 2019. This document summarizes the data collected for pre-treatment measurements (November 2016) and post-treatment measurements at one-month and one-year (May 2018 and March 2019 respectively). Results of the noise measurements are presented along with the initial analyses conducted to identify preliminary trends in the data. As the pavements age and additional measurements are made, these data and analyses will be updated in future reports.

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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: Alison Ainsworth, Justin DeSantis, Sarah Raube, Kevin Green, Josh Hoines, Frank Lambert 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, Robert Downs, John MacDonald, and David Read. We would also like to thank the peer reviewers for this document – Kurt Fristrup, Ashley Pipkin and Cynthia Lee.

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 three 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. Measurement data for the pre-treatment condition provide a baseline/reference by which the surface treatments can be compared. Data for post-treatment conditions were collected in May 2018, approximately one month after treatments were applied, and in March 2019, nominally one year after treatments were applied. Post-treatment data regarding the four surface treatments under investigation will be collected at regular intervals over the duration of this study (2016-2022). The Death Valley study is being conducted in cooperation with DEVA staff and the Federal Highway Administration (FHWA).

Quieter pavements have been studied and used successfully in highway applications in the US and abroad for a number of years. Sohaney (2013) published a synthesis of quieter pavements research and applications ("Quieter Pavements Guidance Document") for the National Park Service in June 2013. An addendum to that document was prepared in 2018 (Hastings, 2018), which included 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 may not be conducive at all NPS sites. 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 greater distances than highway planners (who often only consider effects up to 1000feet 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 the parks for pavement preservation. Based on discussions with FHWA and NPS, chip seal (with 3/8-inch and 1/4-inch 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 provide a baseline/reference by which the surface treatments can be compared. For instance, chip seal is a common surface treatment that has 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 determine that change in noise levels. 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 National Park System's largest park 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 longer 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 already planned for 2017–2018. Site selection within this area was based on proximity to acoustically sensitive areas: frequency of 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, receiving pavement surface rehabilitation treatments in early 2018, and having 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, California (see Figure 1).

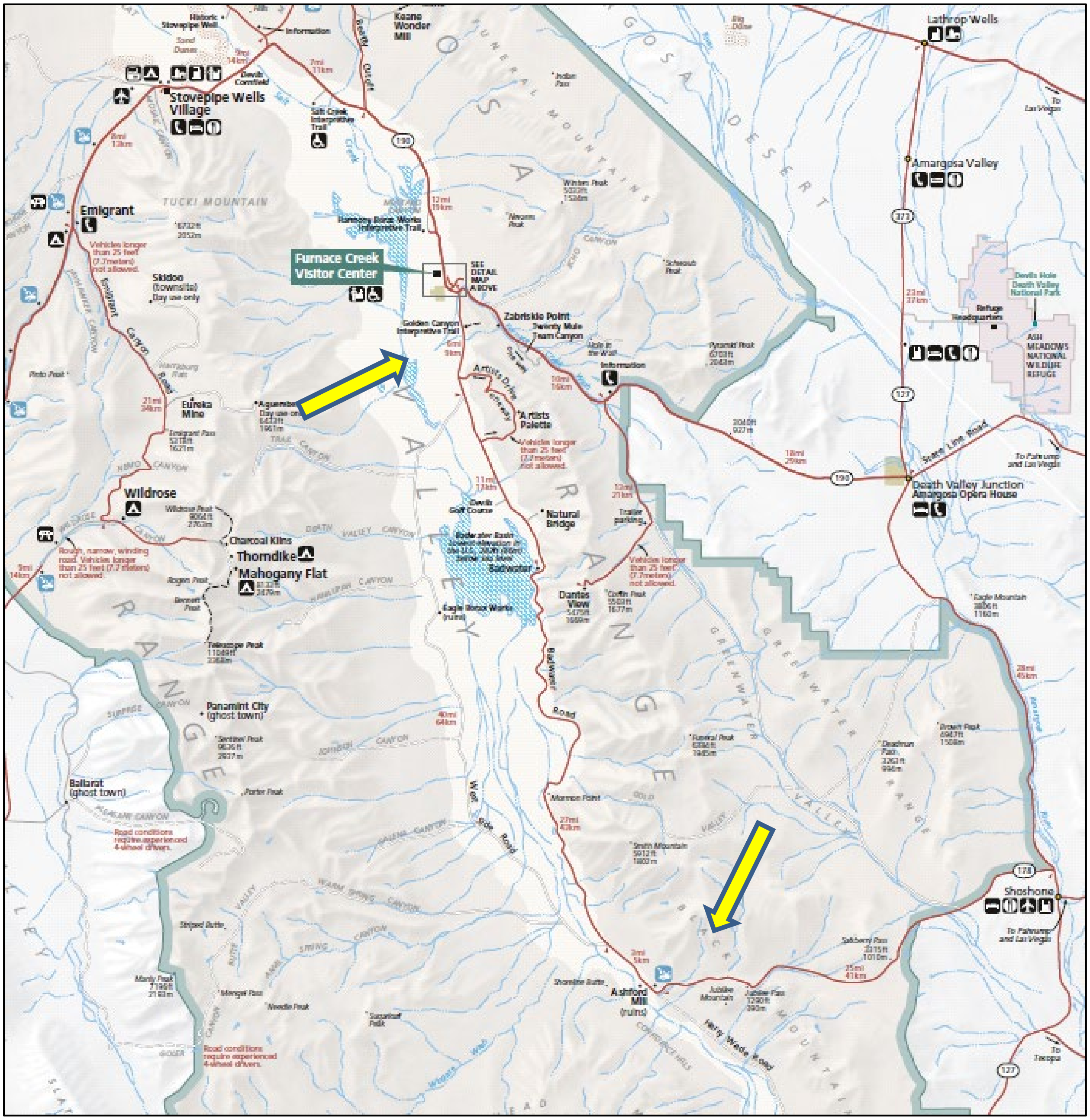

Figure 1. Park map showing Badwater / Furnace Creek area. Arrows point to the geographical areas along Badwater Road selected for measurements

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. Eight locations were selected around two geographical areas, creating a northern and a southern group. Each of the four pavement treatments were applied in both the northern and southern site groups. The northern group of sites (S01-S04) has more traffic with 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 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 subjected to damaging flash flooding.

The Badwater Road re-paving project took place during March and April 2018 with coordination and oversight from the FHWA Office of Federal Lands Highway. The repaving was part of a larger project in Death Valley, where numerous sections of park roadways were resurfaced. The 3/8-inch 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-inch 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 were at least 2000feet from the nearest change in surface treatment.

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 effective flow resistivity (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.

Before testing began for the pavements at one-year of age in March 2019, the northern sites (S01-S04) experienced periods of flooding and washouts; mud was caked into the pavements. The southern sites (S05-S08) did not show evidence of flooding. Figure 2 shows a worst-case example of a portion of mud-caked roadway, where portions were completely filled in and covered over with dirt. Road conditions immediately after a period of flash flooding witnessed during the measurement trip on March 22, 2019 is evidenced in Figure 3, where portions of the roadway are not visible beneath the mud. Because of the flooding, the S01 wayside measurement location was relocated approximately 1000feet south of the original location to avoid the worst of the mud-caked roadway. This relocated site was in an area with the same 3/8-inch chip seal pavement type, as this was the default pavement for the entire roadway. This site was designated S01A. The flooding has the potential to effectively and prematurely age the pavement by increasing the amount of air voids filled with dirt and by increasing the wear on the surface due to the clearing process used for removing the detritus post-flooding.

Figures 4 through Figure 12 show photographic examples of the pre-treatment pavement in March 2016 and post-treatment pavement sections of Badwater Road as of March 2019.

Figure 2. Example (worst-case) of mud-caked roadway as seen on northern Badwater Road, March 2019 (VOLPE CENTER)

Figure 3. Example of March 2019 flood conditions on northern Badwater Road (VOLPE CENTER)

Figure 4. Example of pre-treatment pavement at site S02, November 2016 (VOLPE CENTER)

Figure 5. 3/8-inch chip seal treatment at site S01, March 2019 (VOLPE CENTER)

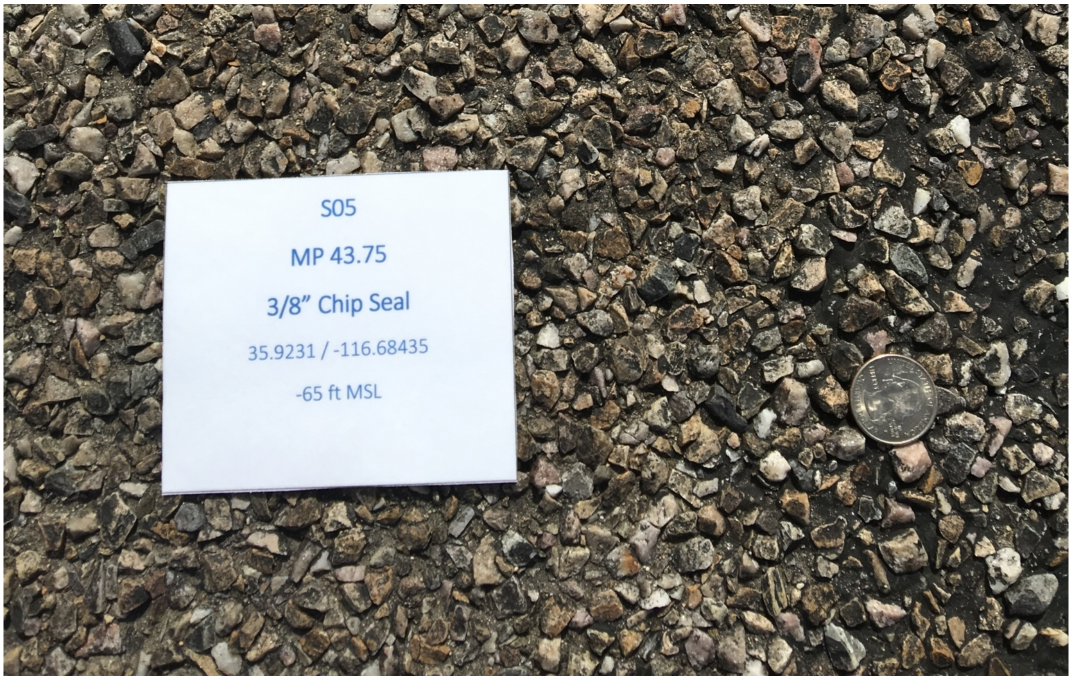

Figure 6. 3/8-inch chip seal treatment at site S05, March 2019 (VOLPE CENTER)

Figure 7. 1/4-inch chip seal treatment at site S02, March 2019 (VOLPE CENTER)

Figure 8. 1/4-inch chip seal treatment at site S08, March 2019 (VOLPE CENTER)

Figure 9. Type II microsurfacing treatment at site S03, March 2019 (VOLPE CENTER)

Figure 10. Type II microsurfacing treatment at site S07, March 2019 (VOLPE CENTER)

Figure 11. Type III microsurfacing treatment at site S04, March 2019 (VOLPE CENTER)

Figure 12. Type III microsurfacing treatment at site S06, March 2019 (VOLPE CENTER)

Figure 13 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.

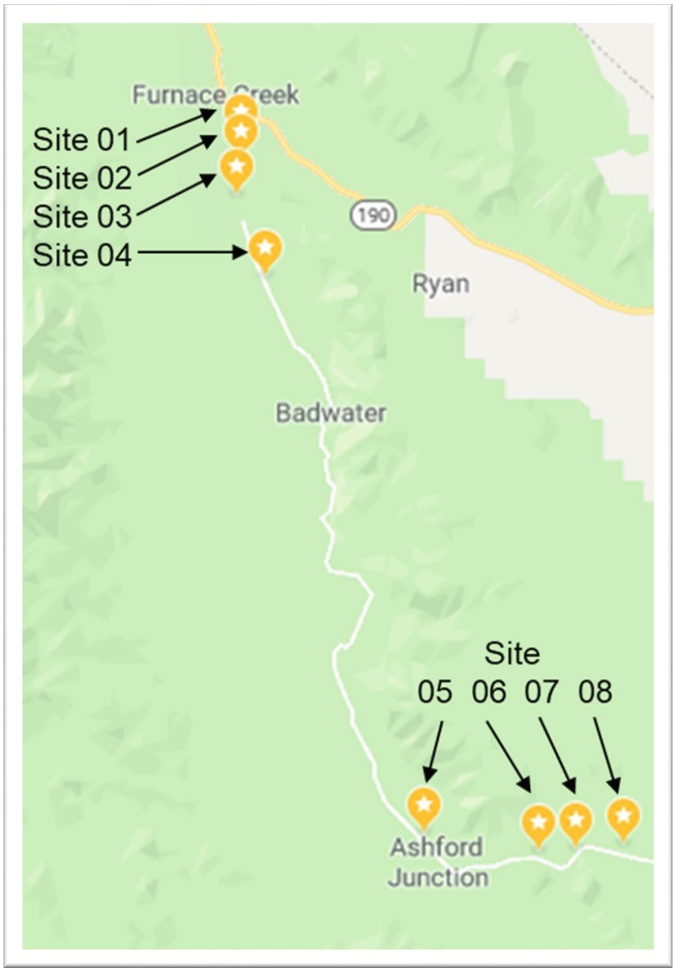

Figure 13. Map of Death Valley, Badwater Road, showing site locations

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-inch chip seal (default)	36.41783	-116.84708	2.0 to 2.5	-187
S01A	3/8-inch chip seal (default)	36.413311	-116.845924°	2.0 to 2.5	-170
S02	1/4-inch 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-inch 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
S08	1/4-inch 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 one-month were collected during May 23-24, 2018. Data for post-treatment conditions at nominally one-year were collected March 20 and 22, 2019. 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 a distance of 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 (referred to as “Eddie” in Figure 14), 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 the 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.

Additional 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 three-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 at each location to form matched datasets. This permits noise measurement along the roadway as well as the noise at the tire/pavement interface and allows analysis of propagation effects. 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 during the three measurement periods in 2016, 2018, and 2019. 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 one-month and one-year post-treatment conditions were collected for each of the four pavement treatment types in the northern section (S01, S02, S03, and S04). 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 14 shows the approximate locations of the OBSI and EFR measurements relative to the wayside location at a single site.

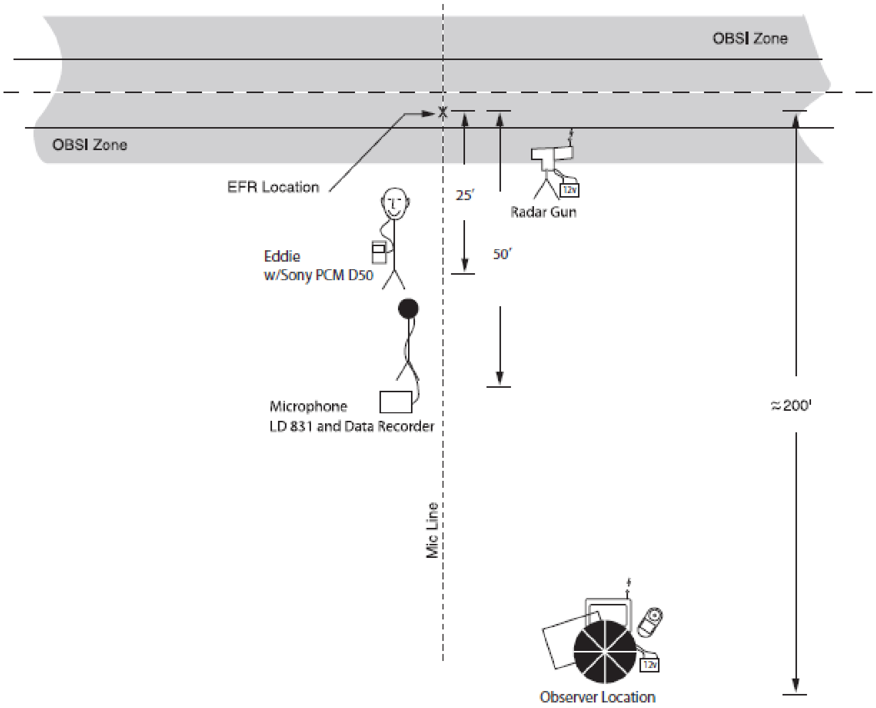

Figure 14. Approximate instrumentation and test locations for OBSI, Wayside, Binaural and EFR measurements.

