QUANTIFYING THE PERFORMANCE OF LOW NOISE TRANSVERSE RUMBLE STRIPS

Final Technical Memo

PROJECT SPR 829A

Oregon Department of Transportation

QUANTIFYING THE PERFORMANCE OF LOW-NOISE TRANSVERSE RUMBLE STRIPS

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by

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Federal Highway Administration
1200 New Jersey Avenue SE
Washington, DC 20590

August 2019

Technical Report Documentation Page

1. Report No. FHWA-OR-RD-20-01	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Quantifying the performance of low-noise transverse rumble strips		5. Report Date -August 2019 6. Performing Organization Code
7. Author(s) David S. Hurwitz, Ph.D. - https://orcid.org/0000-0001-8450-6516 Dylan Horne - https://orcid.org/0000-0003-4981-7161 Hisham Jashami - https://orcid.org/0000-0002-5511-7543		8. Performing Organization Report No.
9. Performing Organization Name and Address Oregon Department of Transportation Research Section 555 13th Street NE, Suite 1 Salem, OR 97301		10. Work Unit No. (TRAIS) 11. Contract or Grant No.
12. Sponsoring Agency Name and Address Oregon Dept. of Transportation Research Section 555 13th Street NE, Suite 1 Salem, OR 97301	Federal Highway Admin. 1200 New Jersey Ave SE Washington, DC 20590	13. Type of Report and Period Covered Final Technical Memo 14. Sponsoring Agency Code
15. Supplementary Notes		

Abstract: Transverse rumble strips (TRS) generate noise and vibration to alert drivers when they are approaching an intersection with traffic control, e.g. stop signs. TRS have been shown to reduce crashes up to 30% but have noise concerns (Finley et al., 2007). This study evaluated the feasibility of using shallow, epoxy filled TRS (EFTRS) as a substitute to address noise concerns. A total of 24 vehicle strikes were recorded. Exterior sound levels generated by TRS strikes were compared to baseline and EFTRS using a probe vehicle. Experimental framework was based on previous studies of RS and the AASHTO SIP Method. Humans can detect differences in noise levels at 3 dB, with 5 dB being easily noticed. The EFTRS vs TRS mean sound dropped from 87.58 dBA to 84.09 dBA, a noticeable 3.49 dBA. When both are compared based on their peak (max value), the difference was a clearly detectable drop of 6.04 dBA. Additionally, the sound level generated from the EFTRS is higher than the paved condition, with a 95% CI [0.14 dBA, 4.77 dBA]. This means that the EFTRS are quieter than the original TRS (4x louder compared to vehicle on flat pavement), but are still noticeable compared to background traffic.

17. Key Words Transverse rumble strips, roadside noise, SIP method	18. Distribution Statement Copies available from NTIS, and online at www.oregon.gov/ODOT/TD/TP_RES/		
19. Security Classification (of this report) Unclassified	20. Security Classification (of this page) Unclassified	21. No. of Pages 46	22. Price

Technical Report Form DOT F 1700.7 (8-72) Reproduction of completed page authorized Printed on recycled paper

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Symbol	When You Know	Multiply By	To Find	Symbol	Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH					**LENGTH**		
in	inches	25.4	millimeters	mm	mm	millimeters	0.039	inches	in
ft	feet	0.305	meters	m	m	meters	3.28	feet	ft
yd	yards	0.914	meters	m	m	meters	1.09	yards	yd
mi	miles	1.61	kilometers	km	km	kilometers	0.621	miles	mi
		AREA					**AREA**		
in^2	square inches	645.2	millimeters squared	mm^2	mm^2	millimeters squared	0.0016	square inches	in^2
ft^2	square feet	0.093	meters squared	m^2	m^2	meters squared	10.764	square feet	ft^2
yd^2	square yards	0.836	meters squared	m^2	m^2	meters squared	1.196	square yards	yd^2
ac	acres	0.405	hectares	ha	ha	hectares	2.47	acres	ac
mi^2	square miles	2.59	kilometers squared	km^2	km^2	kilometers squared	0.386	square miles	mi^2
		VOLUME					**VOLUME**		
fl oz	fluid ounces	29.57	milliliters	ml	ml	milliliters	0.034	fluid ounces	fl oz
gal	gallons	3.785	liters	L	L	liters	0.264	gallons	gal
ft^3	cubic feet	0.028	meters cubed	m^3	m^3	meters cubed	35.315	cubic feet	ft^3
yd^3	cubic yards	0.765	meters cubed	m^3	m^3	meters cubed	1.308	cubic yards	yd^3
~NOTE: Volumes greater than 1000 L shall be shown in m^3.									
		MASS					**MASS**		
oz	ounces	28.35	grams	g	g	grams	0.035	ounces	oz
lb	pounds	0.454	kilograms	kg	kg	kilograms	2.205	pounds	lb
T	short tons (2000 lb)	0.907	megagrams	Mg	Mg	megagrams	1.102	short tons (2000 lb)	T
		TEMPERATURE (exact)					**TEMPERATURE (exact)**		
°F	Fahrenheit	(F-32)/1.8	Celsius	°C	°C	Celsius	1.8C+32	Fahrenheit	°F

*SI is the symbol for the International System of Measurement

ACKNOWLEDGEMENTS

We appreciate the guidance and oversight of Jon Lazarus (ODOT Research Coordinator), Michael Kimlinger (State Traffic Engineer), Eric Leaming (Traffic Devices Engineer), and Keith Blaire (Region 2 Interim Region Traffic Manager) at the Oregon Department of Transportation (ODOT).

We also appreciate the efforts of Oregon State University graduate research assistants Hameed Mohammed and Travis Larsen who helped with the extensive field data collection.

DISCLAIMER

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1.0 INTRODUCTION

1.1 PROBLEM STATEMENT

Transverse rumble strips (TRS) have been shown to reduce crashes by 20 to 30% but are associated with noise concerns (Finley et al., 2007). Residents living adjacent to roadways have complained to ODOT about the noise generated by TRS. Previous research suggests that modifying the shape of the TRS can reduce the intensity of sound associated with TRS, reducing noise pollution and nearby resident complaints (An et al., 2016).

One solution to this noise problem is a shallower TRS, which produces a lower noise profile than the traditional TRS. There is a need to quantify scientifically the noise differential between traditional and shallow TRS. Research suggests that shallower RS generate the necessary in-vehicle noise and reduced roadside noise (Miles et al., 2007; Hurwitz et al., In Press).

1.2 RESEARCH OBJECTIVES

This study will evaluate the feasibility of using an epoxy to reduce the depth of traditional milled rumble strips in transverse applications post-installation. A quantitative and empirical comparison of the roadside noises of epoxy filled and traditional transverse rumble strips will give an indication as to whether the epoxy retrofit can potentially be used to resolve roadside noise complaints associated with transverse applications.

1.3 BENEFITS

If the research project results confirm that an epoxy retrofit applied to transverse rumble strips can effectively reduce roadside noise, the research will provide significant benefit to ODOT and other local jurisdictions within the state of Oregon. Highway safety would clearly be improved and while nearby residences would not experience as much roadside noise.

2.0 METHODOLOGY

This chapter documents the research design, which is based on SPR 800 Quantifying the Performance of Low-Noise Rumble Strips (Hurwitz et al., In Press). The experiment measures the resultant noise of a probe vehicle striking a traditional and shallow TRS.

