RESEARCH & DEVELOPMENT

Comparison of Noise-Level and Frequency of Standard Rumble Strip and Sinusoidal Rumble Strip Designs

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16. Abstract

Residents living near or along roadways with shoulder rumble strips have complained about the excessive noise caused when a vehicle leaves the travel lane and strikes a rumble strip. In an effort to reduce this noise, a new, sinusoidal rumble strip, has been designed and installed in some locations. Sinusoidal rumble strips are designed to reduce noise along the roadside while also delivering the necessary auditory and vibratory cue to alert the driver of the vehicle that the vehicle has left the travel lane. An evaluation of two rumble strip designs – sinusoidal and rounded – was conducted at a test site along NC-71 in the study area near Shannon, North Carolina. The research team tested the rumble strips using three sound meters, a dump truck, a passenger vehicle, and an oscilloscope. This evaluation found that the standard rumble strip was generally louder than the sinusoidal rumble strip and that the distance away from the roadway impacted the difference. At a distance of 50 feet from the edge of the roadway, the loudness of the designs was similar, however at further distances of 100 feet and 200 feet, the sinusoidal design was 3 dBA and 9 dBA quieter, respectively. These results are expected given the results of the frequency analysis because sounds with higher frequency (as generated by striking the sinusoidal rumble strip) do not carry as far as the lower frequency standard rumble strip strike. However, both the standard and sinusoidal rumble strips produce a noise level that is substantially higher (more than double) than the ambient noise level – suggesting that both designs should provide a sufficient warning to drivers of errant vehicles.

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Table of Contents

Table of Contents iii
Introduction 1
  Project Location 3
Analysis and Results 4
  Exterior Data – Sound Level 4
  Interior Data – Sound Level 7
  Frequency (Hertz) of Rumble Strip Strikes 8
Summary 10
References 11
Appendix A: NCDOT Milled Rumble Stripe Specifications 12
Appendix B: NCDOT Sinusoidal Milled Rumble Strip Specifications 14

Introduction

Rumble strips are indentations milled into the roadway at locations where a vehicle's continued path of travel is undesirable, such as the shoulder at the edge of the lane. When struck, the rumble strips are designed to produce noise and vibration such that an inattentive driver may be alerted and correct the course of their vehicle. Rumble strip strikes have been a source of complaints made by residents who live near or along roadways with the strips installed. Previous research has shown that the noise produced from striking a rumble strip is greater than the surrounding road noise (Karkle et al, 2011). A new design, in a sinusoidal shape, known as sinusoidal rumble strips, has shown promise as a treatment that produces the necessary auditory and vibratory impacts for errant vehicles with lower noise levels to the surrounding environment than the traditional, semi-circle shape, standard rumble strips.

Two locations were chosen for data collection along NC-71 in the study area which had an installation of sinusoidal and standard rumble strips on adjacent roadway segments in early October 2019. Data collection activities occurred on October 17, 2019 (interior and exterior measurements with dump truck and passenger vehicle), February 4, 2020 (passenger interior and exterior) and March 26, 2020 (interior measurements). The sites used were similar in setting and environment, both being in open areas without tall trees, buildings, or any large producers of ambient noise or interference close by. The sites offered level ground nearly at-grade with the roadway with over 200 unobstructed feet perpendicular from the outside edge of pavement. The standard style was installed as a rumble stripe (with the edge line applied in the rumble strip) and the sinusoidal style was installed outside of the edge line. Although the standard style was installed as a stripe (which is a rumble strip with lane markings installed inside the strip), the focus of this research effort was about the noise effects related to the shape of the rumble strip and for consistency is referred to as a strip in this report. Figure 1 shows an image of the standard design and Appendix A provides the NCDOT specifications for the installation studied in this effort. Figure 2 shows an image of the sinusoidal design and Appendix B provides the NCDOT specifications for the installation studied in this effort. The standard style was installed with the following dimensions: width of 8 inches, length of 7 inches, depth of 0.5 inches, and center-to-center spacing of 12 inches. The sinusoidal style was installed with the following dimensions: width of 14 inches and continuous milling with a maximum depth of 0.5 inches and a minimum depth of 1/16 inches with a center-to-center spacing of 14 inches.