3.1 Tire/Pavement Sound Intensity Levels (OBSI Measurements)

On-board sound intensity (OBSI) is a measure of the tire/pavement noise generated at the source. The standard test method (AASHTO TP76-10) was used, wherein two intensity probes were placed three-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 15). 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 15. 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 passes 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 15. Cables carried the electrical signal from the probes at the wheel, to the data analyzer and laptop computer inside the car where the sound intensity from the probes was automatically recorded. Data collected for each test run consisted of the overall sound intensity level and the sound intensity level in one-third octave bands between 250 and 5000 Hz. Multiple passes were run on each test section of roadway and averaged to obtain a single OBSI level. 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 TP76-10.

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] (Lee, 1996), where the goal is to collect maximum sound level data for individual vehicle pass-by events. During the pre-treatment measurements, data were collected for 4–6 hours at each site S02 and site

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[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).

S07. During the one-month and one-year post-treatment measurements, data were collected for 2–3 hours each at sites S01/S01A–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 16). A Class 1 sound level meter measured A-weighted maximum sound level (using fast response)[2] as well as one-third octave band one-half second equivalent levels. Meteorological data (air temperature, relative humidity, wind speed, and wind direction) and pavement temperature were recorded at hourly intervals.

During measurements, field personnel monitored pass-by events and recorded the event time, vehicle speed (measured by radar), vehicle type (auto, RV, 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 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 occur when the vehicle is clear of other vehicles by 150feet on each side of the microphone (for multiple automobiles) or 500feet for automobiles with motorcycles nearby.

Figure 16. Example wayside measurement setup at site S03 (VOLPE CENTER)

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

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

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

The half-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 replicate the acoustic conditions in which humans experience sound. Listening to these recordings through high quality headphones produces a simulation of the actual audio environment, thus providing a three-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 17 shows the setup of the binaural head recording system along Badwater Road at site S03.

Figure 17. 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 and/or reflected by the pavement when propagating outwards from the roadway.

In the FHWA Traffic Noise Model (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.

Table 2. Effective Flow Resistivity Data for Ground Types

Ground Type	**Effective Flow Resistivity (x 10^3 Pa-s/m^2)**	**Effective Flow Resistivity (x 10^3 Pa-s/m^2)**
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

EFR measurements at DEVA were conducted in conformance with ANSI S1.18, *Template Method for Ground Impedance*, using “Geometry A”. The instrumentation set-up consisted of an acoustic point source (compression driver with tube) and two microphones a set distance away and at two different heights above the ground (see Figure 18 and Figure 19). Samples were collected four times at each test section, one in the direction of travel (0 degrees), and one each at 90, 180, and 270 degrees of rotation from the direction of travel.

The method generally consists of using a signal generator to produce tones at one-third-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 vary 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.

Figure 1. EFR data collection instrumentation (VOLPE CENTER)

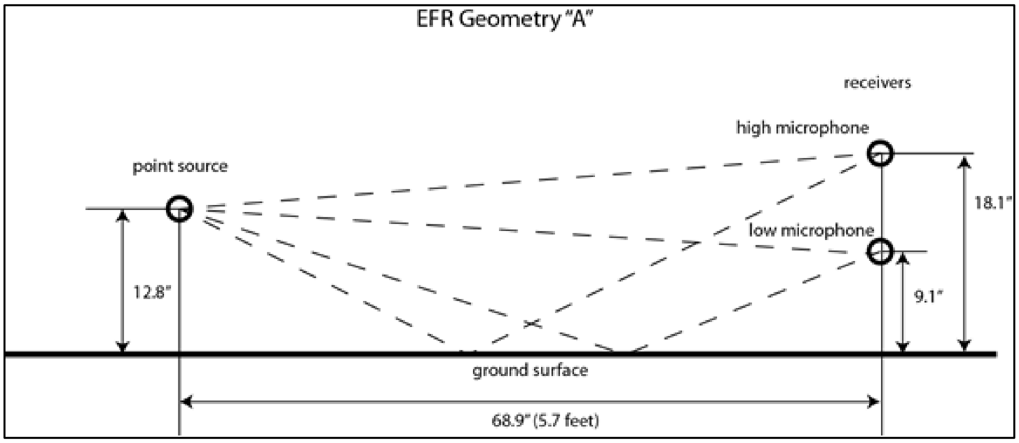

Figure 2. Diagram of EFR set-up

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 one-month and one-year (May 2018 and March 2019 respectively).

4.1 On-Board Sound Intensity Data

Table 3 shows the measured overall on-board sound intensity levels measured with OBSI techniques by location for both pre- and post-treatment pavements. In all cases, the reported overall sound intensity level (SIL) is the arithmetic average of at least three good 'runs' on each surface. As of the one-year post-treatment measurement, all northern sites (S01A-S04) produced higher overall SIL than that of the same pavement type in the southern test region (S05-S08). Moreover, all overall SIL in the northern region increased during the time period between the one-month and one-year measurement, whereas all overall SIL in the southern region decreased during that period. The increase in SIL in the northern region can be attributed to the heavier traffic volume, in addition to flooding at the northern sites, which will contribute to faster pavement deterioration. All post-treatment SILs are within 4 dB of the pre-treatment measurement at each site. These data have not been corrected to adjust for differences in pavement temperature at the time of measurement.

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

Location	Pavement Treatment	Pre-Treatment Overall SIL	One-month Post-Treatment Overall SIL	One-year Post-Treatment Overall SIL	One-year of Deterioration 2018-2019 Delta	Overall 2016-2019 Delta
S01/S01A	3/8-inch Chip Seal	99.7	100.6	101.1	0.5	1.4
S02	1/4-inch Chip Seal	100.1	99.3	99.4	0.1	-0.7
S03	Type II Microsurfacing	98.4	97.4	99.0	1.6	0.6
S04	Type III Microsurfacing	101.1	98.9	100.0	1.1	-1.1
S05	3/8-inch Chip Seal	98.3	100.1	99.4	-0.7	1.1
S06	Type III Microsurfacing	100.8	99.7	98.6	-1.1	-2.2
S07	Type II Microsurfacing	100.2	97.7	96.7	-1.0	-3.5
S08	1/4-inch Chip Seal	99.7	100.2	98.0	-2.2	-1.7

Figure 20 and Figure 21 show the one-third octave band sound intensity levels measured at each site in for the one-month and one-year post-treatment measurements respectively, allowing comparisons across pavement type. These levels correspond to the overall sound intensity levels shown in Table 3. Figure 22 through Figure 25 display the measured one-third octave band sound intensity levels from both for each material compared to the 2016 pre-treatment sound intensity levels, showing the trends for each pavement type over time. Visible trends include:

4. Type III microsurfacing pavement produced the most low-frequency and the least high-frequency content.

5. Type II microsurfacing pavement produced the least low-frequency and significantly, although not always, the most high-frequency content.

6. 3/8-inch chip seal pavement produced the most mid-frequency content with significant peaks at 800 and 1000 Hz.

7. Both chip seal pavements produced less low-frequency content over time.

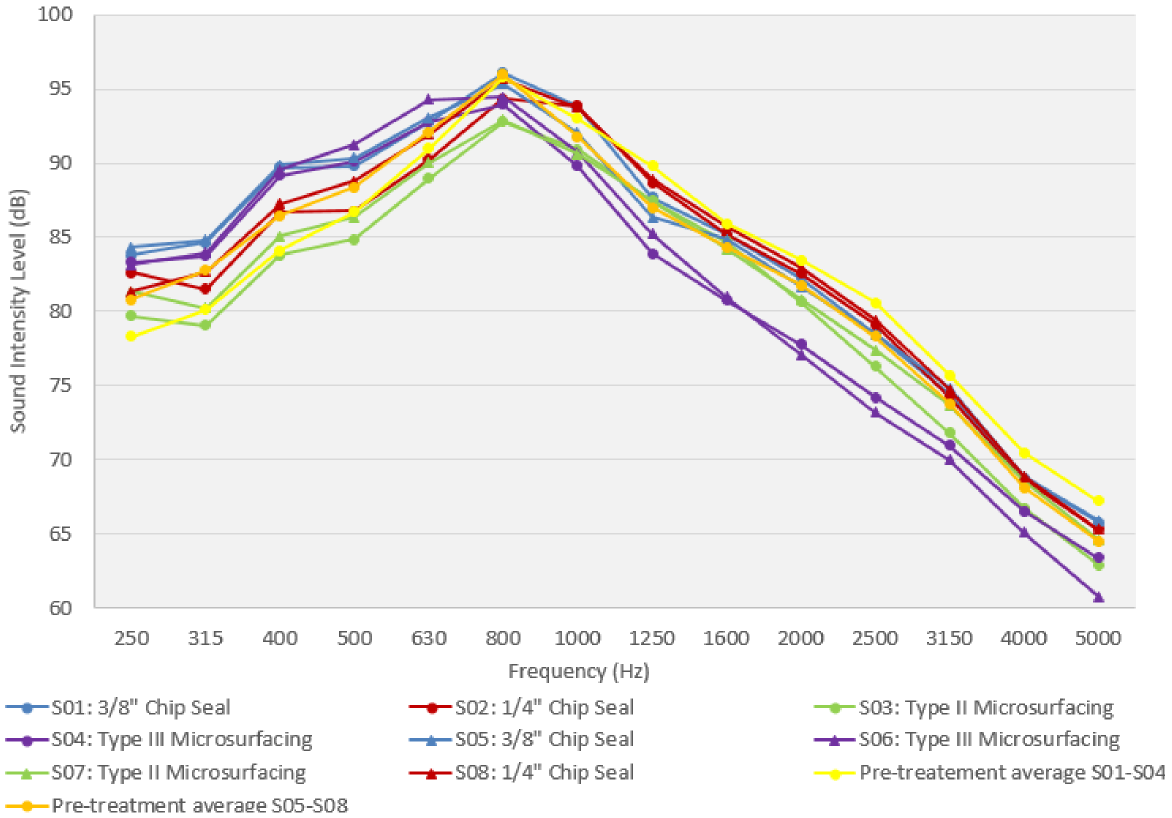

Figure 20. Measured one-third octave band sound intensity levels one-month post-treatment and pre-treatment, 45 mph speed

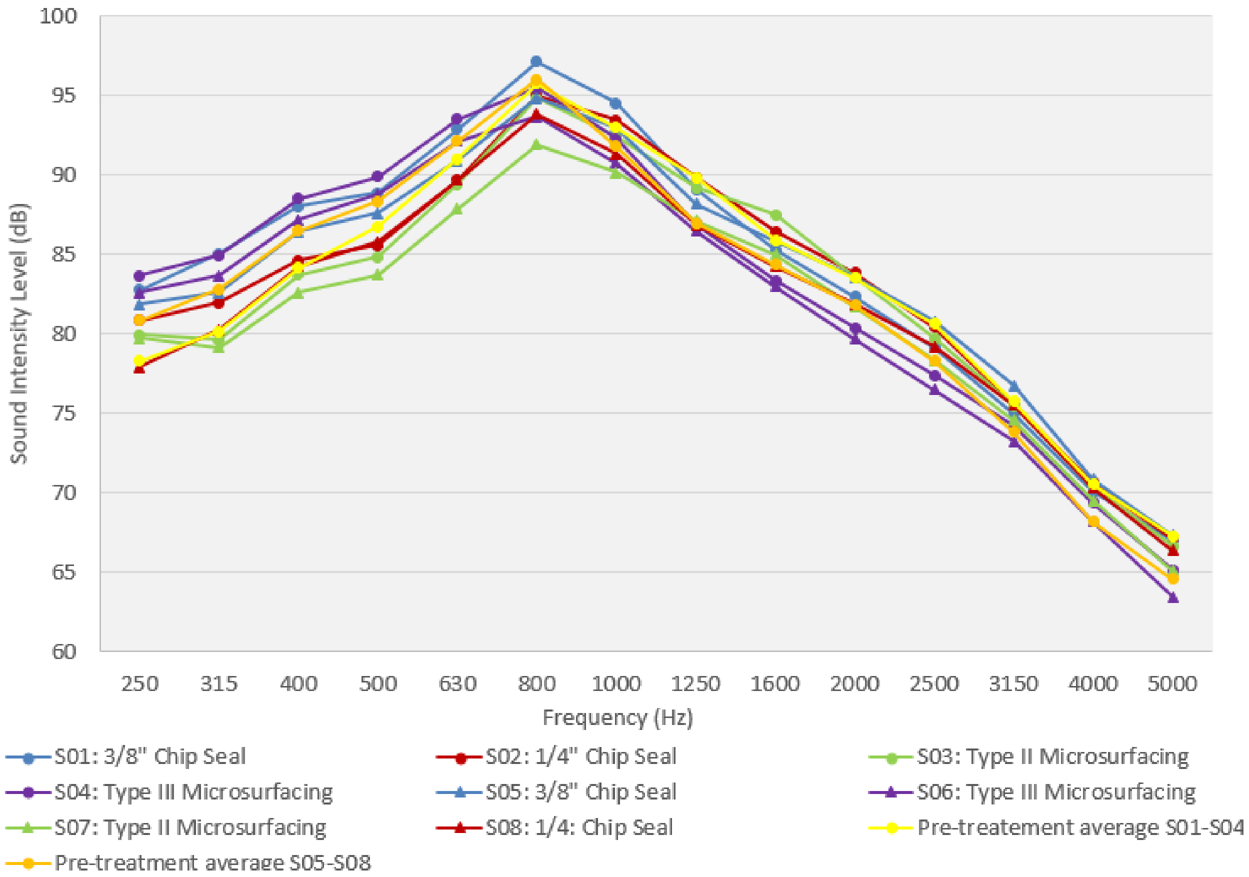

Figure 21. Measured one-third octave band sound intensity levels one-year post-treatment and pre-treatment, 45 mph speed