2.1 EXPERIMENTAL DESIGN

One experimental location was evaluated, the NB ramp terminal of the S. Jefferson Interchange (Exit 238) as shown in Figure 2.2. The before observation focuses on the traditional TRS, and the after observation focuses on the shallower TRS. A passenger car probe vehicle was used to collect at least 3 isolated TRS strikes at 45 mph, which is lower than posted speed limit 55 mph. This speed was used as the TRS are close to an intersection. Probe vehicle strikes have been used previously to evaluate rumble strips (Linden et al., 2018; Hurwitz et al., In Press).

The SIP Method is a standard method for measuring the sound pressure levels of road surfaces (AASHTO, 2013). The maximum A-weighted sound level (dBA) for a given vehicle type is calculated and compared to a baseline ambient sound level to determine the effect of road surface variations. This method establishes standards for equipment, test sites, traffic conditions, microphone positions, calibration, experimental procedures, and data calculations. If excessive background noise, high wind speeds, or partial RS strikes occurred, additional runs were collected. SPR 800 applied this method to evaluating sinusoidal RS, and Figure 2.1 shows the guidelines of the procedure.

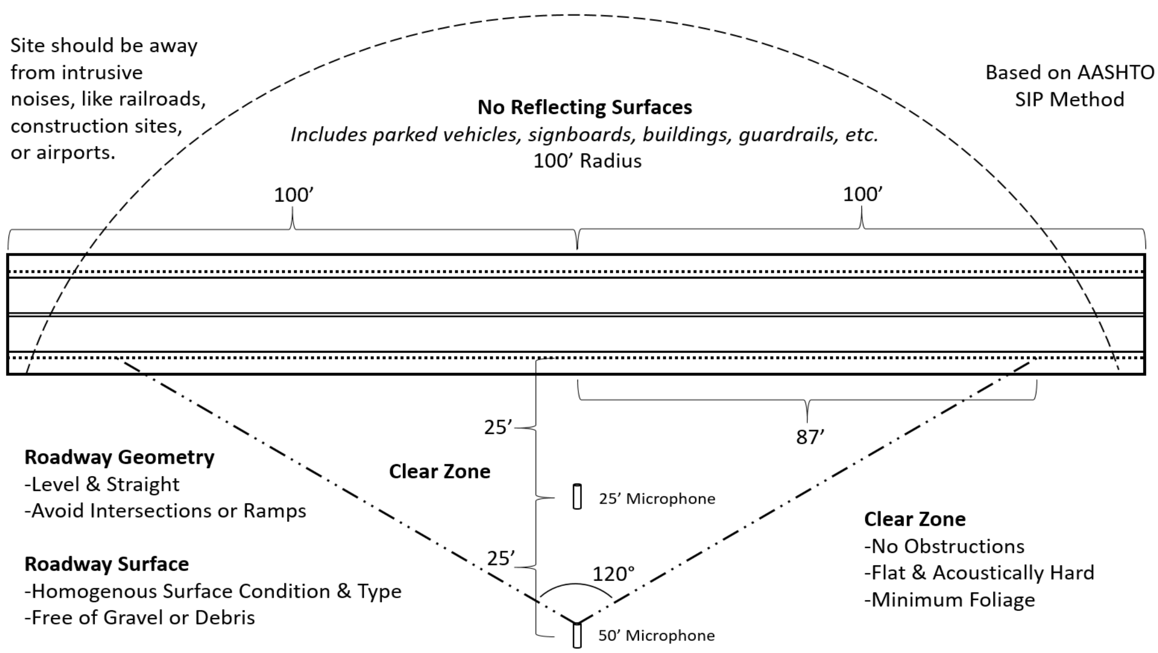

Figure 2.1: Guidelines based on AASHTO SIP method

The TRS site was located on Jefferson Highway (OR 164) at the NB Interstate 5 exit and entrance ramp, near Millersburg, OR (Figure 2.2). The before data was collected on July 10th, 2018, and the after data was collected on October 15th, 2018. The weather was clear, sunny, and warm on both days. Wind was calm, and the road surface was dry.

Figure 2.2: Site location for testing (© OpenStreetMap contributors)

All way stop signs were added to the intersection of OR 164 and the I-5 ramp, which was previously stopped controlled on the ramp only. TRS were installed on the approaches to warn drivers of the new stop condition in addition to stop ahead signs (W3-1) equiped with flashing yellow warning lights as shown in Figure 2.5. The specific TRS evaluated in this study are based on the location identified in Figure 2.3 from ODOT.

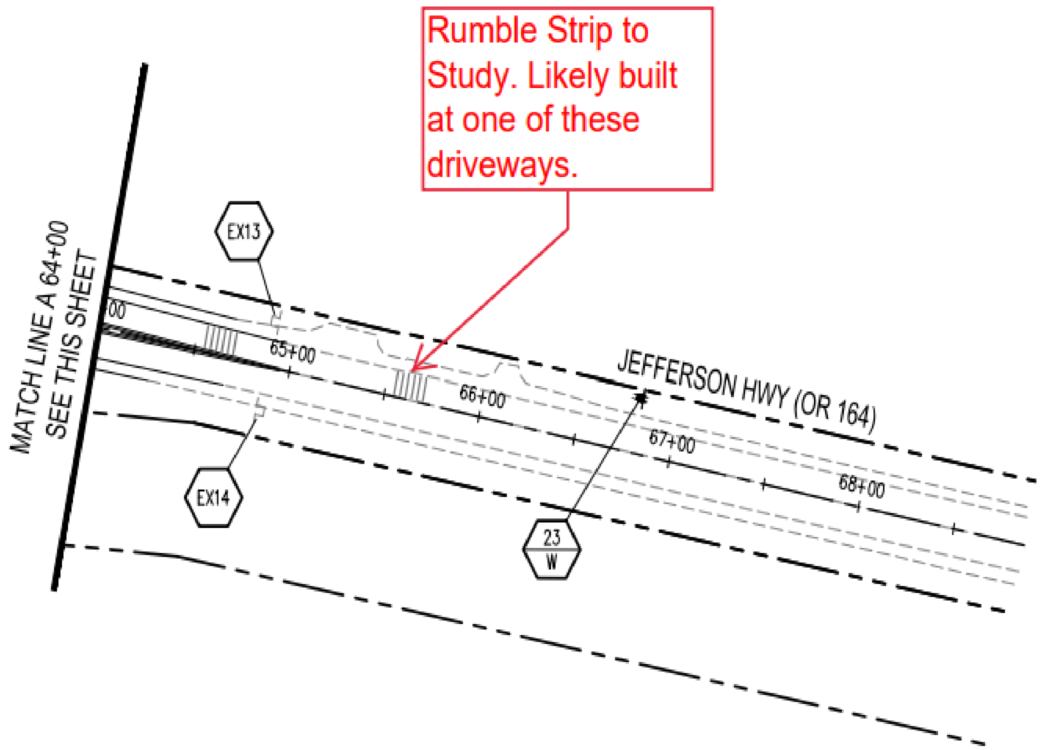

Figure 2.3: TRS location based on ODOT signage plan SN-01

2.2 EXTERIOR NOISE MEASUREMENT

The setup for exterior measurements is shown in Figure 2.4. Due to site constraints, microphones were located closer than prescribed in AASHTO's SIP Method. The microphones were centered on each TRS group, and the microphone was located above the road surface as shown in Figure 2.5. The microphone closer to the stop sign is referred to as the near microphone throughout this report, and the other is termed the far microphone. During each TRS strike, the sound level was monitored on the laptop to ensure that the event was 6 dB louder than the background noise. This decibel difference ensures that the strike event is detectable and independent from the influence of other noise. Additional runs were recorded if there was excess background noise, usually due to traffic in the opposing direction.