This evaluation included two measurement types: 1) decibel, which is the loudness of sound, measured in A-weighted decibels (dBA) and 2) frequency, which is the distance between the sound waves, measured in hertz (Hz). Humans can hear frequencies between 20Hz and 20,000Hz, and decibels starting at 1dBA and higher. Sounds above 90dBA are considered harmful, and the Occupational Safety and Health Administration (OSHA 2020) requires hearing protection if decibels above this threshold are expected. Frequencies at and below 125Hz have been shown to be detrimental to human health, in the form of risk of hypertension, for residents living near a roadway (Chang et al. 2014). A 1 dBA change in sound level is imperceptible, a 3 dBA change is barely noticeable, a 6 dBA change is clearly noticeable, a 10dBA change is twice (or half) as loud, and a 20 dBA change is four (or one-fourth) as loud (Torbic et al. 2009).

Limited published literature exists on the topic of standard and sinusoidal rumble strip design noise measurement and the resultant comparative noise levels. Cerrato (2009) described the vehicle components responsible for the cumulative sound produced by a vehicle. Hurwitz et al. (2019) conducted research in Oregon with the purpose of evaluating the efficiency of sinusoidal rumble strips relative to standard rumble strips. The report concludes that the exterior sound produced by the vehicle when striking the sinusoidal strips is less than that of the standard rounded strips. Similar trends were observed for the interior sound; however, the sound level produced by sinusoidal strips is sufficient to alert the driver.

The primary objective of the study was to understand the differences in external and internal noise between standard and sinusoidal rumble strips generated when traveling over the rumble strip. Internal noise levels, at the driver position, were collected to provide a basis for comparing relative differences between internal and external sound levels for different rumble strips and vehicles.