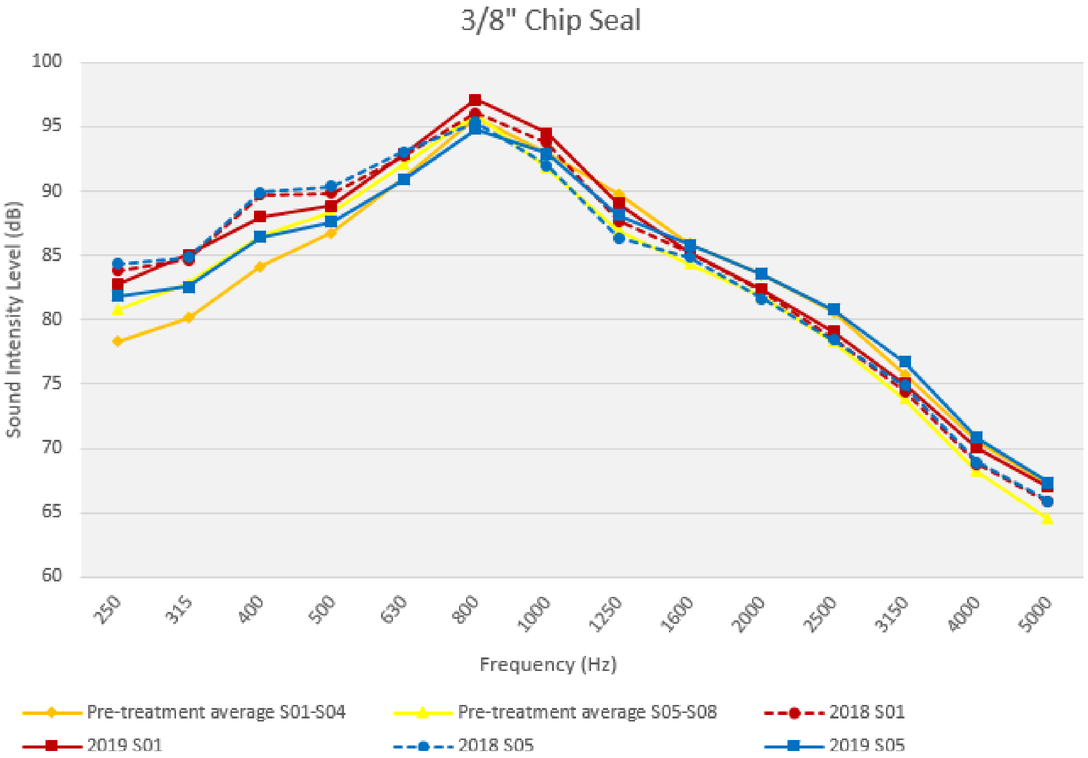

Figure 22. Measured one-third octave band SIL, 3/8-inch chip seal, 45 mph speed

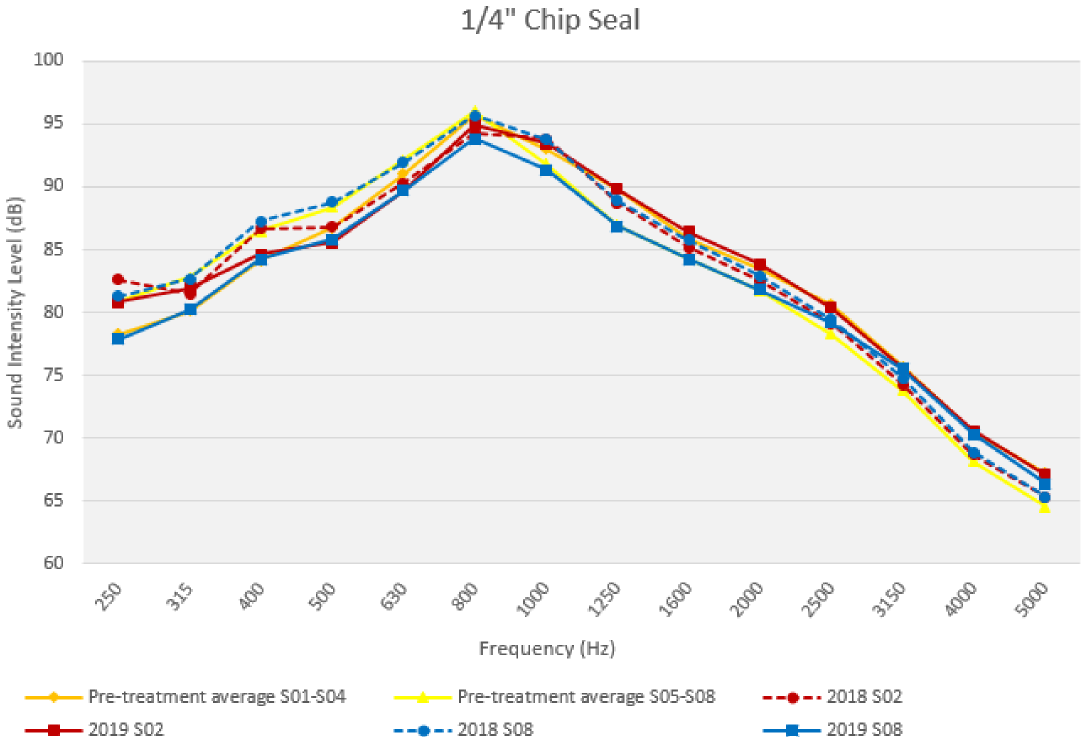

Figure 23. Measured one-third octave band SIL, 1/4-inch chip seal, 45 mph speed

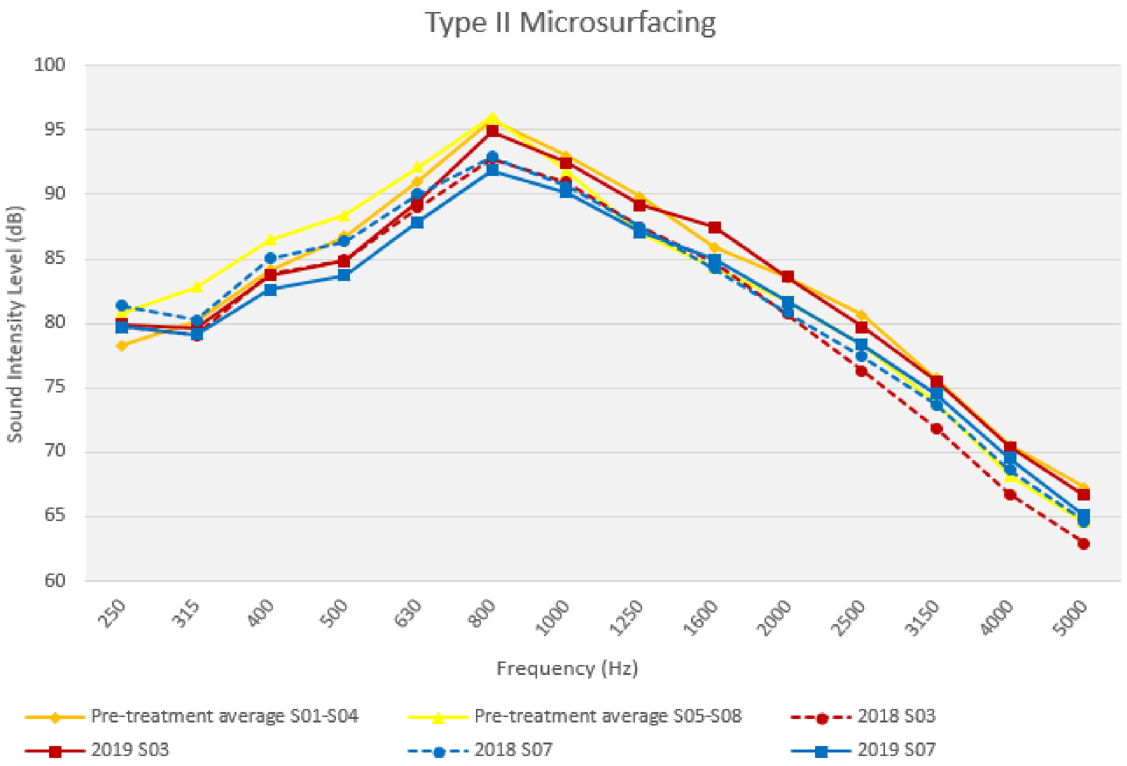

Figure 24. Measured one-third octave band SIL, type II microsurfacing, 45 mph speed

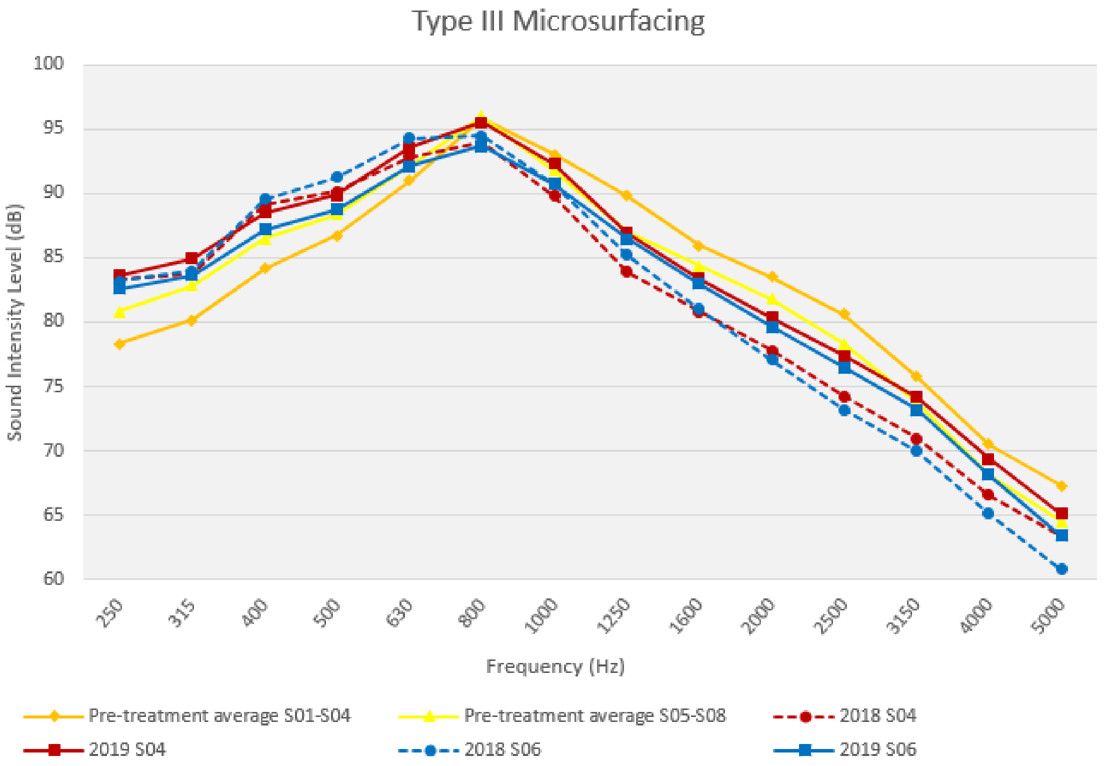

Figure 25. Measured one-third octave band SIL, type III microsurfacing, 45 mph speed

4.2 Wayside 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, both at one month and one year, wayside vehicle pass-by data were collected for each of the four treatment types at the more heavily trafficked locations S01 through S04. Table 4 summarizes the wayside maximum sound level pass-by data obtained in March 2019, one year after application of treatments..

Table 4. Summary of one-year wayside pass-by measurements

Location	Pavement Type	Number of Clean Pass-bys	Speed Range (mph)	Average Speed (mph)	Average Pavement Temperature (°F)	LAFmx Sound Level Range (dBA)	LAFmx Sound Level Average (dBA)
S01A	3/8-inch Chip Seal	33	30-54	43.7	85	65.1-74.5	69.8
S02	1/4-inch Chip Seal	38	30-64	48.8	64	61.2-78.4	71.0
S03	Type II Microsurfacing	34	30-57	45.1	67	65.1-74.5	70.0
S04	Type III Microsurfacing	24	42-67	56.0	81	65.2-76.4	71.1

Figure 26 depicts the wayside data for the pre-treatment conditions, while Figure 27 and Figure 28 depict the data for post-treatment conditions, one month and one year after treatments were applied respectively. 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®, Version 1.0 (Fleming et al. 1995) and measured with similar procedures, thus allowing for direct comparison.

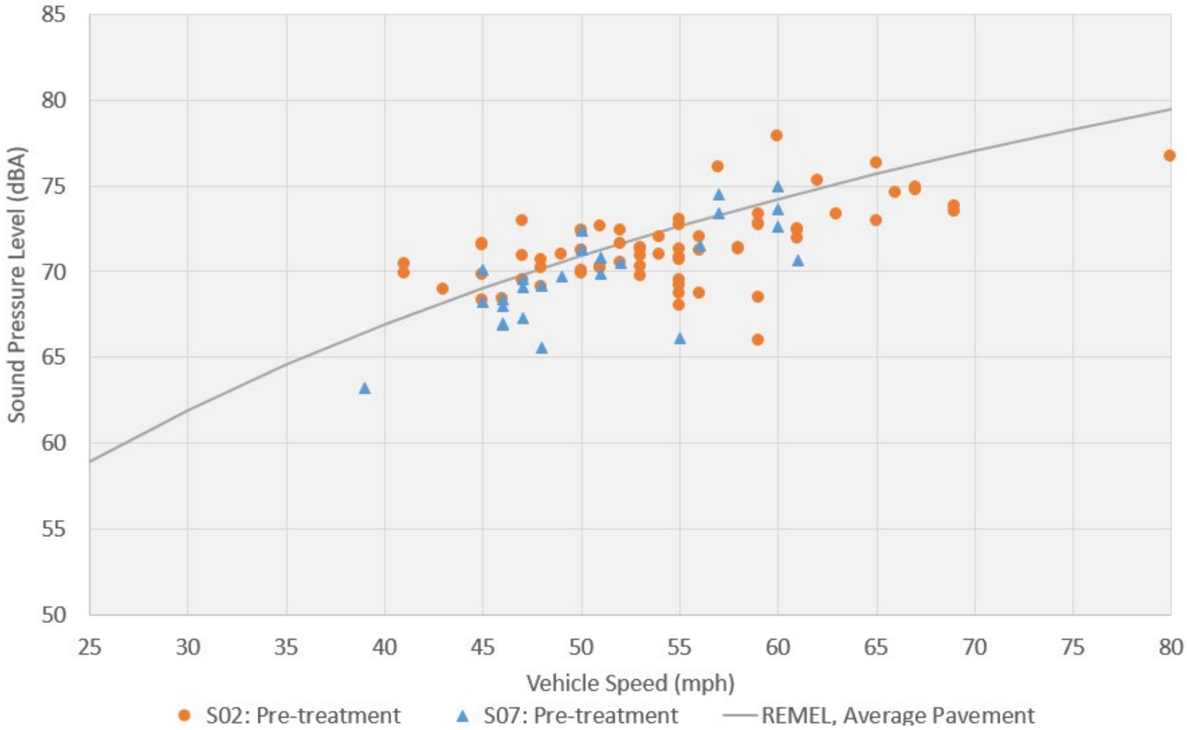

Figure 3. Measured wayside (50feet) A-weighted maximum sound pressure level data, pre-treatment conditions, sites S02 and S07. The REMEL relationship for automobiles is overlaid for comparison.

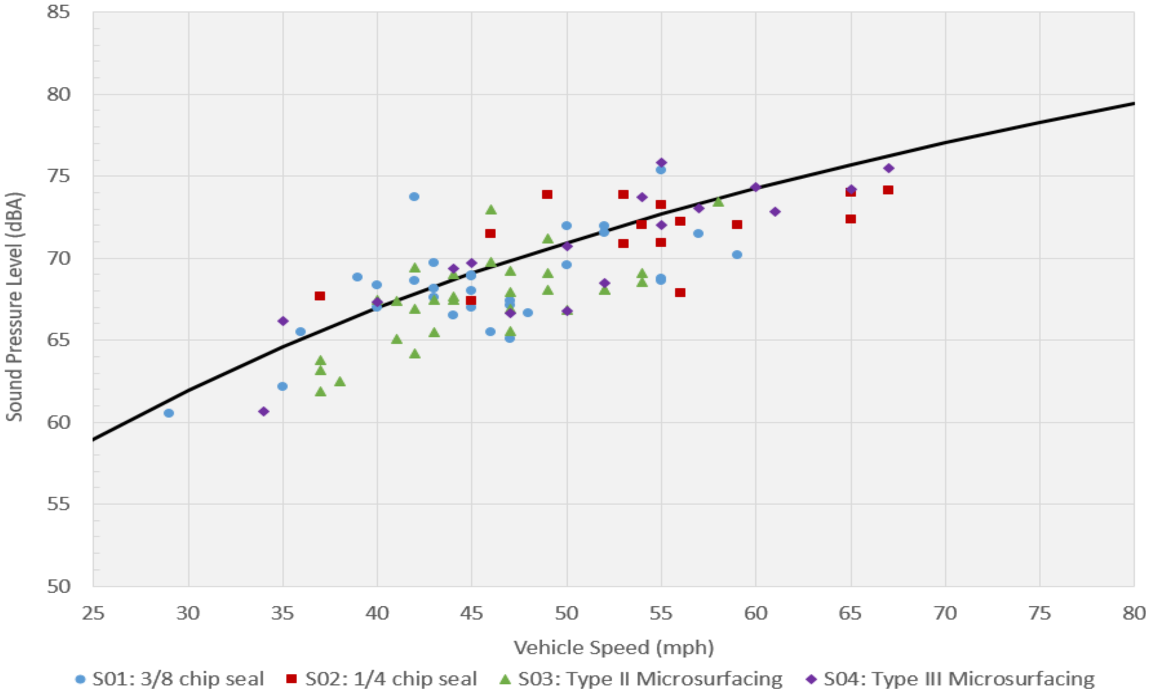

Figure 4. Measured wayside (50feet) A-weighted maximum sound pressure level, one-month post-treatment conditions, sites S01 through S04. The solid line represents the REMEL relationship for automobiles, which is overlaid for comparison.