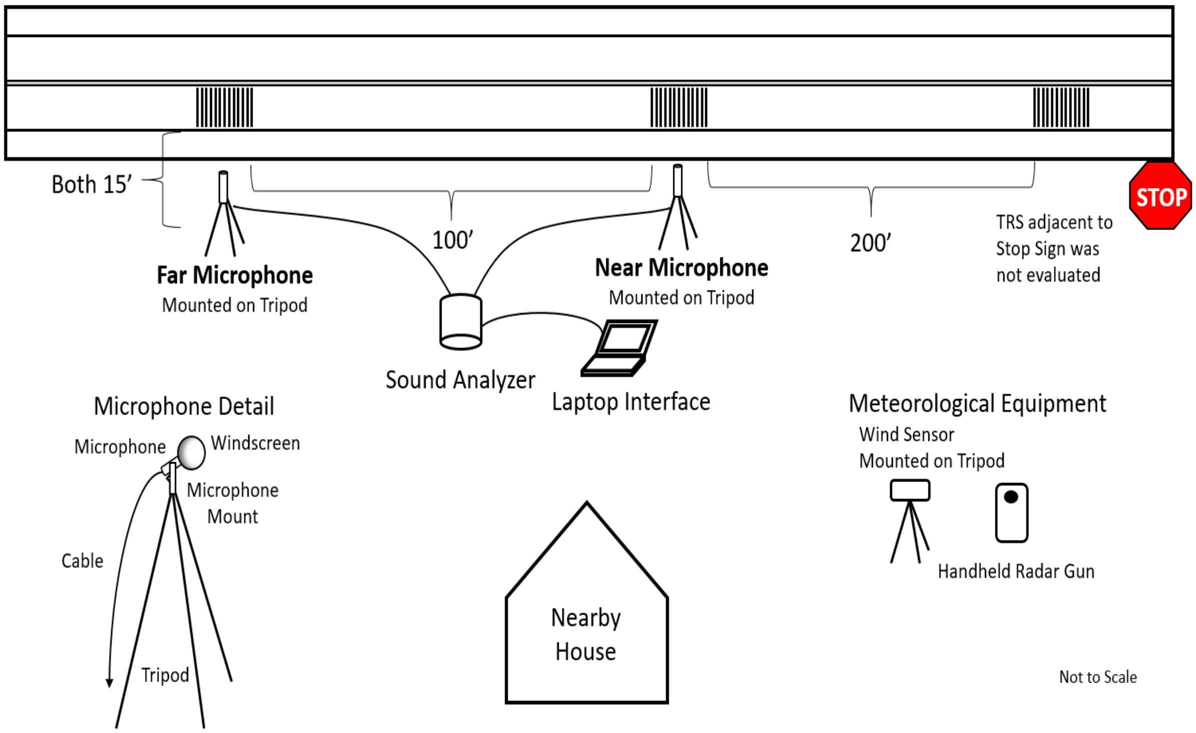

Figure 2.4: TRS sound measurement diagram

Figure 2.5: Before TRS roadside microphone setup

2.1 PROBE VEHICLE

A passenger car (Figure 2.6) was rented from Oregon State's motor pool and driven by licensed graduate research assistants. Drivers were instructed to drive at the posted speed at a safe operating distance from other vehicles on the roadway. Two-way radios were used to communicate between the vehicle assistant and the roadside team at the measurement location. The passenger car was a 2017 Ford Focus Hatchback (license plate number E269179). The tires were Continental ContiProContact 215/55 R 16 93 H. Tire pressures are shown in Table 2.1.

Figure 2.6: Passenger car probe vehicle

Table 2.1: Tire Pressure for Probe Vehicle

psi	Front	Rear
Driver Side	28.5	34
Passenger Side	34.5	32

3.0 RESULTS

3.1 RUMBLE STRIP CHARACTERISTICS

Geometric characteristics of each TRS type were measured and recorded to document the general properties of the tested TRS in the before and after data collection. Average field geometric characteristics of the before TRS are shown in Figure 3.1. The epoxy filled shallow TRS at the near location is dimensioned in Figure 3.2, and the paved TRS at the far location is shown in Figure 3.3. Large characteristics, such as the total length of the TRS group, were measured to the nearest half foot. Smaller characteristics, such as the mill depth, were measured to the nearest 1/16 in. Mill depth was measured several times at different mills due to slight variances in milling, and the average of these measurements is presented.

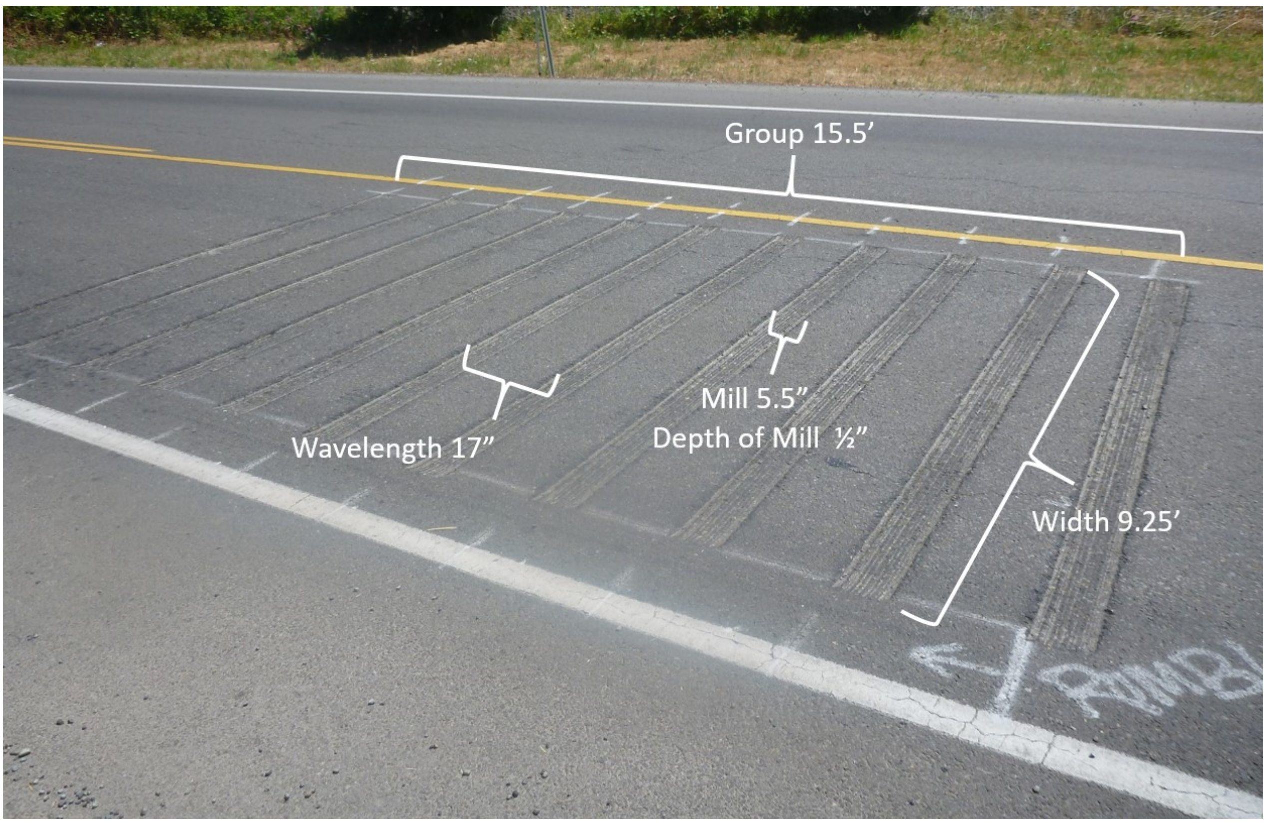

Figure 3.1: Before condition: TRS geometric characteristics

The TRS appeared to be installed as specified. Irregularities in pavement aggregates caused some variation in mill depth, as larger aggregate chunks chipped away. Similar variation exists across the epoxy TRS, but the fill appeared consistent. The new pavement at the paved TRS is likely to influence the sound slightly, as the pavement has a generally rougher surface when new.