Figure 1. Standard-Style Rumble Stripes

Figure 2. Sinusoidal-Style Rumble Strips

Project Location

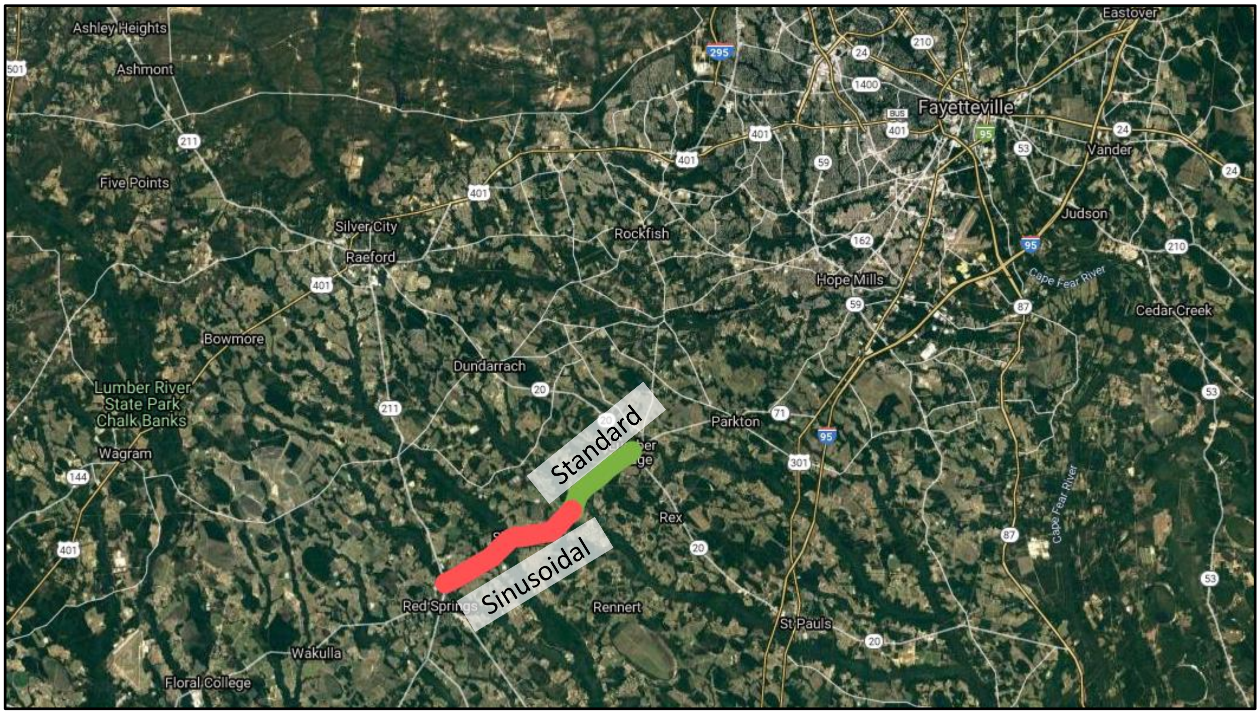

Figure 3. Project Location (west of I-95 and southwest of Fayetteville) – Standard Rumble Strips are shown in Green and Sinusoidal Rumble Strips are shown in Red.

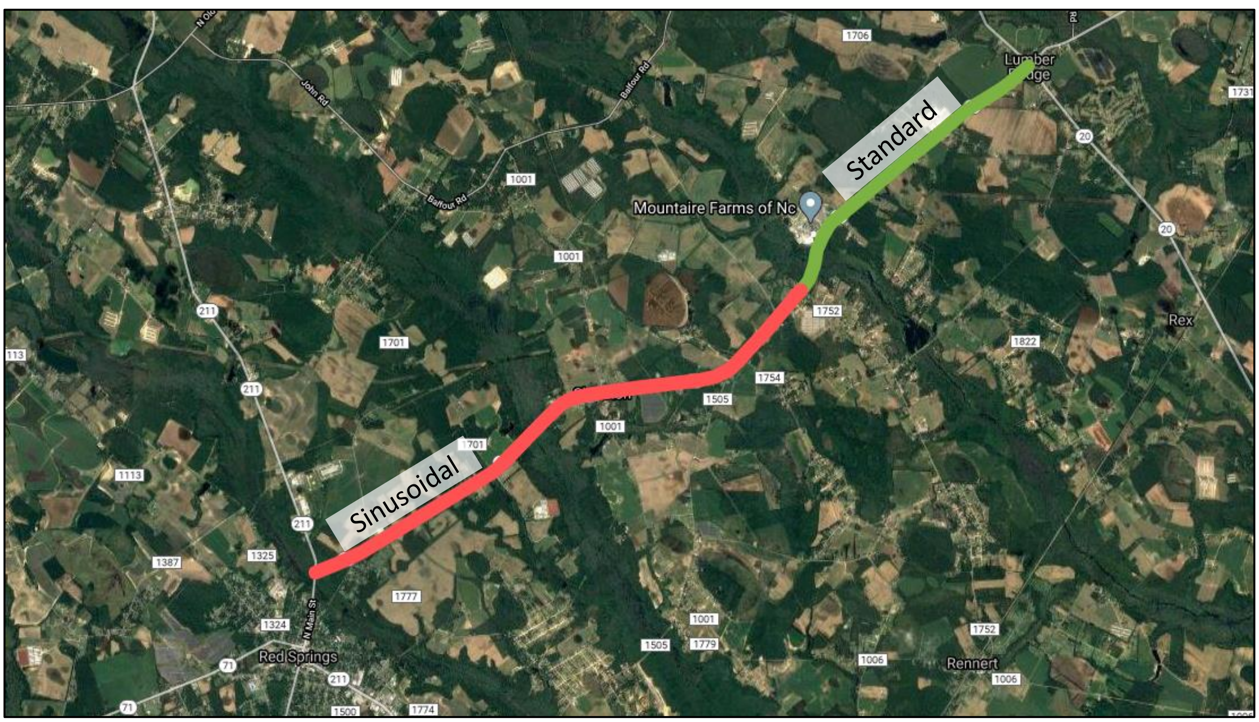

Figure 4. Project Location Along NC71 near Shannon Between Red Springs and Lumber Bridge – Standard Rumble Strips are shown in Green and Sinusoidal Rumble Strips are shown in Red.