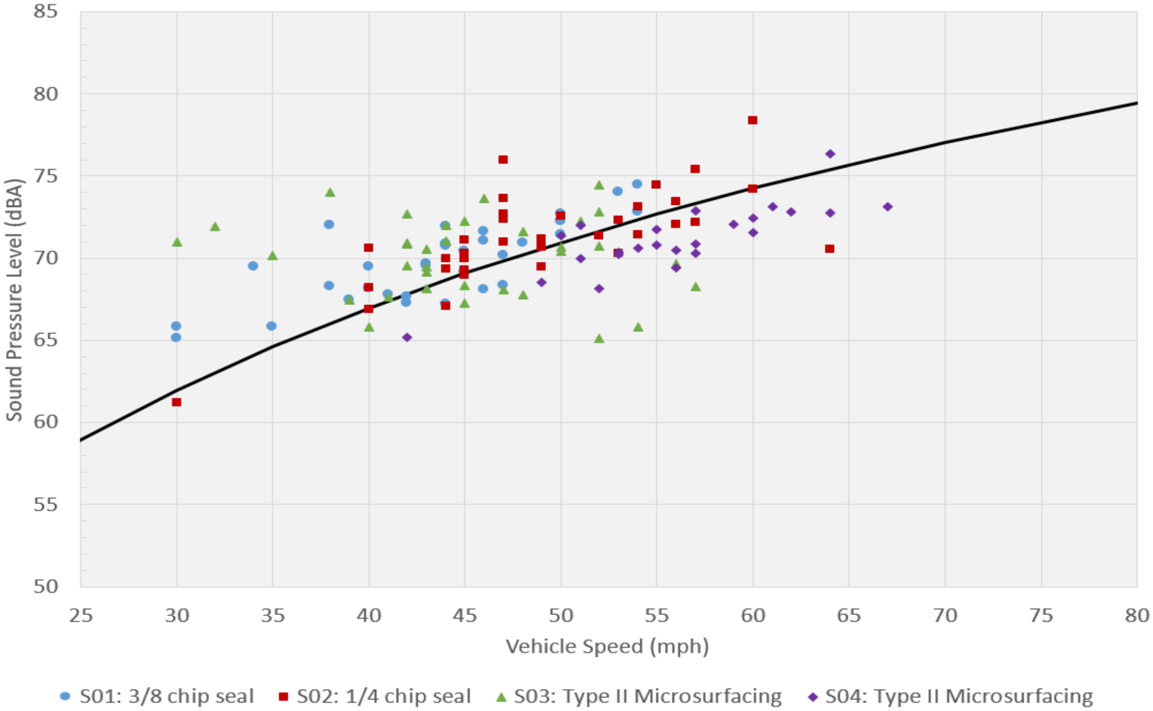

Figure 5. Measured wayside (50feet) A-weighted maximum sound pressure level, one-year post-treatment conditions, sites S01 through S04. The solid line represents the REMEL relationship for automobiles, which is overlaid for comparison.

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 analysis of variance (ANOVA) model, the response in the statistical model is a matrix (number of observations × number of one-third octave bands as response variables) rather than a single vector (number of observations × single response variable). This analysis allows the greatest amount of data to be utilized in order to isolate the contribution of pavement type on the difference in measured levels.

The results of the MANOVA are shown in Table 5. 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 level 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 1. Multiple analysis of variance of wayside pass-by sound pressure levels for one-year post-treatment measurements

Metric	**Df**	**Pillai**	**approx F**	**num Df**	**den Df**	**Pr(>F)**
Treatment	4	2.383	10.315	108	756	< 0.001
Pavement Temperature	1	0.223	1.982	27	186	0.004
Speed	1	0.685	14.946	27	186	< 0.001
Pavement Temperature : Speed	1	0.175	1.461	27	186	0.076
Treatment : Speed	4	0.707	1.502	108	756	0.001
Residuals	212	–	–	–	–	–

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 29 through Figure 32 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 percent, rather than the typical ± 1.96 standard errors, which provides a 95 percent 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:

8. Type II microsurfacing pavement produced less of both high and low frequencies, than the pre-treatment pavement.
9. Type III microsurfacing pavement produced more low frequency content and less high frequency content than the pre-treatment pavement.
10. Both chip seal pavements differ from the pre-treatment pavement almost identically.

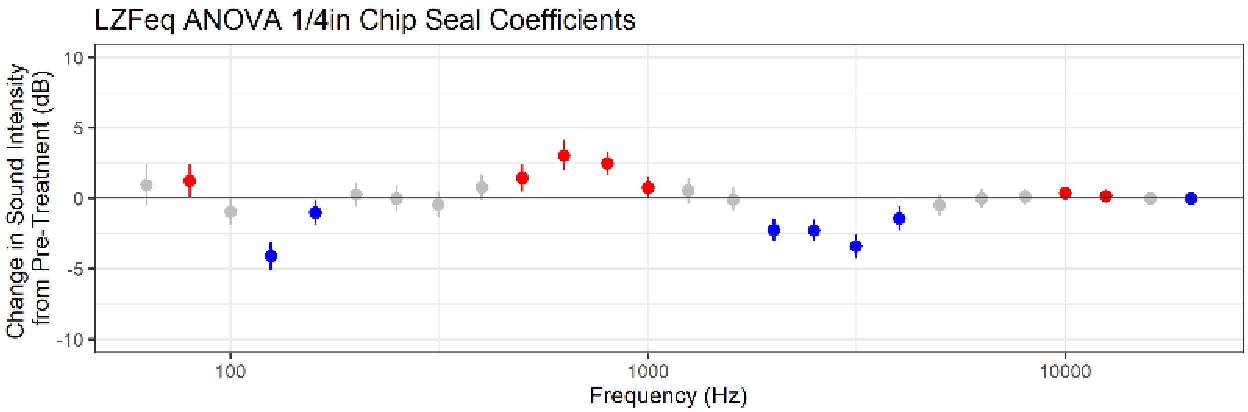

Figure 29. Spectral sound intensity difference between pre-treatment and 1/4-inch chip seal pavement. ANOVA analysis adjusting for average parameters: 50 mph average speed and 90° F pavement temperature.

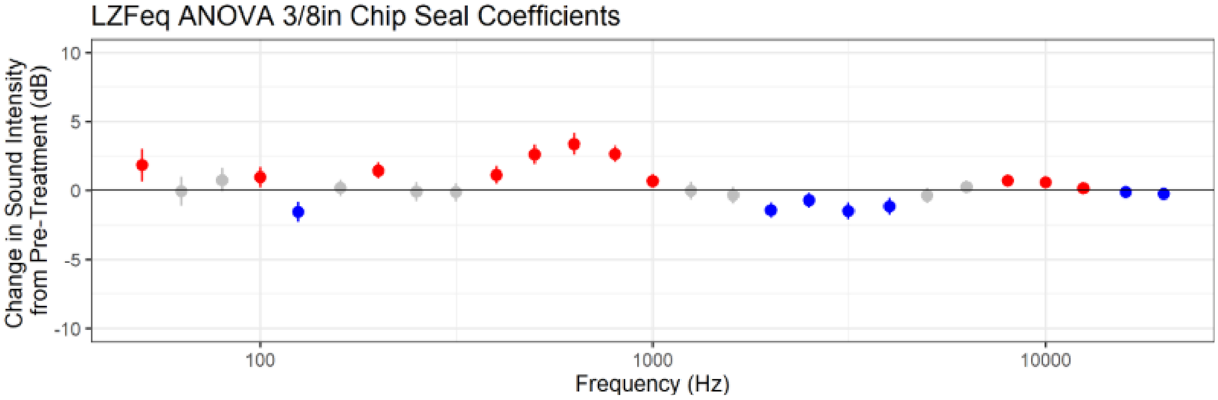

Figure 30. Spectral sound intensity difference between pre-treatment and 3/8-inch chip seal pavement. ANOVA analysis adjusting for average parameters: 50 mph average speed and 90° F pavement temperature.

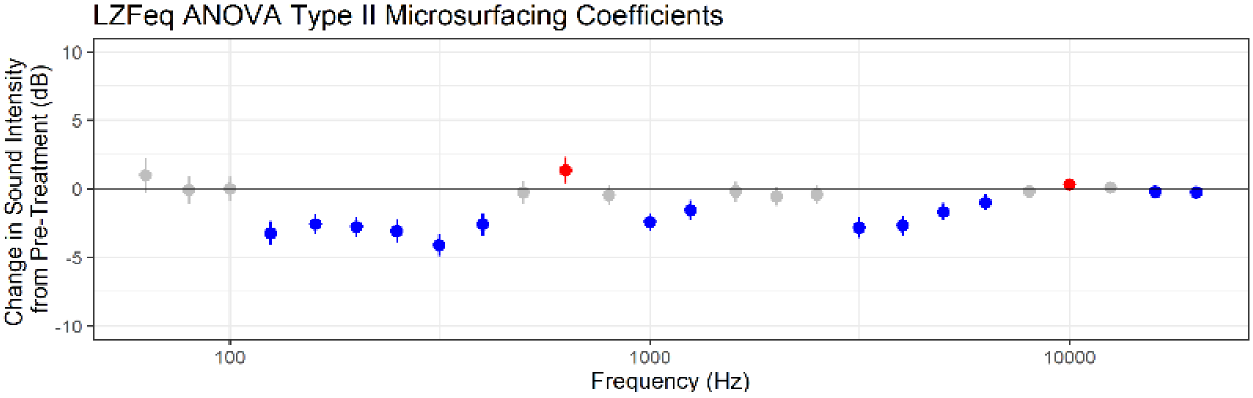

Figure 31. Spectral sound intensity difference between pre-treatment and type II microsurfacing pavement. ANOVA analysis adjusting for average parameters: 50 mph average speed and 90 °F pavement temperature.

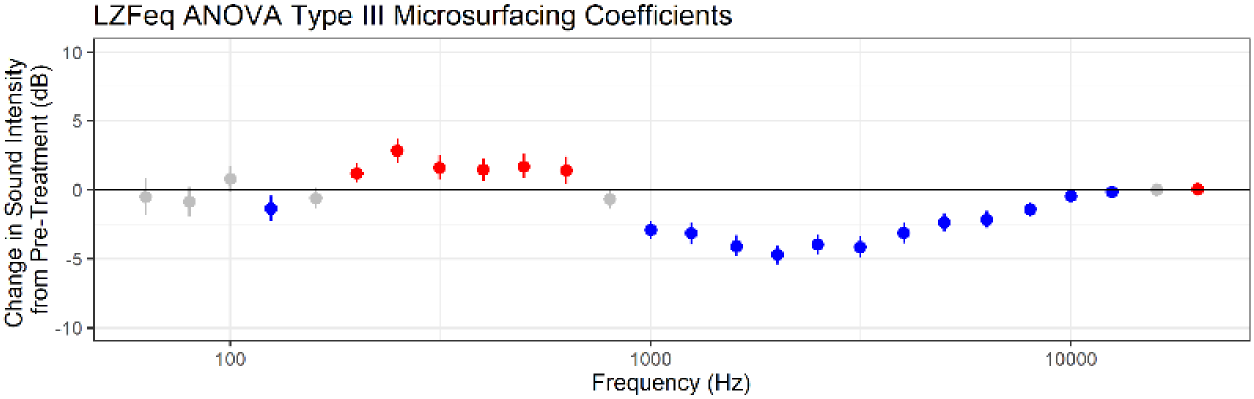

Figure 32. Spectral sound intensity difference between pre-treatment and type III microsurfacing pavement. ANOVA analysis adjusting for average parameters: 50 mph average speed and 90 °F pavement temperature.

Figure 33 shows the REMEL curve for automobiles on average pavement as well as the trend lines developed using the results from the ANOVAs for the one-year data. Figure 34 through Figure 37 display the change in these trends over time for each pavement for the pre-treatment and post-treatment conditions. Note that the trend lines are linear while the REMEL curve has a logarithmic form. For limited speed ranges, comparison between the two forms is useful and the following observations are noted:

11. The slope of the pre-treatment trend line is in good agreement with the REMEL relationship albeit with a slightly lower level.
12. All one-year post-treatment trend lines slopes are similar to the REMEL relationship, and to each other, suggesting that all pavement treatments respond similarly to changes in speed.
13. The two chip seal pavement trend lines as of one-year post-treatment are shifted slightly above the predicted REMEL relationship, meaning the sound levels are slightly louder than average for all speeds.
14. The trend lines for both microsurfacing pavements as of one-year post-treatment are by contrast, slightly below the REMEL relationship for speeds greater than about 40 mph therefore the sound levels are slightly quieter than average[3].
15. The 3/8-inch chip seal pavement has become significantly louder over the period between one-month and one-year measurements, whereas the 1/4-inch chip seal pavement has not changed significantly. It is possible that this is due to clogging of the larger air voids in the 3/8-inch chip seal as a result of the flooding[4].

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[3] Note below 40 mph the linear approximation may not hold for comparisons with the REMELs curve. So this analysis focuses on speeds 40 mph and greater.

[4] Although we moved the 3/8-inch chip seal measurement location, there was still some residual flooding effects at the new location.