Figure 3.2: After condition: Epoxy filled TRS at near location

Figure 3.3: After condition: Paved TRS at far location

3.2 TRAFFIC VOLUMES

Traffic volumes were gathered with a manual count recorded from 2:15 to 3:25pm during the before data collection at milepost 8 on OR-164. A total of 211 vehicles (11 % heavy vehicles) passed the TRS. Vehicles were classified using FHWA standard vehicle classification groups. These classifications were used to estimate the total number of axles that pass over the TRS per minute. As each axle strikes the TRS, multi axle trucks produce many TRS strikes with each vehicle. During the before data collection, over 9 axles per minute were observed, indicating 9 TRS strikes per minute.

3.3 EXTERIOR SOUND MEASUREMENT

A total of 24 sound measurements were collected (10 before, 14 after). Several of the measurements were not used as they had additional ambient traffic noise from other vehicles passing at the time of the strike. Ultimately, 5 measurements were used at the near location for the before and after conditions. Similarilary, 3 messurements were used at the far location for the before and after conditions. The measurements were combined using a weighted averaged, as dBA is a logrithmic scale as shown in the time series documented in Figure 3.4. In this figure, the before far TRS individual measurements are shown as dashed lines, and the overall average is shown with the solid line. Similar figures are shown in Appendix C for the other TRS locations.

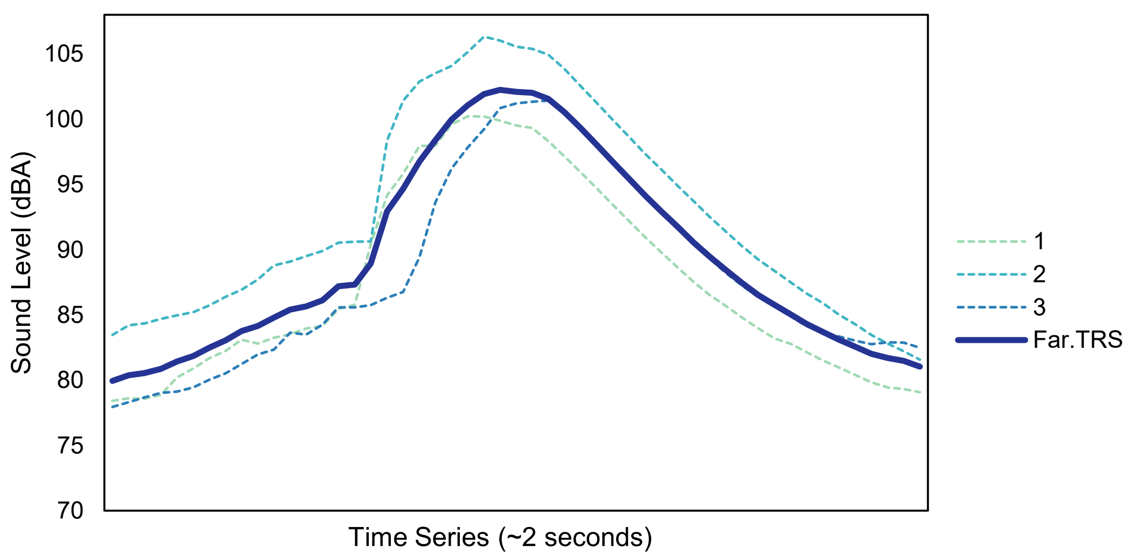

Figure 3.4: Exterior sound measurement from passenger car striking the far TRS

Figure 3.5 shows the overall time series weighted averages. The far TRS value is the same as shown in Figure 3.4. This is the highest intensity sound, which corresponds to the deep TRS, as well as the highest vehicle speeds. The near TRS value has similar depth the as the far, but vehicle speeds are lower as drivers decelerate in response to the stop sign. The next highest signal come from the near epoxy filled TRS. The depth of the TRS has a large influence on the amount of additional noise generated by rumble strip strikes (Miles et al., 2007; Hurwitz et al., In Press). The lowest intensity sounds were recorded at the far paved location, where the TRS was removed with new pavement. This value was used as a baseline for comparison of the other TRS measurements that describes the sound of a vehicle passing the location.

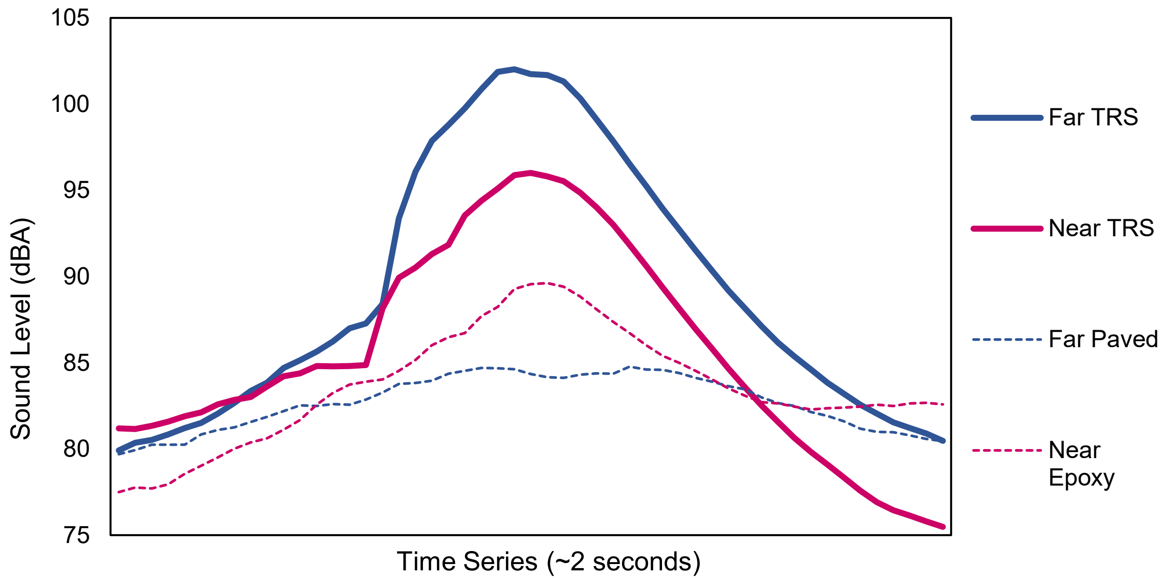

Figure 3.5: Exterior sound measurement from passenger car striking the TRS

3.4 STATISTICAL ANALYSIS

Data were analyzed in the Minitab statistical software package (version 18). All tests were performed at a 95% confidence level. Table 3.1 shows the mean (μ), standard deviation (SD), minimum, and maximum sound level in dBA for a milled TRS in each factor group. As shown in Table 3.1, TRS in the before scenario generated the highest average sound level based on the observed field measurements. The sound levels are higher in the presence of milled TRS for both locations. The far location in the before scenario reported the highest mean sound level (μ = 89.40, SD = 7.40) with a maximum value of 102.25 dBA. This higher sound measurement is likely related to the fact that the speed of vehicles is higher at the far location than at the near location. Drivers tend to decrease their speed during the approach to an intersection; those lower speeds generate less noise.