Exterior Data – Sound Level

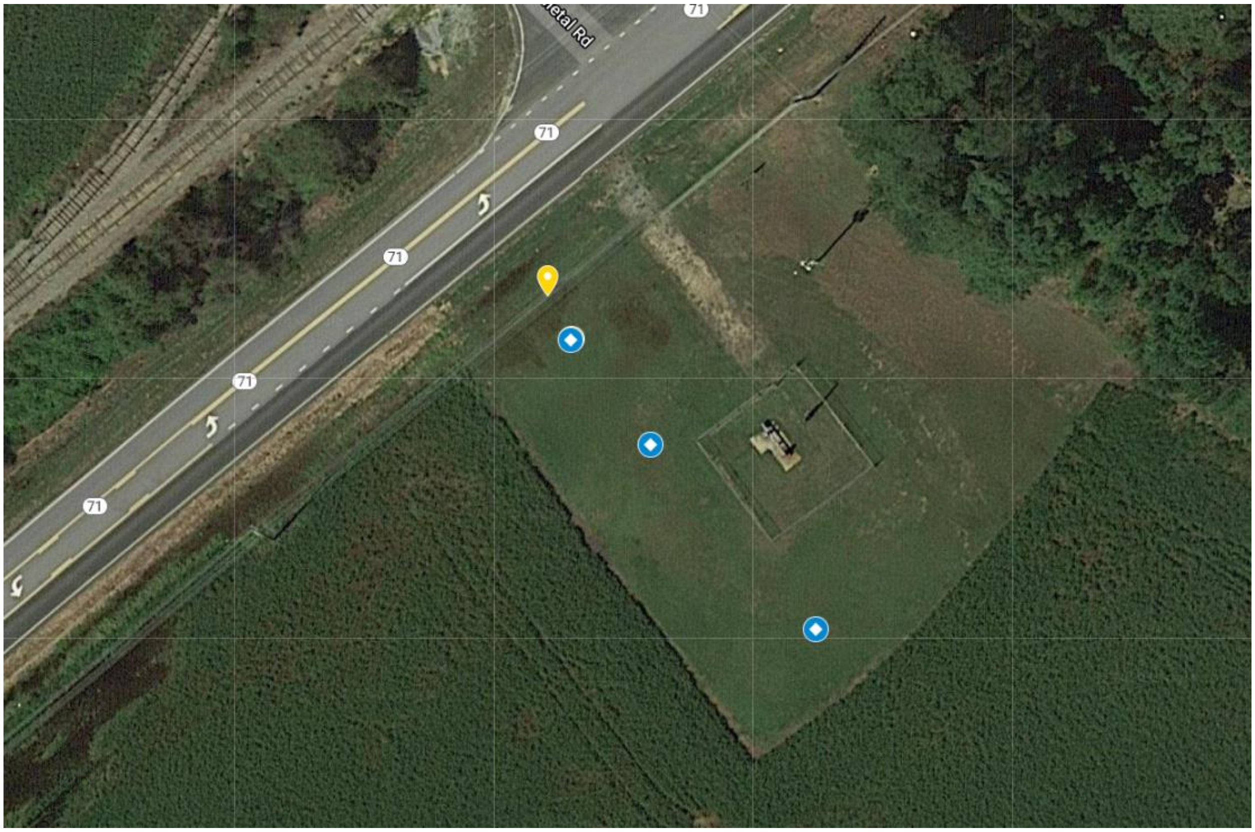

Figure 4. Field Instrument Setup (Sound meters shown in blue at distances from the roadway of 50 feet, 100 feet, and 200 feet; oscilloscope shown in yellow)

Sound meters were placed at distances for 50 feet, 100 feet, and 200 feet from the edge of the roadway to measure the sound level of the roadway, including rumble strip strikes and ambient traffic noise (Figure 4). The researchers then conducted two passes at each speed (45, 50, and 55 mph) by the data collection location, driving over the adjacent rumble strip the entire time they were passing the data collection devices (starting approximately 50 feet upstream from the sound meter and ending approximately 50 feet downstream of the sound meter). This ensured expedient and efficient data collection instead of waiting for other drivers to strike the rumble strips near the sound meters.