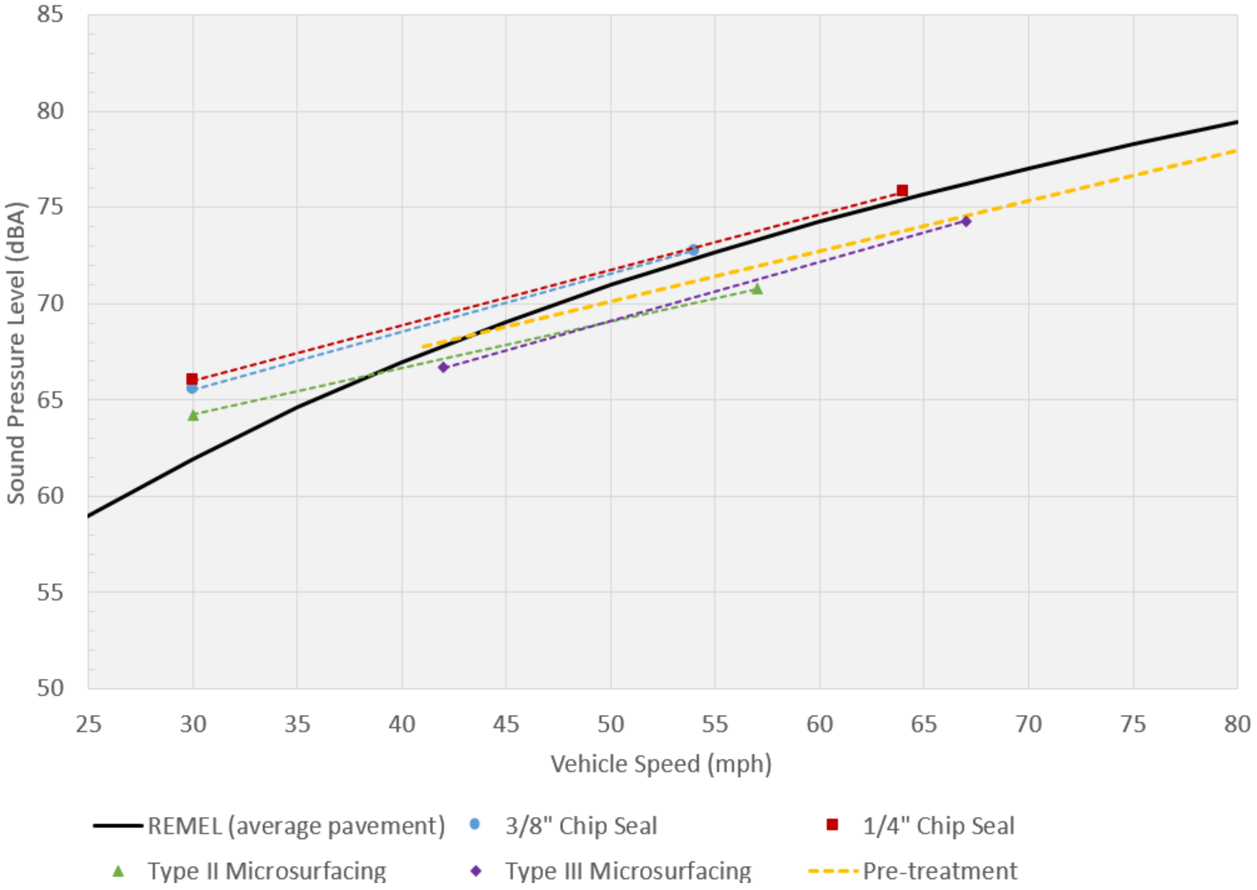

Figure 33. Comparison of standard REMELs and linear models of pavement treatments

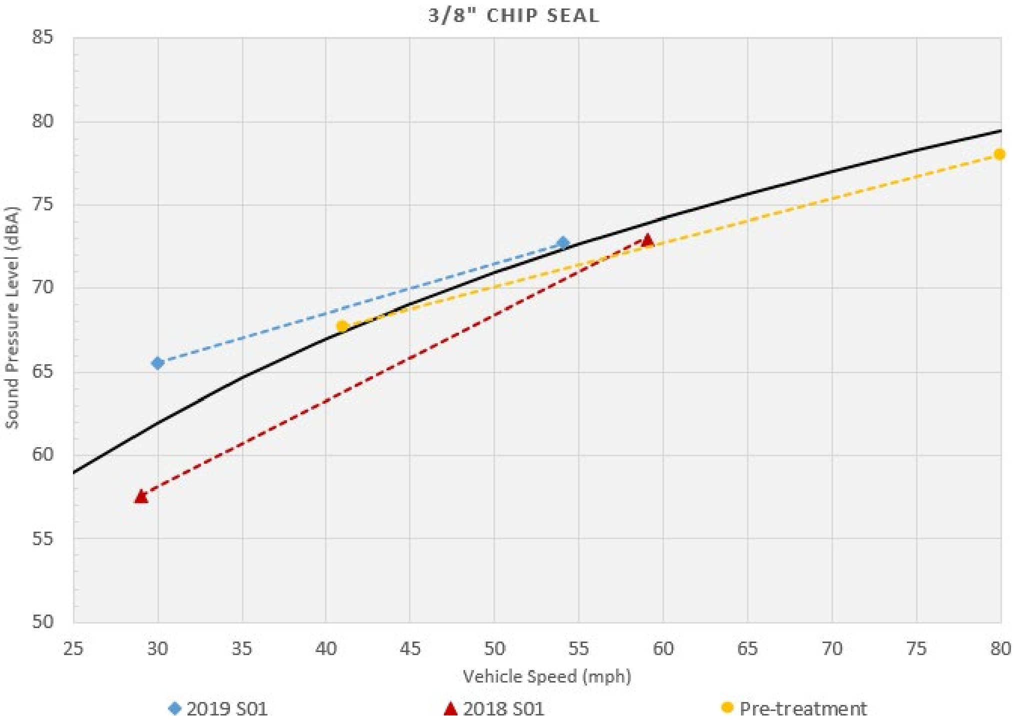

Figure 34. Comparison of standard REMELs and linear models of pre- and post-treatment conditions, 3/8-inch chip seal pavement

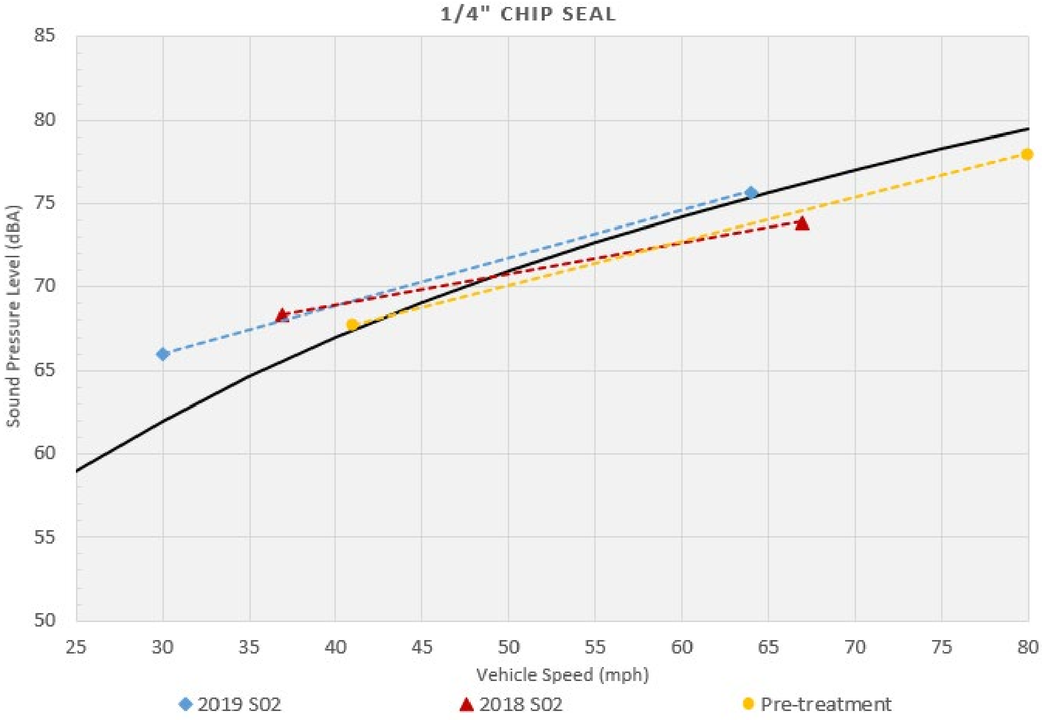

Figure 6. Comparison of standard REMELs and linear models of pre- and post-treatment conditions, 1/4-inch chip seal pavement

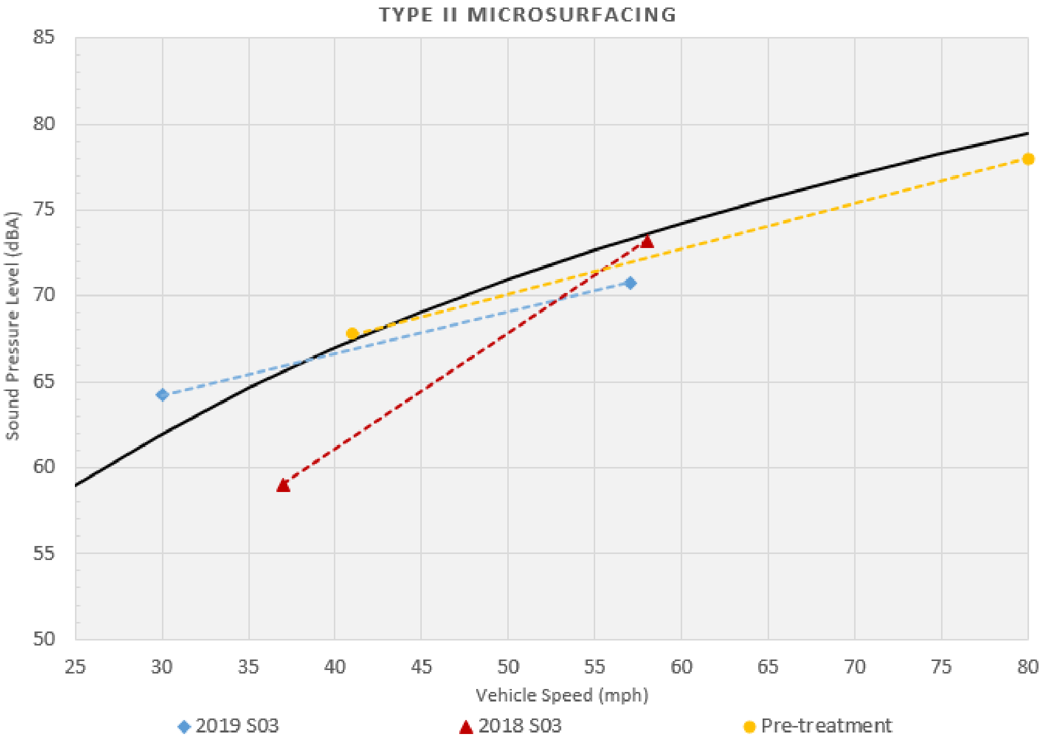

Figure 36. Comparison of standard REMELs and linear models of pre- and post-treatment conditions, type II microsurfacing pavement

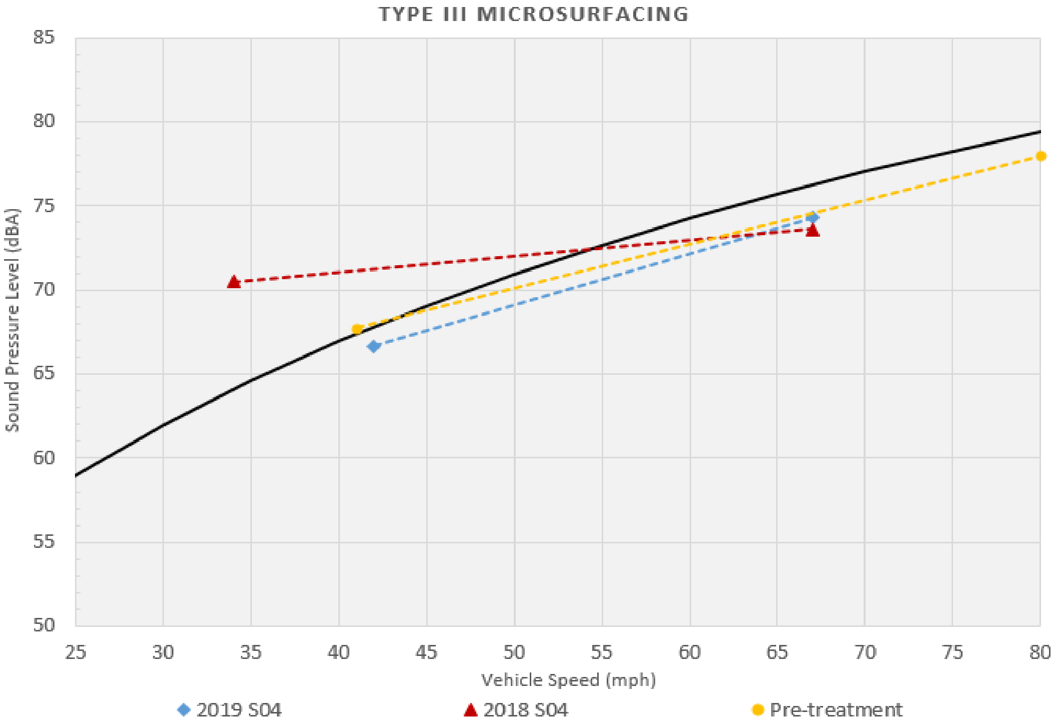

Figure 37. Comparison of standard REMELs and linear models of pre- and post-treatment conditions, type III microsurfacing pavement

Having completed the ANOVA, the sound levels for each pavement type can be normalized to account for the other parameters. This allows for a simple comparison of the pavement types as shown in Table 6, where the predicted sound level for each pavement type is given for vehicles traveling at 50 mph and with a pavement temperature of 90 °F.

Table 2. Overall A-weighted ANOVA predicted wayside data at 50 mph speed, 90 °F pavement temperature

Location	**Pavement Treatment**	**Pre-treatment ANOVA Sound Pressure Level (dBA)**	**One-month post-treatment ANOVA Sound Pressure Level (dBA)**	**One-year post-treatment ANOVA Sound Pressure Level (dBA)**	**One Year of Deterioration 2018-2019 Delta (dBA)**	**Overall 2016-2019 Delta (dBA)**
S01	3/8-inch Chip Seal	69.9	67.9	71.5	3.6	1.6
S02	1/4-inch Chip Seal	69.9	70.6	71.3	0.7	1.4
S03	Type II Microsurfacing	69.9	67.5	68.9	1.4	-1.0
S04	Type III Microsurfacing	69.9	71.6	69.1	-2.5	-0.8

Similarly, Figure 38 and Figure 39 show predicted spectra associated with the wayside measurement locations for all sites for the pre- and post-treatment conditions, one-month and one-year respectively. Figure 40 through Figure 43 illustrate the change over time of the spectra for each pavement. All spectra in the following figures have been normalized for vehicles traveling at 50 mph and with a pavement temperature of 90 °F in order to facilitate an accurate comparison (as shown in Table 6). The following observations are noted as of one-year:

16. The type II microsurfacing produced the least low-frequency content.
17. The type III microsurfacing data produced less high-frequency content but more low-frequency content (relative to their overall level) than the other pavement types.
18. The 3/8-inch chip seal pavement has significantly increased in overall level and the type III microsurfacing pavement has significantly decreased in overall level after a year of usage.
19. The chip seal pavements produced a higher overall level while the microsurfacing pavements produced a lower overall level compared to the pre-treatment pavement.
20. The one-month and one-year 1/4-inch chip seal pavement spectra are very similar, suggesting little deterioration to date.