In the after scenario, when the far location was paved, the average sound level measurement dropped from 89.40 dBA to 81.64 dBA, a 7.76 dBA difference. For human hearing, this is a clearly noticeable change in the sound level, as discussed in Appendix: A TableA-2. When both measurements are compared based on their peak (max value), the difference in sound measurement is approximately 18 dBA. When the near TRS in the after scenario was treated with epoxy, the average sound level measurements dropped from 87.58 dBA to 84.09 dBA, a 3.49 dBA difference. This is a noticeable change in intensity. However, the peak difference in sound measurement was 6.04 dBA, or a clearly noticeable change.

Table 3.1: Descriptive Statistics dBA Magnitudes for the Factor Groups

RS Type	Scenario	Location/Treatment	Mean	SD	Min	Max
Transverse	**Before**	Far/TRS	89.40	7.40	79.95	102.25
		Near/TRS	87.58	5.90	78.18	97.92
	After	Far/Paved	81.64	1.94	78.34	84.35
		Near/Epoxy	84.09	4.10	78.11	91.88

Figure 3.6 shows a boxplot of sound levels for the two scenarios (before-after) by location (far-near) and treatment type. Roadside noise generated by the TRS strike was higher in the before condition. Alternatively, the alert generated by the TRS strike was reduced when the treatments were applied.

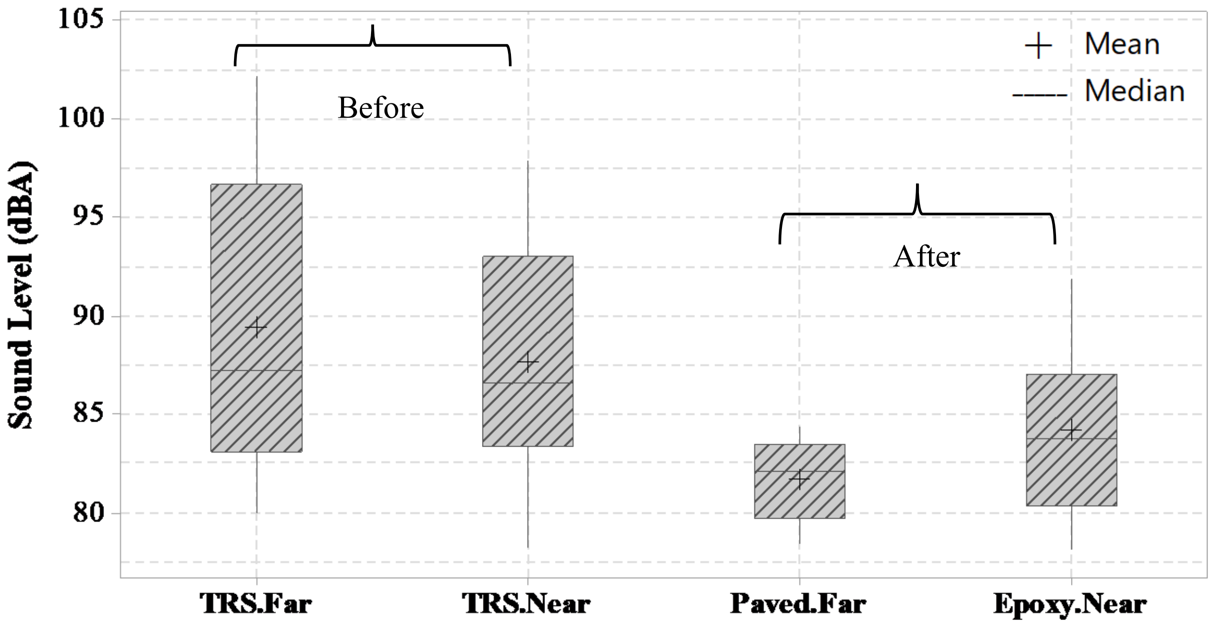

Figure 3.6: Boxplots by treatment and location for sound measurements.

Researchers performed a one-way ANOVA test on the sound measurements to determine whether the average sound levels differed between the 3-treatment procedure (TRS, epoxy, and paved). A statistically significant difference between means was found for at least 1 treatment type, $p < 0.001$. To identify where differences between group means occurred, a Dunnett multiple comparison test with paved as the control treatment was performed. As shown in Figure 3.7, regardless of location, the sound level generated from a TRS strike is higher than the paved condition, p-value < 0.001, 95% CI [4.85 dBA, 8.86 dBA]. This CI range indicates that the TRS is readily noticeable at least, and nearly doubling the roadside noise at most. Additionally, the sound level generated from the TRS treated with epoxy is higher than the paved condition, p-value = 0.03, 95% CI [0.14 dBA, 4.77 dBA], but is significantly lower when compared to the TRS strike. This CI range indicates that the epoxy filled TRS was indiscernible at least, and clearly noticeable at most compared to a baseline vehicle pass.

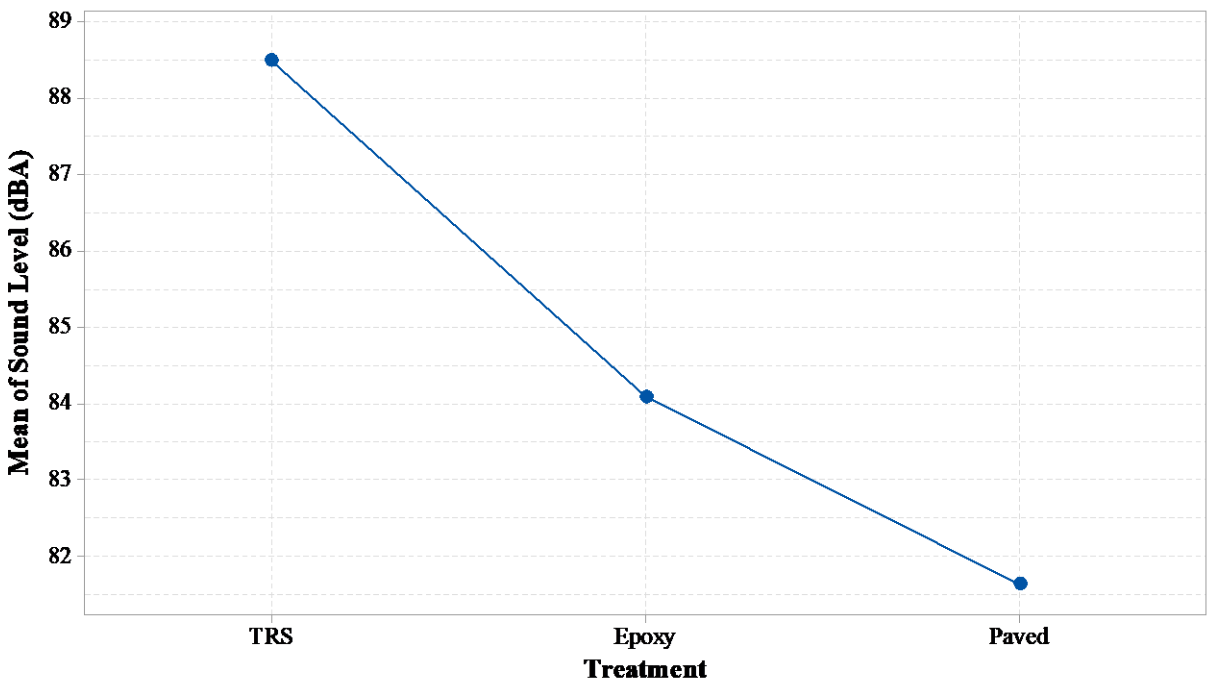

Figure 3.7: Main effect plot of sound measurement by treatments factor

Then, a two-way ANOVA test was performed on sound measurements to determine whether the average sound levels differed between the before and after scenarios, or between the near and far locations. Figure 3.8 shows the main effect plots, where differences can be observed between specific factors while all other factors are held constant. A statistically significant difference between means was found for the before and after scenarios, $p < 0.001$, 95% CI [4.18 dBA, 7.08 dBA]. This makes sense as the TRS were modified between these conditions. In the after scenario, the far TRS was paved, and the near TRS was partially filled with epoxy. This is consistent with previous research that shows TRS add 7 to 11 dBA to roadside noise compared to flat road pavement (An et al., 2016).