The researchers found that the standard rumble strip was louder than the sinusoidal rumble strip, but that this loudness was related to the distance from the roadway (Figure 5). The ambient sound level at the standard site was 1.3dBA louder than the ambient at the sinusoidal site during the passenger car data collection time period. Ambient noise was recorded by all noise meters at each location and represent an average of the noise levels at any time when the test vehicle was not striking the rumble strip. The ambient measurements included time periods when passing cars were present and not present at the location adjacent to noise meters (all rumble strip strikes were excluded from the ambient measurements). However, the volume of traffic at these locations was consistent enough that most time periods of ambient noise levels were influenced by vehicles in the adjacent roadway segments. Although the data collection locations were as similar as possible, localized impacts of terrain, vegetation, and other factors impact the noise levels, therefore, the ambient noise was recorded to understand how these differences may impact the results. Additionally, at 50 feet, the researchers were unable to statistically distinguish between either rumble strip design. However, at 100 feet, the sinusoidal strip was 3.12dBA quieter and statistically significantly different from the standard design at the 0.05 significance level. Furthermore, at 200 feet, the sinusoidal was 9.12 dBA quieter than the standard rumble strip and statistically significantly different from the standard design at the 0.05 significance level. These results are expected given the results of the frequency analysis because sounds with higher frequency (as generated by striking the sinusoidal rumble strip) do not carry as far as the lower frequency standard rumble strip strike.