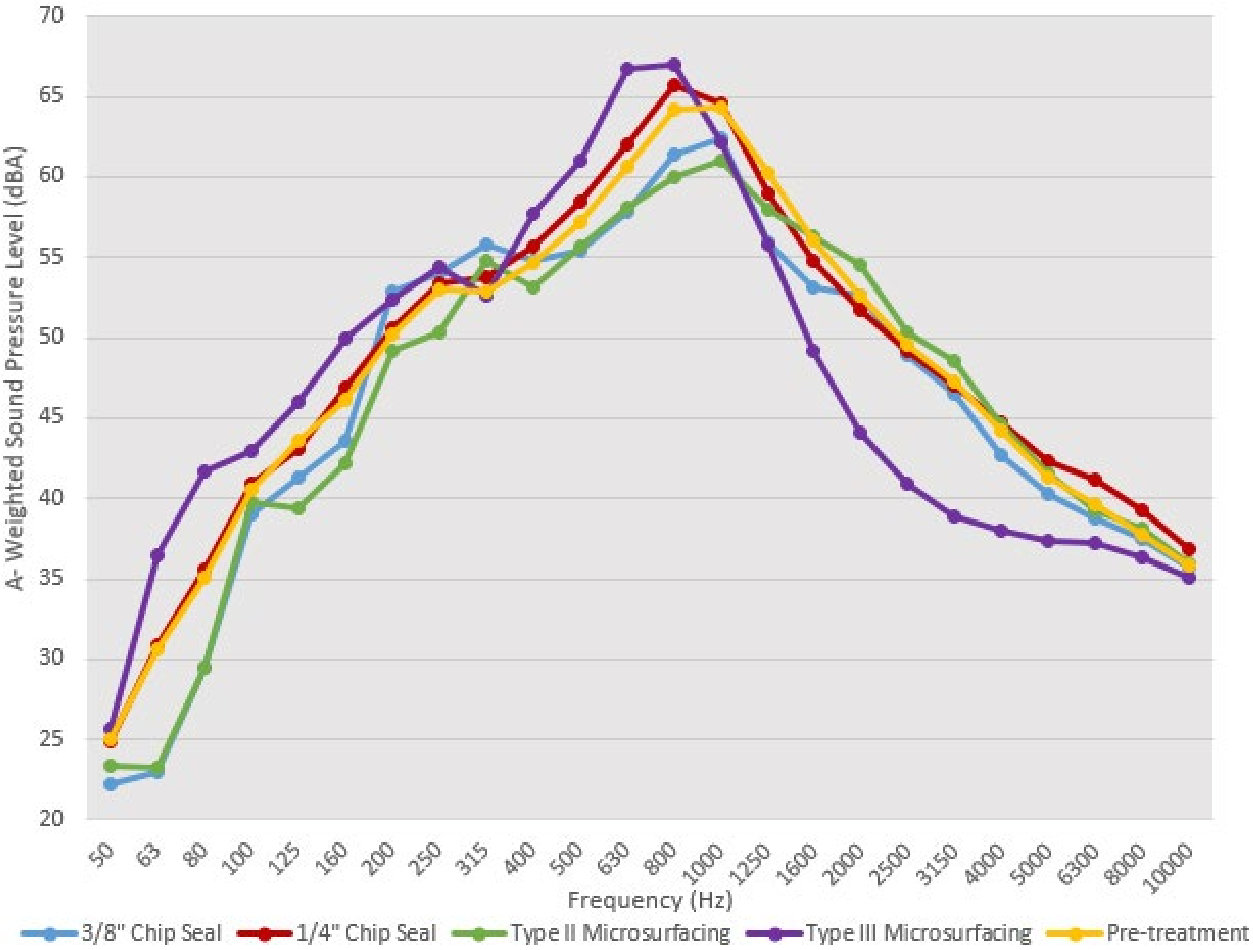

Figure 38. Measured wayside (50feet) A-weighted spectral data, pre- and one-month post-treatment conditions. ANOVA analysis adjusting for average parameters: 50 mph average speed and 90 °F pavement temperature

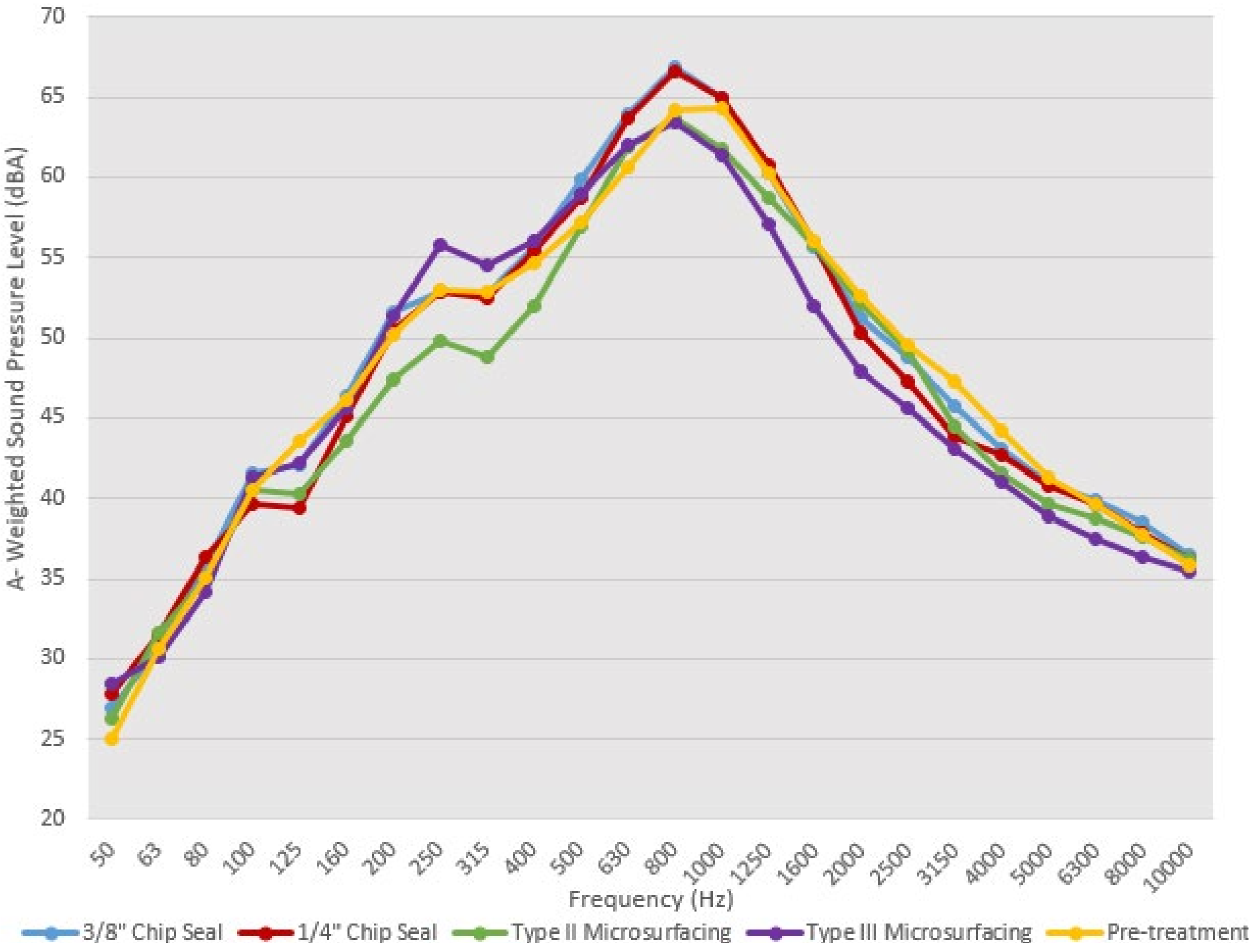

Figure 39. Measured wayside (50feet) A-weighted spectral data, pre- and one-year post-treatment conditions. ANOVA analysis adjusting for average parameters: 50 mph average speed and 90 °F pavement temperature

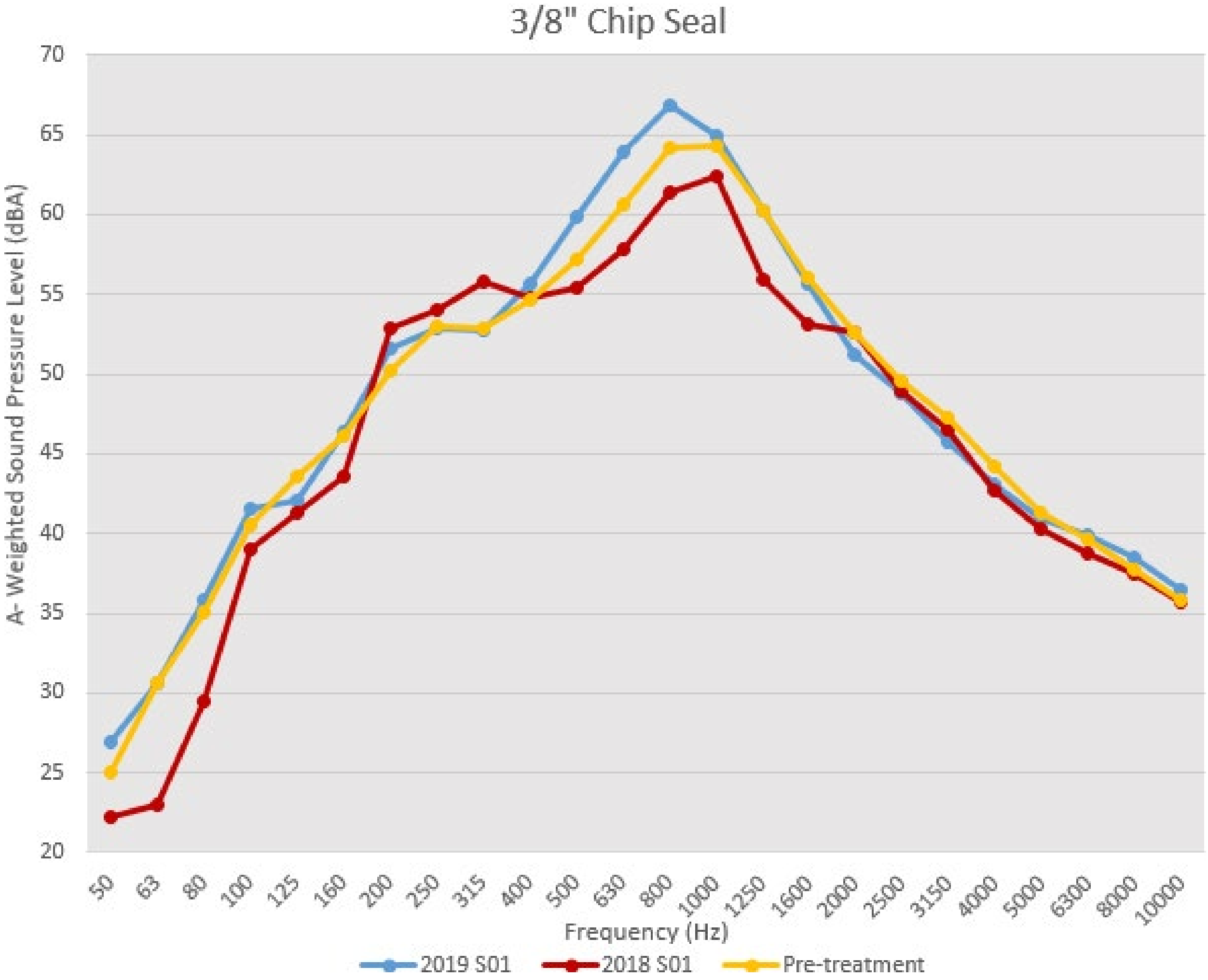

Figure 40. Measured wayside (50feet) A-weighted spectral data, pre- and post-treatment conditions, 3/8-inch chip seal pavement. ANOVA analysis adjusting for average parameters: 50 mph average speed and 90 °F pavement temperature

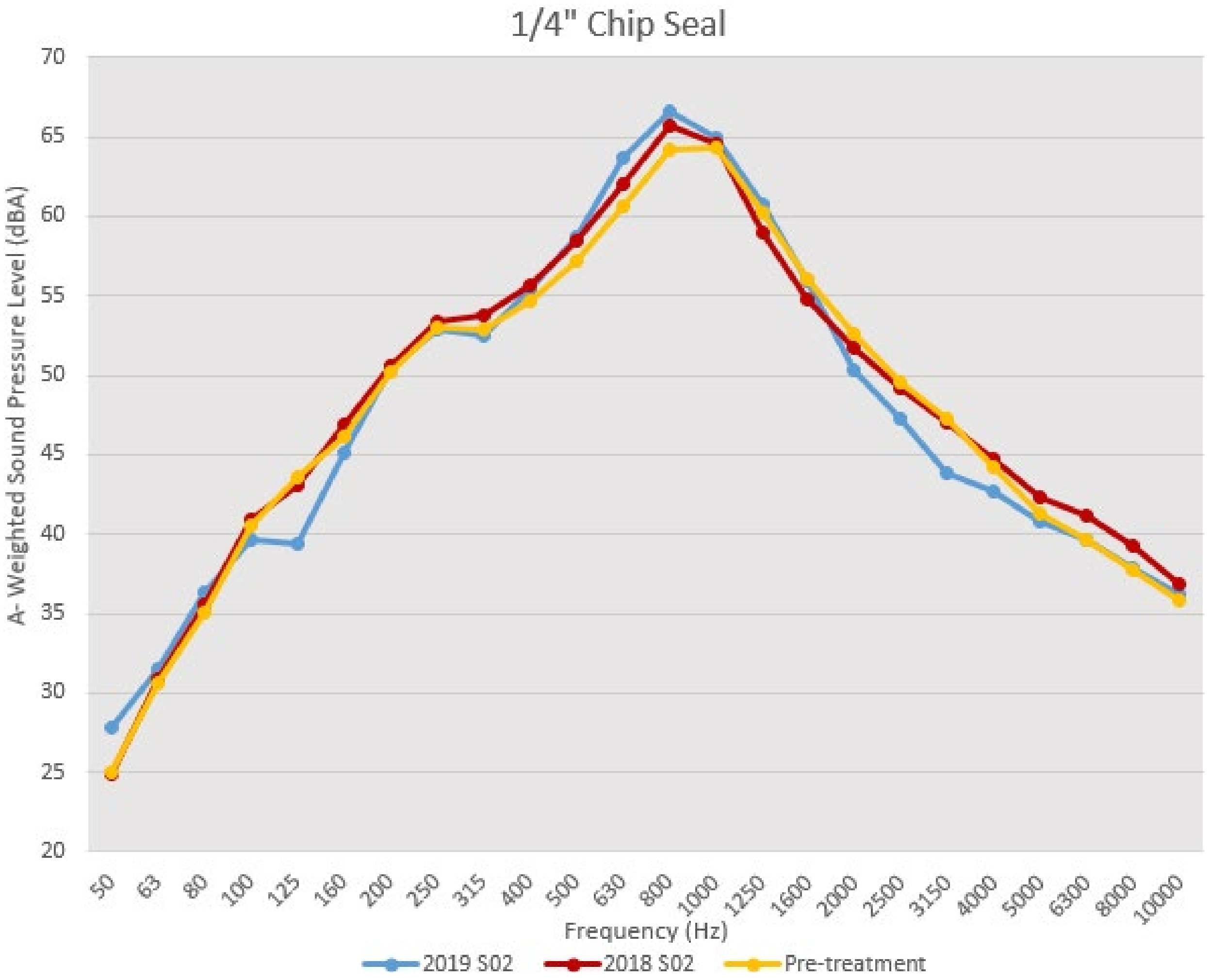

Figure 41. Measured wayside (50feet) A-weighted spectral data, pre- and post-treatment conditions, 1/4-inch chip seal pavement. ANOVA analysis adjusting for average parameters: 50 mph average speed and 90 °F pavement temperature