The noise generated from the far TRS and near TRS were not statistically significant, $p = 0.66$, [-1.13 dBA, 1.76 dBA]. This finding was expected, during the before scenario both TRS locations had the same deep treatment. The near is slightly higher, as it has the shallow TRS in the after condition. In terms of interaction factors, there was a statistically significant interaction between the scenario (before/after) and the TRS location ($p < 0.001$).

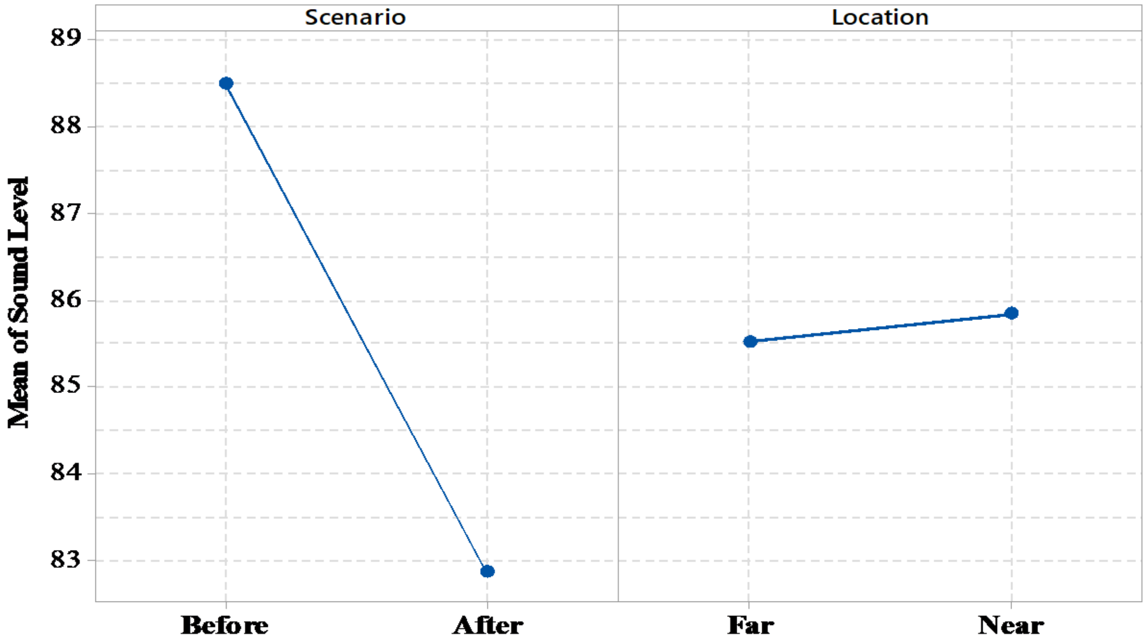

Figure 3.8: Main effect plots of sound measurement by scenario and location factors

Figure 3.9 plots the mean noise at each level of each factor. Results of pairwise comparisons showed that, the far TRS in the before scenario generated significantly more noise than when the TRS was paved over in the after scenario, $p < 0.001$, 95% CI [5.08 dBA, 10.45 dBA]. Similarly, the near TRS in the before scenario generated more noise than with the epoxy filled TRS in the after scenario, $p = 0.005$, 95% CI [0.80 dBA, 6.18 dBA].

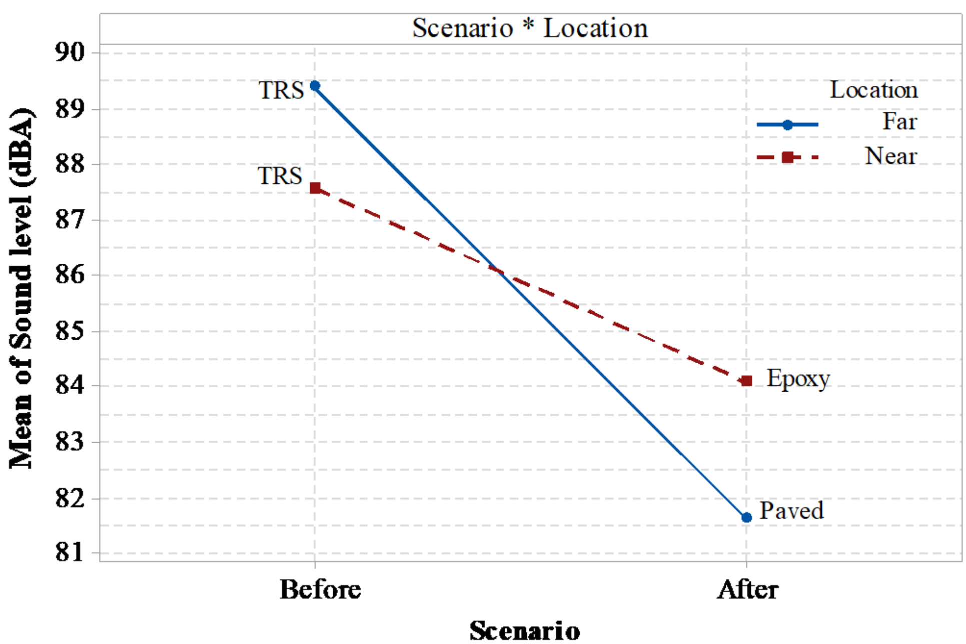

Figure 3.9: Interaction comparison of sound measurement

4.0 CONCLUSIONS AND RECOMMENDATIONS

This research study compared exterior sound levels for a probe vehicle striking traditional deep and shallow epoxy filled TRS in a before and after study. The framework for the experiment was based on previous studies of TRS noise and effectiveness, and the AASHTO SIP Method. At least 3 passes were recorded for each factor group, and weighted averages were used to calculate differences between TRS conditions. These delta measurements provided an estimate of the increased noise generated by the strike while holding other factors as constant as possible. According to the literature, humans can detect differences in noise levels at 3 dB, with 5 dB being easily noticed. A difference of 3 dBA between noise sources is the minimum amount needed for a typical human to perceive a difference in sound intensity.

From the results, the research team developed 3 conclusions concerning the use of epoxy to modification of TRS as an alternative to traditional TRS.