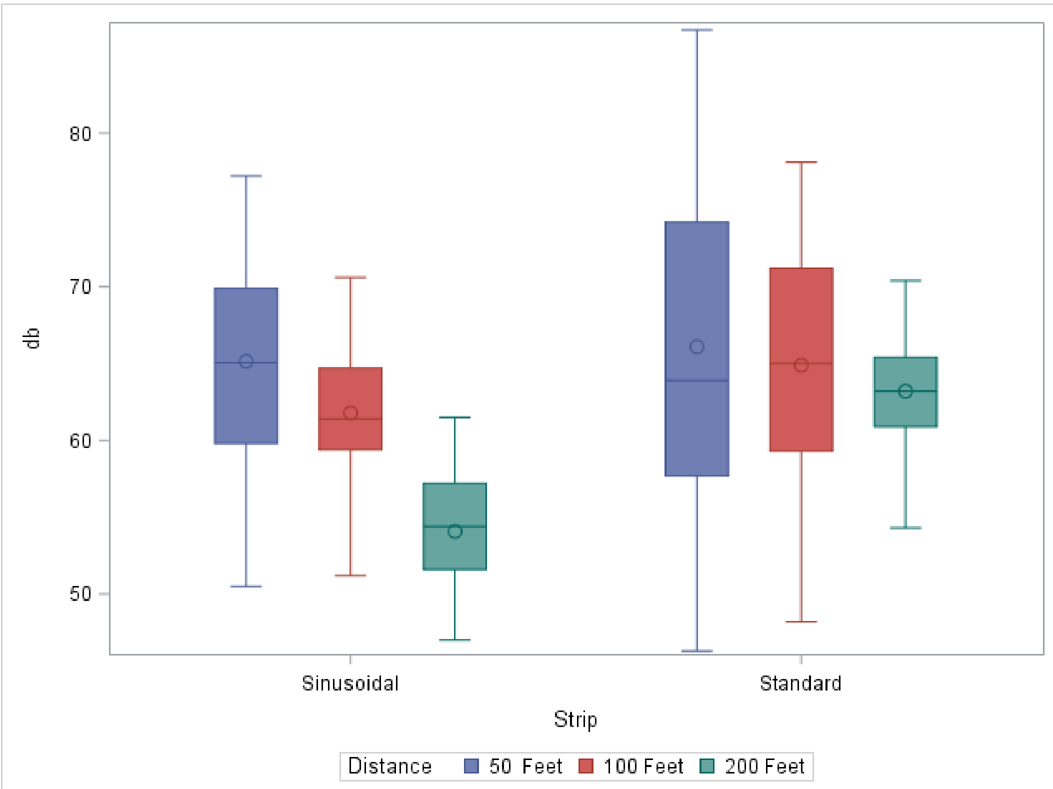

Figure 5. Exterior Data Box Plot

The data collection also included a dump truck during a separate test setup, with only one sound meter that was located at a distance of 50 feet from the edge of the road. This dump truck traversed the adjacent rumble strip in the same way that the other data collection vehicle was used. At the sinusoidal installation, there was no significant difference between the ambient sound of the site and the sound of the truck striking the rumble strip ($p = 0.772$). The researchers were able to detect, however, a slight difference between the standard rumble strip, when struck, and the ambient noise at that site ($p < 0.0001$), a 1.24 dBA increase when the truck struck the strip (although this difference is likely not practically significant). The study also found a 4 dBA increase comparing the sinusoidal design to the standard design ($p < 0.0001$), but this is balanced out by a 2.9 dBA increase in the ambient noise between the sinusoidal and standard sites ($p < 0.0001$) during the truck data collection period. The net result is a 1.1 dBA reduction in noise due to the sinusoidal strip. The width and diameter of the truck tires might be the reason for the marginal differences.

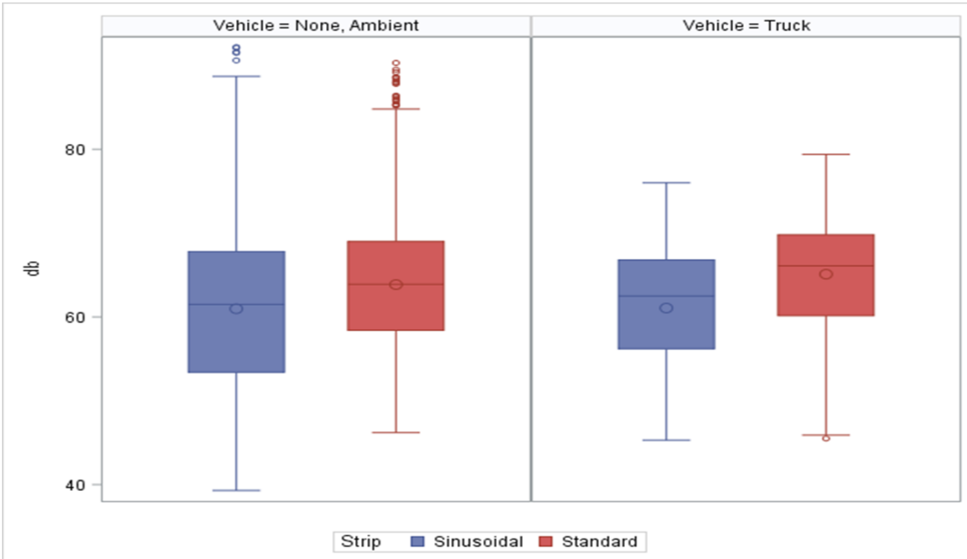

Figure 6. Truck Data Box Plot

Interior Data – Sound Level

Sound data were collected inside the vehicle at multiple speeds (45, 50, and 55 MPH) for approximately 30 seconds of a continuous rumble strip strike at the test location. Sound meters were placed inside the vehicle adjacent to the driver's ear to capture the noise levels that would be comparable to those heard by the driver. The driver would move the tires to the rumble strip and drive at the test speed, signaling to the other researcher to start the sound measurement. The driver maintained the vehicle on the rumble strip for approximately 30 seconds, then would signal to the other researcher to stop the recordings. This process was used to ensure that the only sound data being captured with the interior sound recordings was that of the vehicle striking the rumble strip. This also ensured that the recordings could be accurately distinguished between each other, with written notes and time stamps keeping track of which sound recordings were associated with which test speed.

The data include the decibel values when the vehicle hit the strips at each speed and the ambient noise level at each speed. The results show that for different speed levels the sinusoidal rumble strips result in a lower sound level than the standard design inside the vehicle at each of the speeds. However, both the standard and sinusoidal rumble strips produce a noise level that is substantially higher (more than double) than the ambient noise level – suggesting that both designs should provide a sufficient warning to drivers of errant vehicles.