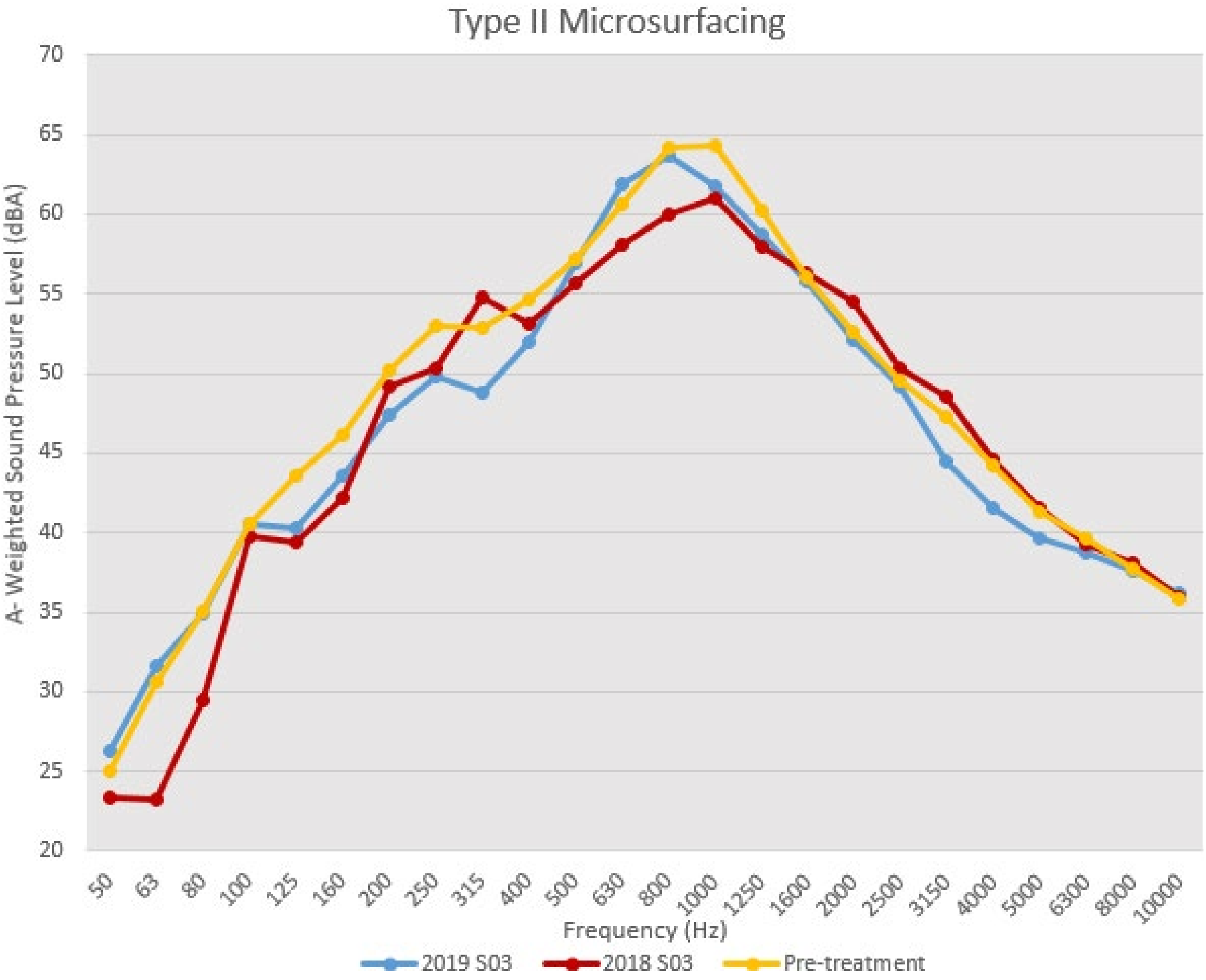

Figure 42. Measured wayside (50feet) A-weighted spectral data, pre- and post-treatment conditions, type II microsurfacing pavement. ANOVA analysis adjusting for average parameters: 50 mph average speed and 90 °F pavement temperature

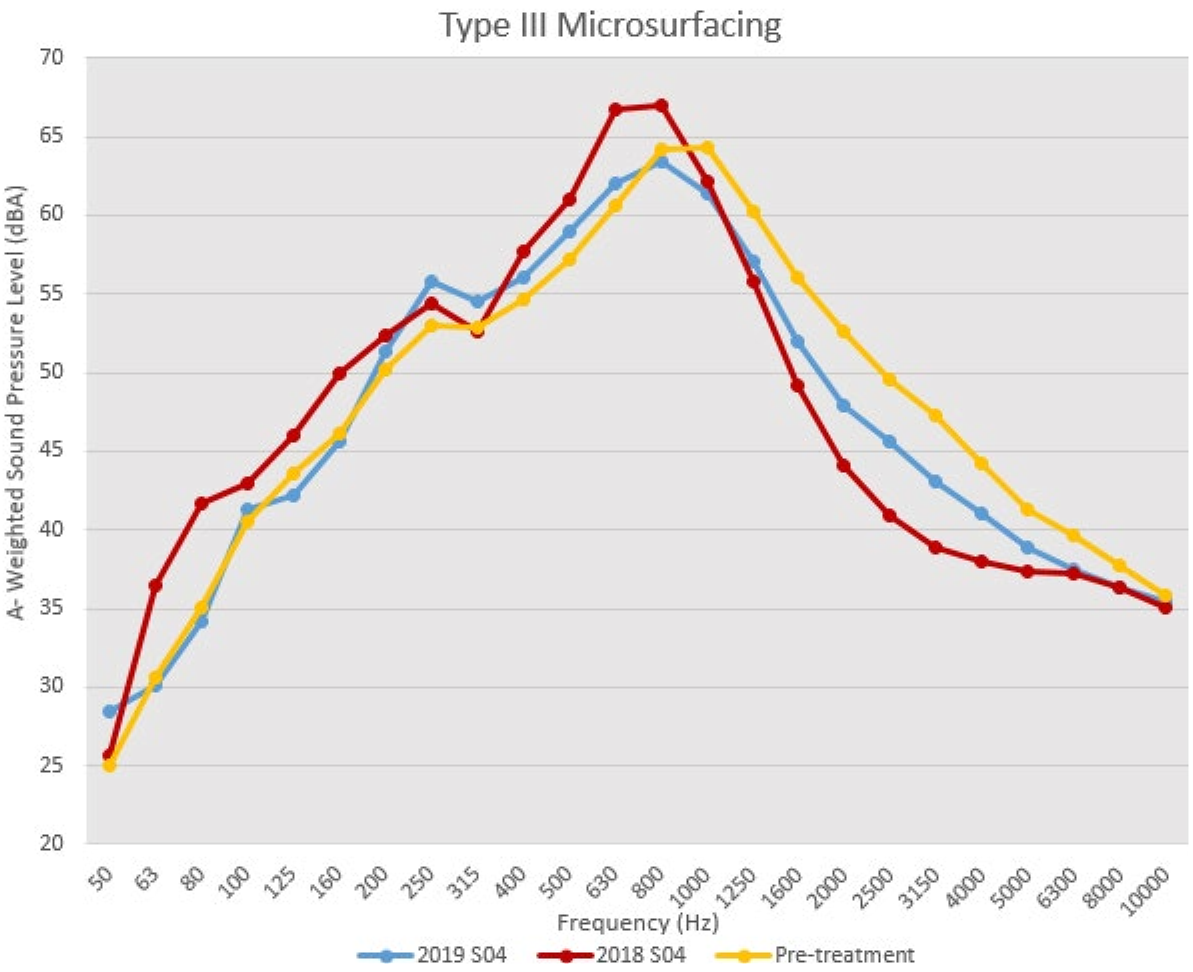

Figure 43. Measured wayside (50feet) A-weighted spectral data, pre- and post-treatment conditions, type III microsurfacing pavement. ANOVA analysis adjusting for average parameters: 50 mph average speed and 90 °F pavement temperature.

4.3 Effective Flow Resistivity Data

Pre-treatment EFR data were collected at measurement location S02, S07 and S08, while post-treatment data were collected at the four northern sites (S01-S04). Pre-treatment EFR data at S02 is considered representative of all the northern sites that were separately evaluated in following years the as they all had the same pavement material and similar traffic volume.

EFR data were measured and analyzed in conformance with the ANSI S1.18 standard. Figure 44 through Figure 47 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 that best fits the data.

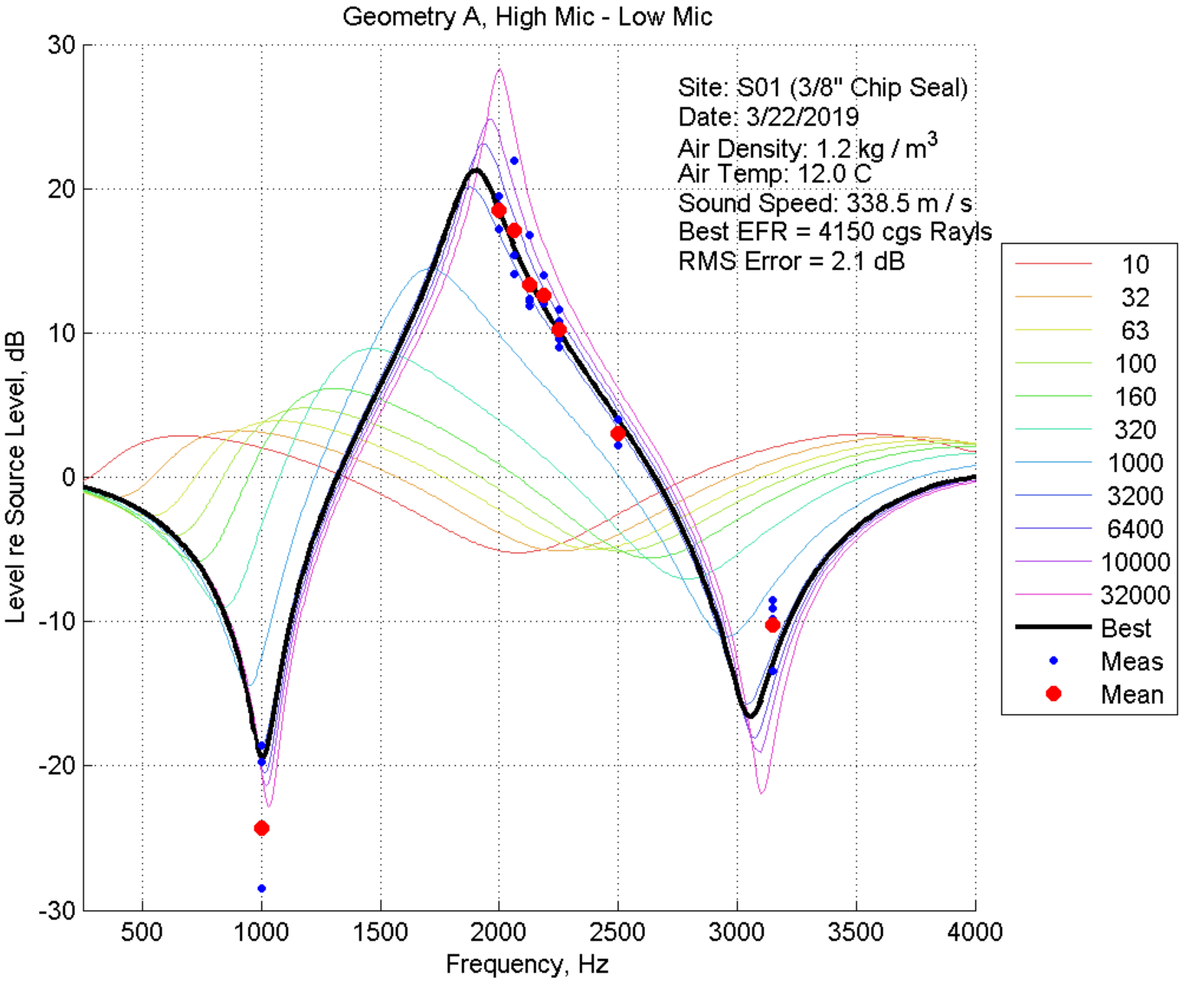

Figure 44. Comparison of measured (blue dots), mean measured (red dots) and computed best-fit (solid lines) sound level differences by frequency at site S01, post-treatment 3/8-inch chip seal conditions at one year. A black line indicates the differences computed for the EFR value that best fits the measured data (4150 cgs rayls)

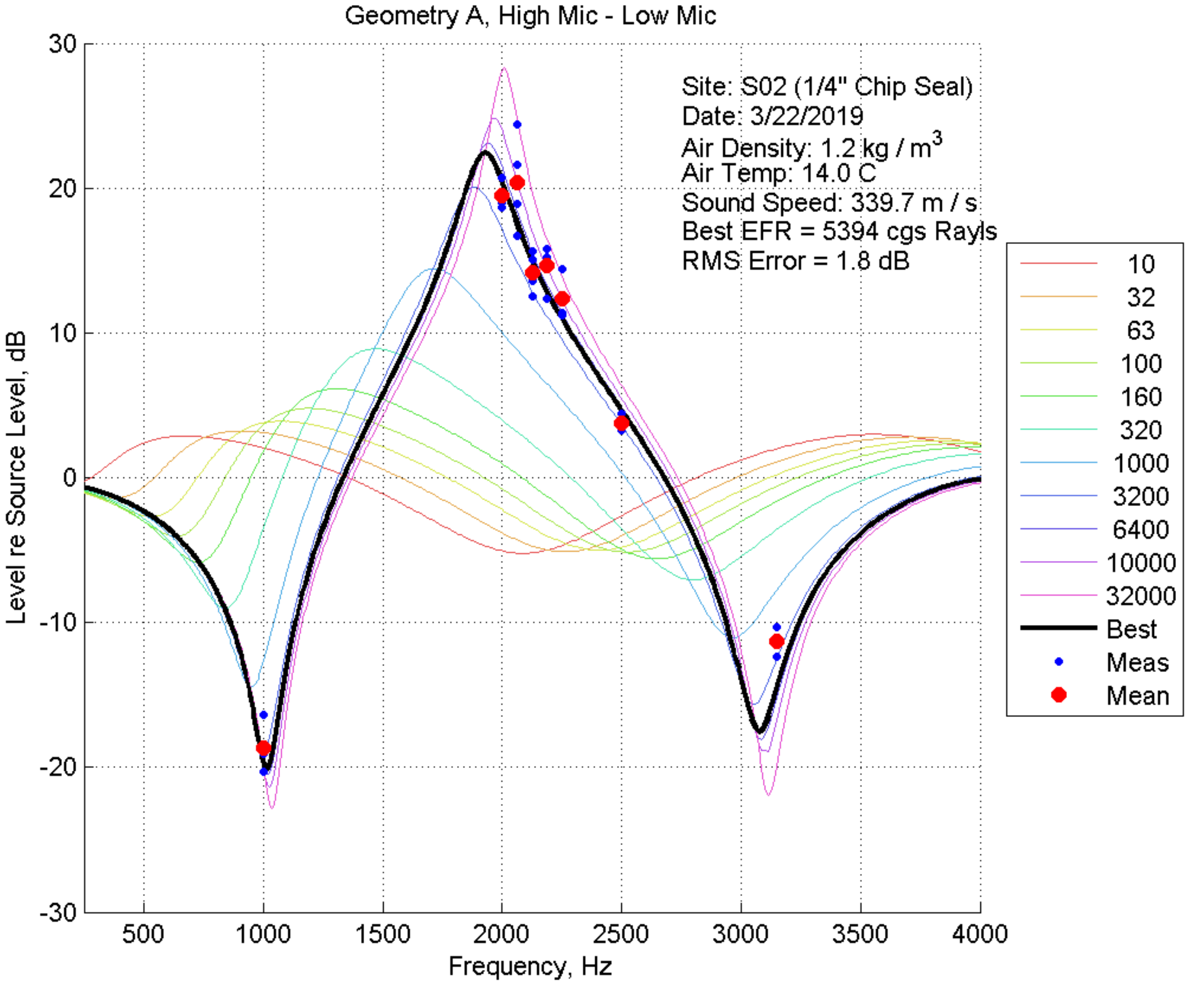

Figure 45. Comparison of measured (blue dots), mean measured (red dots) and computed best-fit (solid lines) sound level differences by frequency at site S02, post-treatment 1/4-inch chip seal conditions, at one year. A black line indicates the differences computed for the EFR value that best fits the measured data (5394 cgs rayls)