1. Roadside noise levels are a combination of vehicle noises from the tire, engine, and aerodynamics, as well as other environmental noises like wind, wildlife and other non-transportation related human activities. The TRS strike adds a distinctive new sound to this profile, and humans interpret that variation from the background condition as the sound of the TRS strike. Compared to the before condition of the deep TRS, the epoxy filled TRS average sound level measurements dropped from 87.58 dBA to 84.09 dBA, a 3.49 dBA difference. This is a noticeable change in intensity. However, the peak difference in sound measurement was 6.04 dBA, or a clearly noticeable change. Additionally, the sound level generated from the epoxy TRS is higher than the paved condition, p-value = 0.03, 95% CI [0.14 dBA, 4.77 dBA], but is significantly lower when compared to the TRS strike. This CI range indicates that the epoxy filled TRS was indiscernible at least, and clearly noticeable at most compared to a baseline vehicle pass, meaning that the epoxy TRS is still noticeable compared to background traffic.

2. Comparing the original TRS to the after paved TRS, the average sound level measurement dropped from 89.40 dBA to 81.64 dBA, a 7.76 dBA difference. This is a clearly noticeable change in sound level. When both measurements are compared based on their peak (max value), the difference in sound measurement is approximately 18 dBA. This indicates that the original TRS is nearly four times louder than the same passing vehicle on flat pavement.

4.1 LIMITATIONS OF THE RESEARCH

Only one speed was tested for all factor groups, the free flow speed limit of 45 mph. Increasing the speed has been shown to increase the noise generated in a RS strike, but the consistency of that relationship is unclear.

Only one vehicle was used as the probe vehicle, differences between vehicle types were expected, as the suspension, tire characteristics, and vehicle weight influence noise generation.

Only 2 TRS designs were tested (traditional deep, and shallow epoxy). Small changes in RS dimensions, especially mill depth, have a large influence on noise generation. Other mill depths could be used to further reduce noise (shallower), or increase driver alert (deeper).

Although this study focuses on roadside noise measurement, the driver also experiences a haptic and audible cue when striking TRS. An avenue for more research should include cases where the driver’s perception of both haptic and audible cues in the vehicle are considered through the lens of road safety in addition to reduced exterior noise.

Many roadway conditions were controlled for between test locations, to minimize differences between measurements during the experiment. The results reflect the pavement type and condition, mill quality, type of sound-absorbing materials at the site (foliage, trees, etc.), and atmospheric conditions at the time of observation. Other locations may generate more or less noise, as these factors will vary across the built environment. However, it is expected that the differences observed between the baseline and strike conditions would be similar, as these variables would have a similar effect on both conditions in other locations.

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APPENDIX: A

NOISE DETECTABILITY

Noise detectability is a measure of the intensity of a sound compared to the amount of background noise (Terhaar et al., 2016). If a noise is audible (able to be heard) but not louder than the ambient noise, then it will not be distinguishable to a listener. Continuous noise (steady or background) is more comfortable than impulsive noise, which is more noticeable and, in turn, more annoying (Caltrans, 2012). Time of day influences noise perception, with loud noises at night being more annoying because there is less ambient noise, and people are more likely to be resting (Caltrans, 2012). The A-weighted decibel (dBA) scale is based on the range of human hearing, as shown with example sounds in Table 6-1 (FHWA, 2015). Figure A.1 shows key sound terminology (Terhaar, 2016).

AMBIENT NOISE: The total of all noise in the environment, other than the noise from the source of interest. This term is used interchangeably with background noise.

dB: A unit of sound pressure level, abbreviated as dB. Decibel means 1/10 of Bel (named after Alexander Graham Bell). The decibel uses a logarithmic scale to cover the very large range of sound pressures that can be heard by the human ear. Under the decibel unit of measure, a 10 dB increase will be perceived by most people to be a doubling in loudness, i.e., 80 dB seems twice as loud as 70 dB

dBA: The A-weighted Decibel (dBA) is the most common unit used for measuring environmental sound levels. It adjusts, or weights, the frequency components of sound to conform with the normal response of the human ear at conversational levels. dBA is an international metric that is used for assessing environmental noise exposure of all noise sources.

Figure A.1: Key sound terminology (Terhaar, 2016).

The volume and frequency of sound determine the loudness and propagation of noise, with low-frequency noises travelling further due to lower energy losses, thereby affecting a wider audience of people (Sexton, 2014). Low-frequency noises in the 10–250 Hz frequency range are the most noticeable noises and may contribute to disturbed sleep, stress, and heart-rhythm disorders (An et al., 2016). For each doubling of distance away from the source, sound intensity decreases by 6 dB for point sources or 3 dB for line sources (FHWA, 2015).

Table A.1: Typical Sound Levels Expressed in dBA (Terhaar et al., 2016).

SOUND SOURCE OR LOCATION	LEVEL (DBA)
Rocket Launching Pad	180
Artillery at Shooters Ear	170
Rifle at Shooters Ear	160
Loud Trumpet at 5 in	150
Jet Takeoff 200 ft	140
Jet Aircraft Workers on Tarmac	130
20 ft from Rock Band Speakers	120
Nightclub, Diesel Generator Room	110
Subway, Chain Saw, Stereo Headphones	100
Noise Appliances, Lawn Mower at Users Ear	90
Typical Home Stereo Level, Inside Factory	80
Freeway at 200 ft	70
Speech at 3 ft or Air Conditioner at 20 ft	60
Typical Urban Ambient	50
Typical Rural Ambient (35-40), Quiet Office	40
Quiet Rural Ambient, Quiet Library, Soft Whisper	30
Winter with no wind, Concert Hall	20
Wilderness in Winter	10
Threshold of Hearing	0

To understand the noise generation of a RS strike, imagine the complex interaction of all the sounds on the roadside. Some noises are generated by vehicles, tires, engines, radios, aerodynamics or braking (especially from heavy vehicles). Other noises are produced by in-situ conditions, like wind, wildlife, or other non-transportation related human activities. Generally, most of these noises are similar between the baseline and strike condition. The RS strike introduces a new distinctive sound into the mix, that has a very specific frequency (the specific dB increase), as well as increasing the overall intensity of vehicle noises (particularly the tire noise). Tire noise is one of the largest contributors of roadside noise, especially at higher speeds, and as the RS strike intensifies this noise is the result of repeatedly hammering the tire into the RS mill.

Humans can discern differences in noise levels at 3 decibels (dB), with 5 dB being easily noticed. The most common range of frequencies heard by humans is 400–2000 Hz (Himes, S. et al, 2017). Changes in sound levels and the related perceived intensity are shown in Table 6-2 (Table 75, Torbic et al., 2009). NCHRP 641 recommends a noise level increase of 6–12 dBA to alert drivers that they are encroaching on a RS (Torbic, 2009).

Table A.1: Approximate Human Perception of Changes in Sound Levels (from Table 75 in Torbic et al., 2009)

CHANGE IN SOUND LEVEL (DBA)	CHANGE IN APPARENT INTENSITY
1	Imperceptible
3	Barely noticeable
6	Clearly noticeable
10	About twice – or half as loud
20	About four times – or one-fourth as loud

APPENDIX: B

GLOSSARY

This glossary contains definitions of abbreviations, acronyms, and common terms.