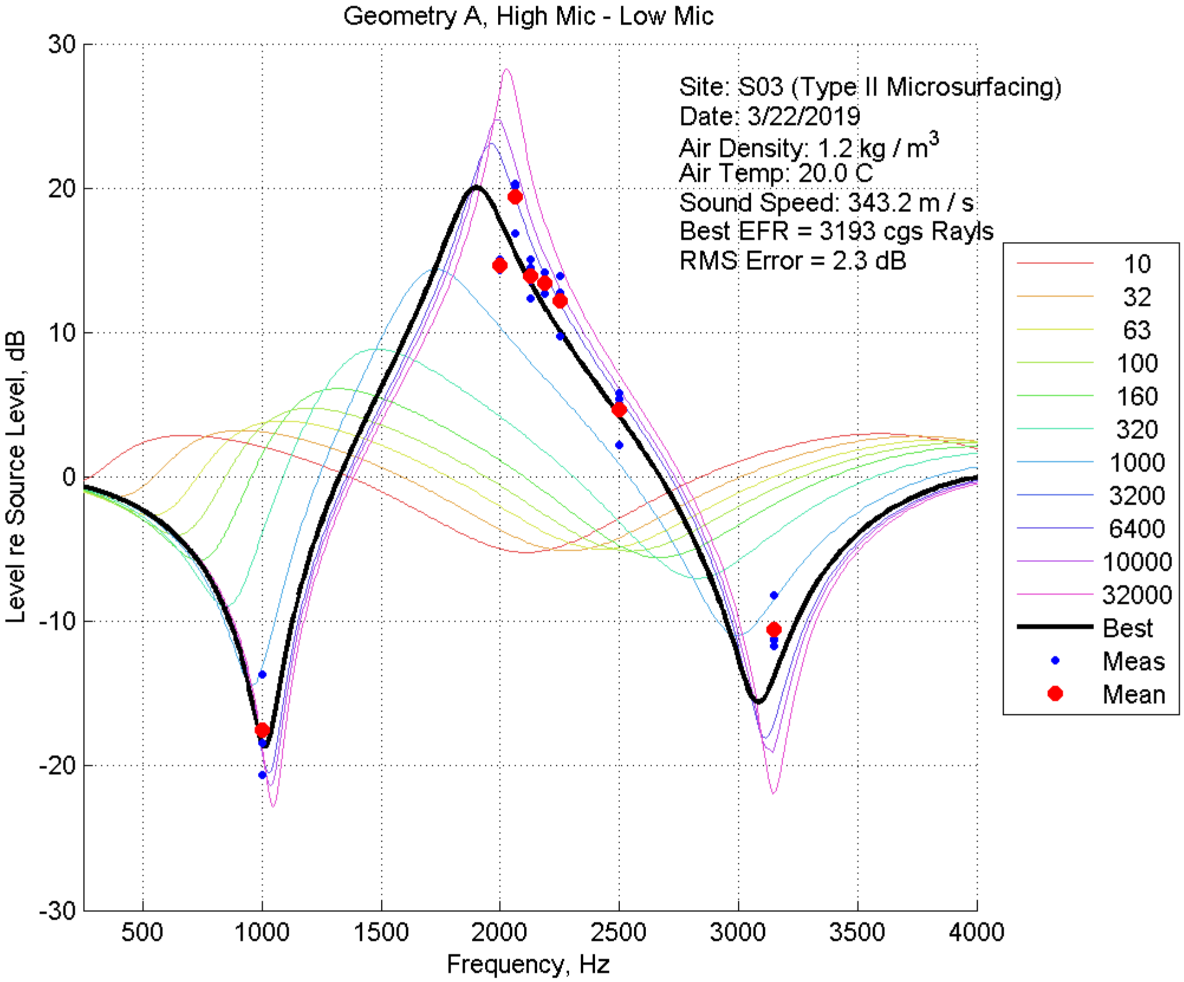

Figure 46. Comparison of measured (blue dots), mean measured (red dots) and computed best-fit (solid lines) sound level differences by frequency at site S03, post-treatment type II microsurfacing conditions, at one year. A black line indicates the differences computed for the EFR value that best fits the measured data (3193 cgs rayls)

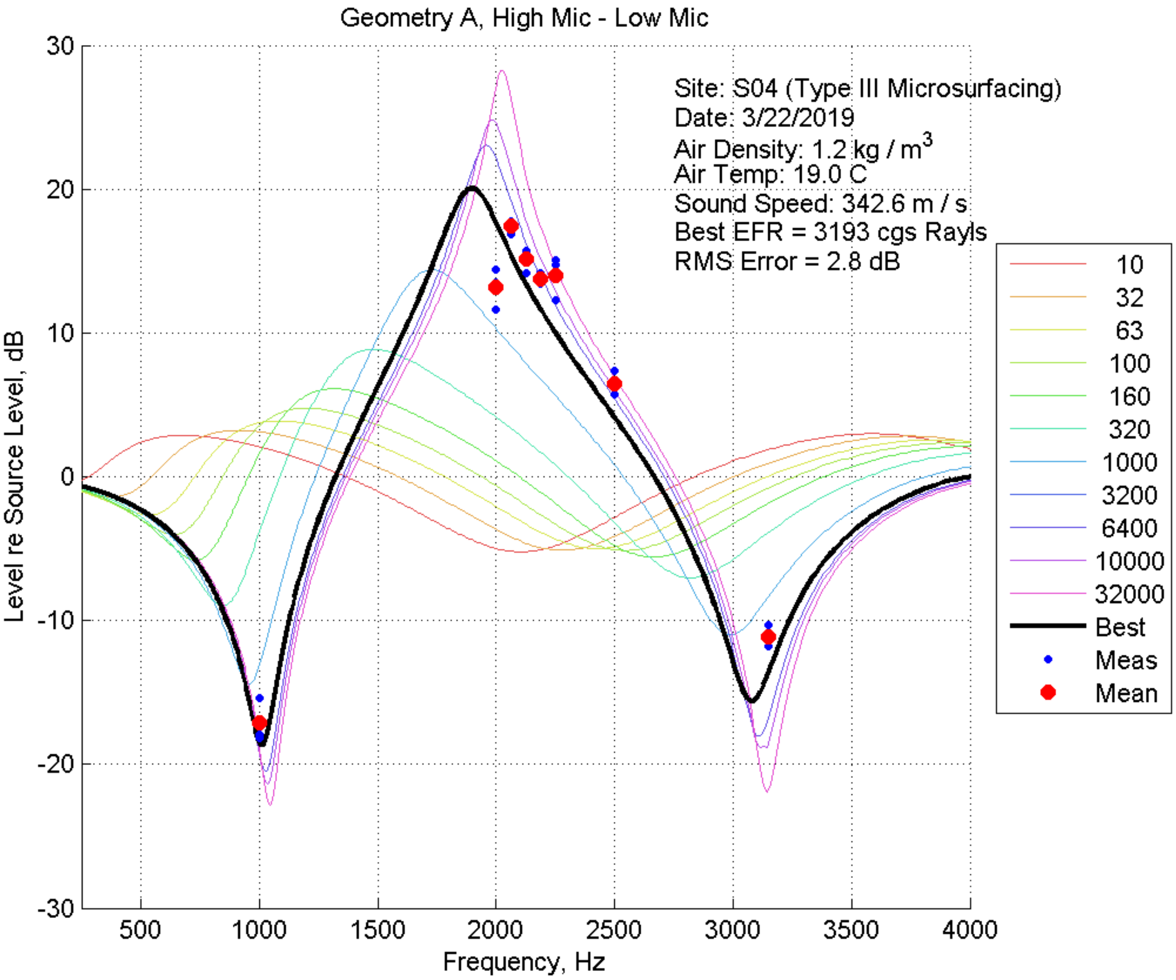

Figure 47. Comparison of measured (blue dots), mean measured (red dots) and computed best-fit (solid lines) sound level differences by frequency at site S04, post-treatment type III microsurfacing conditions, at oneyear. The black line indicates the differences computed for the EFR value that best fits the measured data (3193 cgs rayls)

In these measurements, EFR data were measured with more data collected between the 2000-2500 Hz, one-third octave band center frequencies (as indicated with a greater concentration of blue data points at those frequency bands in the following figures). 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 post-treatment measurement locations are presented in Table 7. At one year post-treatment, all values shown below fall within the expected range for pavements (2,000 to 30,000). The pre-treatment pavement produced the highest EFR value, followed by the new chip seal pavements (S01 and S02), and the new microsurfacing pavements at S03 and S04 produced the lowest EFR values. Therefore, the microsurfacing pavements are still the most absorptive, which is consistent with the calculated EFR values measured at one month post-treatment. However, it should be noted that the type III microsurfacing pavement is becoming more reflective as it deteriorates, illustrated by a positive EFR 2018-2019 delta, whereas the type II microsurfacing pavement has thus far maintained its acoustic performance with a steady nominal EFR value despite wear and tear from usage. These changes over time will continue to be monitored for remainder of the study period.

Table 7. Best-fit EFR values (cgs rayls) for the four measurement locations

Measurement Location	**Pavement Type**	**Pre-treatment**	**2018**	**2019**	**One-year of Deterioration 2018-2019 Delta (dB)**	**Overall 2016-2019 Delta (dB)**
S01:	3/8-inch Chip Seal	7010	9111	4150	-4961	-2860
S02:	1/4-inch Chip Seal	7010	9111	5394	-3717	-1616
S03:	Type II Microsurfacing	7010	3193	3193	0	-3817
S04:	Type III Microsurfacing	7010	1455	3193	1738	-3817

5. Discussion

Pre-treatment OBSI levels ranged from 98.3 to 101.1 dB. One month after four different surface treatments were applied, OBSI levels ranged from 97.4 to 100.6 dB. One year after these surface treatments were applied, OBSI levels ranged from 96.7 to 101.1 dB. During both measurements, 3/8-inch chip seal produced the highest levels and type II microsurfacing produced the lowest levels. This shows that there is about a 3.0–4.5 dB range in the noise produced at the tire pavement interface for the different surface treatments, and that type II microsurfacing produces the best benefit, while the default treatment, 3/8-inch chip seal is the loudest.

It should be noted that all northern sites, which were subject to harsher environmental conditions and increased traffic volumes compared to the southern sites, produced higher OBSI sound intensity levels in 2019 than in 2018, whereas all southern sites at one year produced lower sound intensity levels than the previous measurements at one month. Continuing measurements over time will monitor if these differences continue.

When wayside measurements were corrected for speed and pavement temperature based on a MANOVA and multiple ANOVAs, similar trends were found with type II microsurfacing continuing to be the quietest pavement (67.5 dB after one month, 68.9 dBA after one year), but the loudest pavement differed. At one month, type III microsurfacing was the loudest at 71.6 dBA. At one year, 3/8-inch chip seal was the loudest at 71.5 dBA. Type III microsurfacing's dominance at one month is likely due to its increased low frequency content, which can have an effect on propagation even at the short distances associated with wayside measurements. The type II microsurfacing was about 4 dB quieter than the loudest treatment at one month and about 2.5 dB quieter at one year.

In addition to the trends in overall sound level differences, changes in frequency content over time are also demonstrative of the pavement's performance. Research has shown that the frequency content of the emitted sound can vary substantially, even between two pavements having the same overall sound level. It was noted that even casual observers can hear and discern a difference between the sounds generated by each pavement type.[5] 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.).

In general, type II microsurfacing had a typical spectral shape distinguishable mainly by the reduced level across all frequencies. Type III microsurfacing was notable in that it produced the lowest high frequency content but the greatest low frequency content at one month. At one year, the type III

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

microsurfacing spectrum was similar; however, the low frequency content did reduce to become more in line with the other treatments. Both chip seals produced spectra that were consistent with the pre-treatment pavement surface, which was also a chip seal. The main change from one month to one year for these spectra was due to the increase in overall level of the 3/8-inch chip seal.

The measured EFR values as of one year show the pre-treatment pavement produced the highest EFR value, followed by the new chip seal pavements and microsurfacing pavements respectively Therefore, the microsurfacing pavements are the most absorptive, although the chip seal pavements are still an improvement over the pre-existing pavement. Despite the fact that the microsurfacing pavements at one year produced the same nominal EFR value, the type III pavement is becoming more reflective over time, while the type II pavement has maintained its EFR value. Differences in EFR values can affect both OBSI and wayside measurements. However, differences in pavement EFR are expected to have a greater effect on noise levels at locations that involve the sound wave propagating longer distances over the pavement. An example of such a situation would be sound propagating from the front of the vehicle toward a receiver location adjacent to a distant point on the road in the direction of vehicle travel. In this example the sound would propagate over the pavement in front of the vehicle for most of its journey, crossing over the edge of the pavement near the receiver location.

In the 2019 measurements, EFR data were measured with more data collected between the 2000–2500 Hz, one-third octave band center frequencies. 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. Following this process can produce a greater spread for the individual samples. 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 easier for the algorithm to identify the best-fit line. Future measurements may include additional frequencies to increase further the EFR estimate accuracy.

6. Next Steps

This document reports the results of noise measurements for the pre-treatment data, consisting of 6 year old 3/8-inch chip seal pavement as well as the one-month and one-year post-treatment conditions at Death Valley National Park (DEVA). Pre-treatment data were collected in November 2016, while post-treatment data were collected both in May 2018 at one month, and in March 2019 at one year.

Tracking these data over the course of the next several years 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, and (2) practicality in terms of durability and cost. To date, statistical analyses have looked at the 2018 and 2019 measurements separately. Additional measurements are anticipated to occur during fall 2020, 2021, and 2022 (2.5, 3.5 and 4.5 years age). As additional measurement years are added, it is expected that the pavement age will be added to the variable list in the statistical analysis so that trends related to pavement age may be more systematically evaluated.

Future work may include expanding this type of study to additional parks— those that may have access to, or preference for different pavement types— such as for parks nearer population centers, or those that may have different maintenance and durability challenges due to climate (for example parks with greater seasonal weather changes). This could include and leverage the pre-treatment data previously collected at 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). Through this work, park managers will have more choices on the type of pavement that is best suited to their particular park environment.

7. 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.

Fleming, Gregg G., Amanda Rapoza, and Cynthia S.Y. Lee. 1995. Development of National Reference Energy Mean Emission Levels for the FHWA Traffic Noise Model (FHWA TNM®), Version 1.0, Report No. FHWA-PD-96-008, U.S. Department of Transportation, Volpe National Transportation Systems Center, Cambridge, MA, USA.

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

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, Cambridge, MA, USA.

Lee, Cynthia and John MacDonald, 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. FHWA (TBD) and DOT-VNTSC-FHWA-12-01, U.S. Department of Transportation, Volpe National Transportation Systems Center.

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: February 2020
3. REPORT TYPE AND DATES COVERED: Final Report
4. TITLE AND SUBTITLE: Quieter Pavement Project - Death Valley National Park: Interim report for one-year post-treatment conditions
5. FUNDING NUMBERS: VXAEA1 / SG341
6. AUTHOR(S): Aaron L Hastings, Amanda S Rapoza, Sophie R Kaye, Daniel Flynn
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES):

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    John A. Volpe National Transportation Systems Center
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    Cambridge, MA 02142-1093

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   Natural Resource Program Center
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   Fort Collins, CO 80525

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    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 pre-treatment conditions, before application of the surface treatments, were collected November 7-8, 2016. Acoustic data for immediate post-treatment conditions, one month after treatments were applied, were collected May 23-24, 2018. Acoustic data for post-treatment conditions, nominally one year after treatments were applied, were collected March 19-22, 2019. This document summarizes the data collected for pre-treatment measurements and post-treatment measurements at one-month and one-year (May 2018 and March 2019 respectively). Results of the noise measurements are presented along with the initial analyses conducted to identify preliminary trends in the data. As the pavements age and additional measurements are made, these data and analyses will be updated.

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

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