Table B.1: Definitions of Abbreviations and Acronyms

ACRONYM/ABBREVIATION	DEFINITION
AASHTO	American Association of State Highway Transportation Officials
RS	Rumble Strip
TRS	Transverse Rumble Strip
SIP	Statistical Isolated Pass-By Method
ANOVA	Analysis of Variance
OSU	Oregon State University
dBA	A-weighted decibel
µ	Mean
SD	Standard Deviation
CI	Confidence Interval

APPENDIX: C

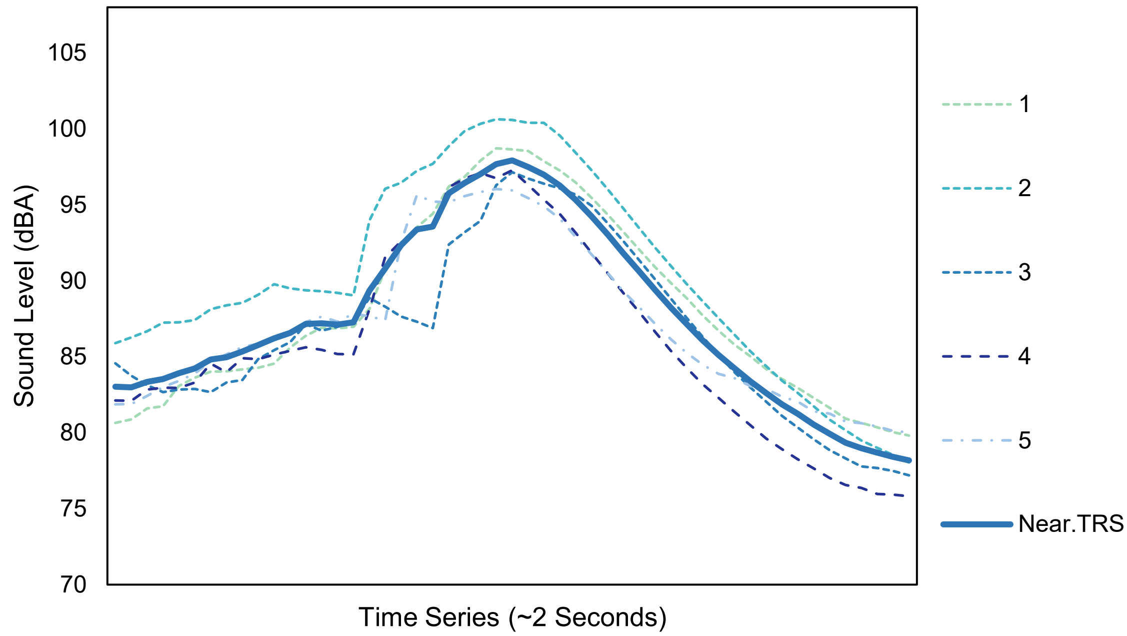

Figure C.1: Exterior sound measurement from passenger car striking the near TRS

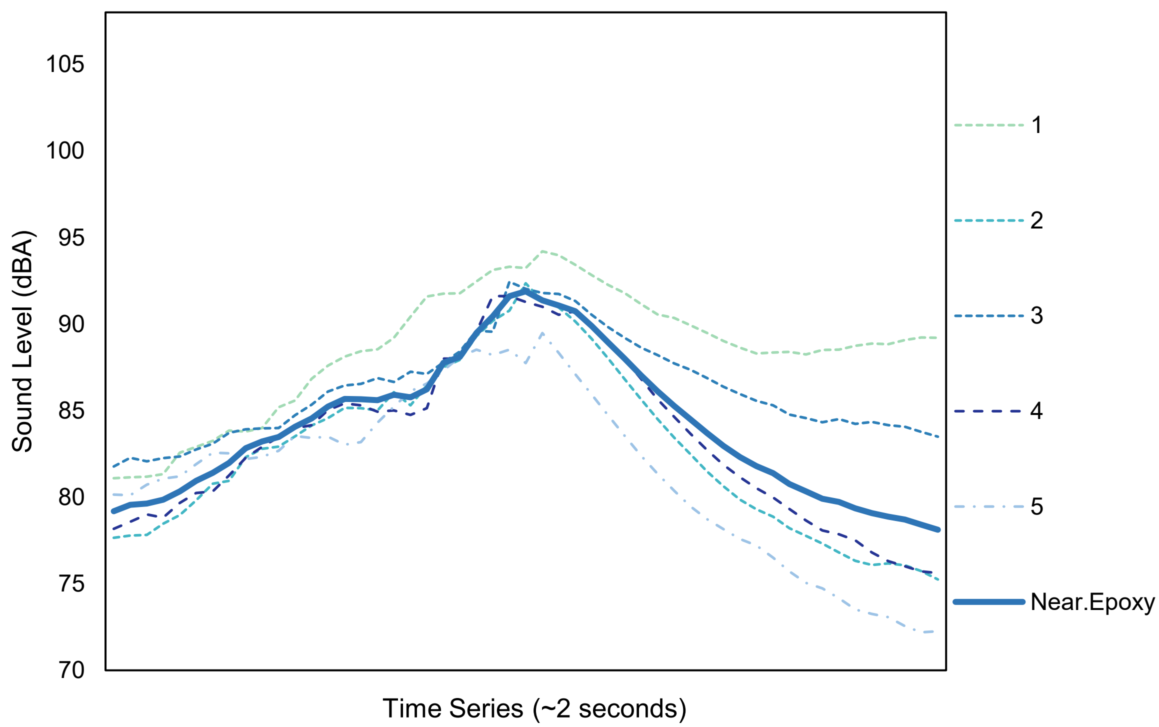

Figure C.2: Exterior sound measurement from passenger car striking the epoxy TRS

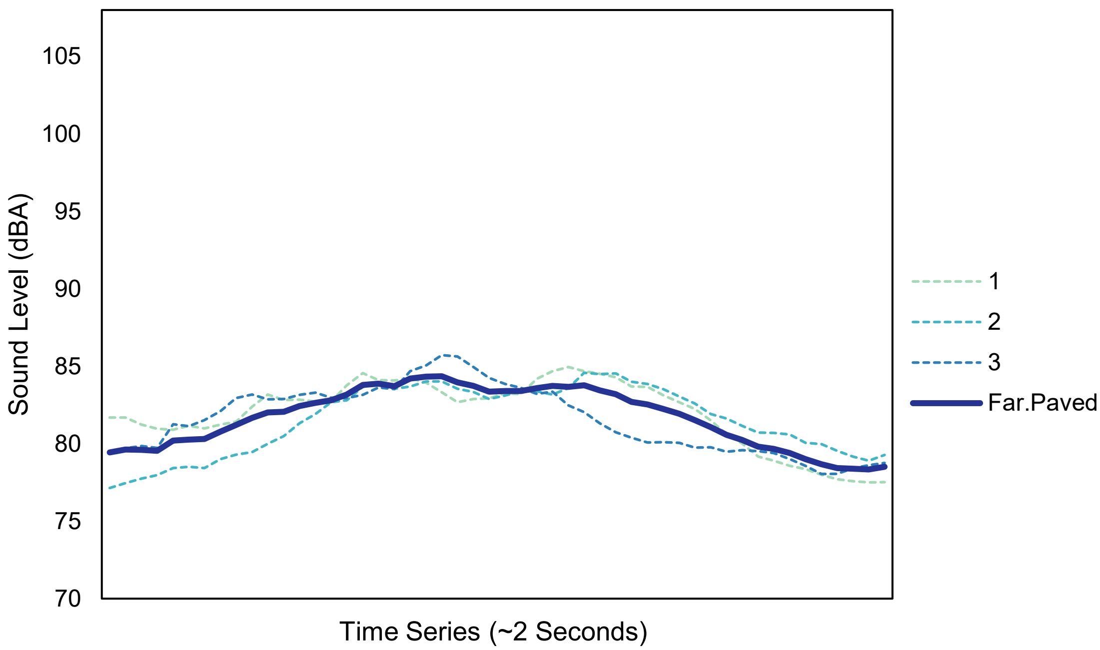

Figure C.3: Exterior sound measurement from passenger car striking the paved TRS