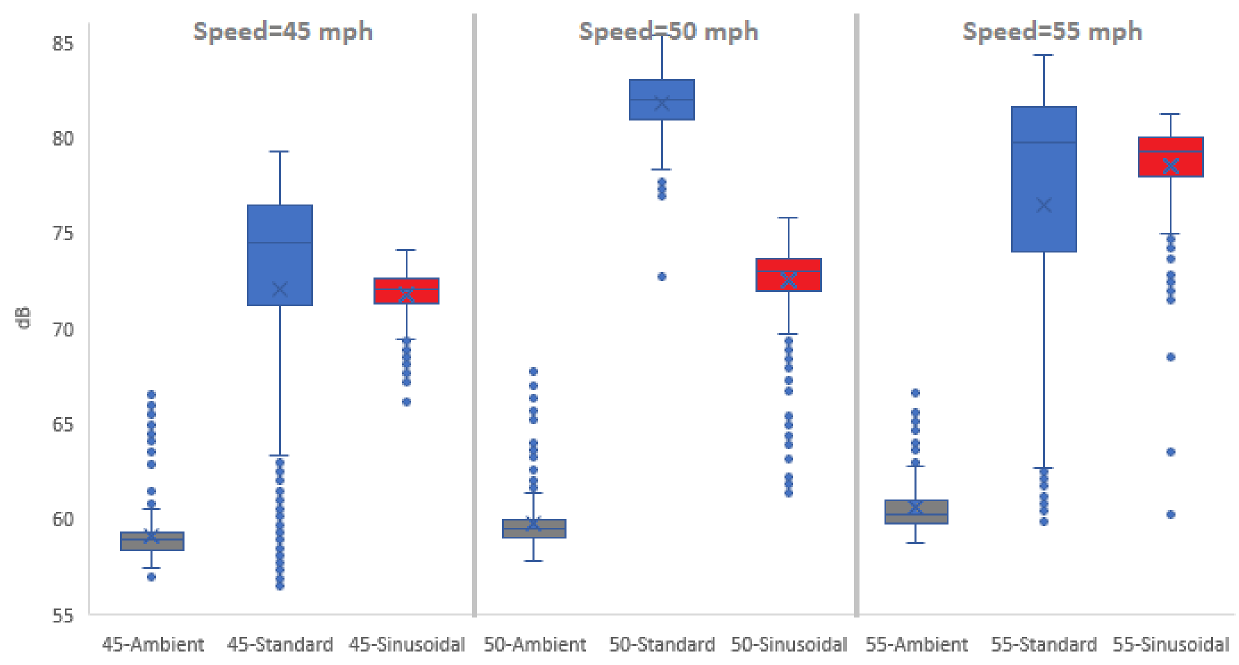

Figure 7. Interior Data Box Plot

Frequency (Hertz) of Rumble Strip Strikes

The frequency of a sound describes the pitch of the sound and is measured in hertz (hertz values are calculated by dividing the period of the wave by 2 pi and are abbreviated as "Hz"). Lower frequency values correspond to lower pitch. An oscilloscope was used in the same manner as the noise meters outside and inside of the vehicle to capture the noise frequency when the test vehicle struck the rumble strip.

The standard rumble strip, when struck, produced a frequency of 122.5Hz at the roadside, exterior locations, which had a much lower pitch than the 525Hz sound produced by the sinusoidal rumble strip. Surprisingly, this relationship was not replicated inside the vehicle. When struck, the standard rumble strip produced a sound in the 525Hz range within the vehicle, while the sinusoidal variant produced a relatively deeper 366Hz pitch. Figure 8 and Figure 9 show the frequency of rumble strip strike events for both sinusoidal and standard rumble strips, respectively. Each graph shows the voltage over time of the electric current which the sound produces when entering the microphone. The frequency, Hz, is a measure of the number of peaks within the specified time frame. The figures include multiple speeds (45, 50, and 55 MPH), as well as external and interior frequencies. The speed of the vehicle was highly impactful on the frequency of the sound produced for the sinusoidal rumble strips ($p < 0.001$).

The ambient road noise inside a vehicle (not when the rumble strips were struck) had a frequency between 50 and 200 Hz.[1] Thus, the sinusoidal rumble strip's deeper 366Hz tone is closer to the sound already present in a vehicle, making it less noticeable to a human listener, while the standard rumble strip's 525Hz range would stand out to the human ear from the ambient.

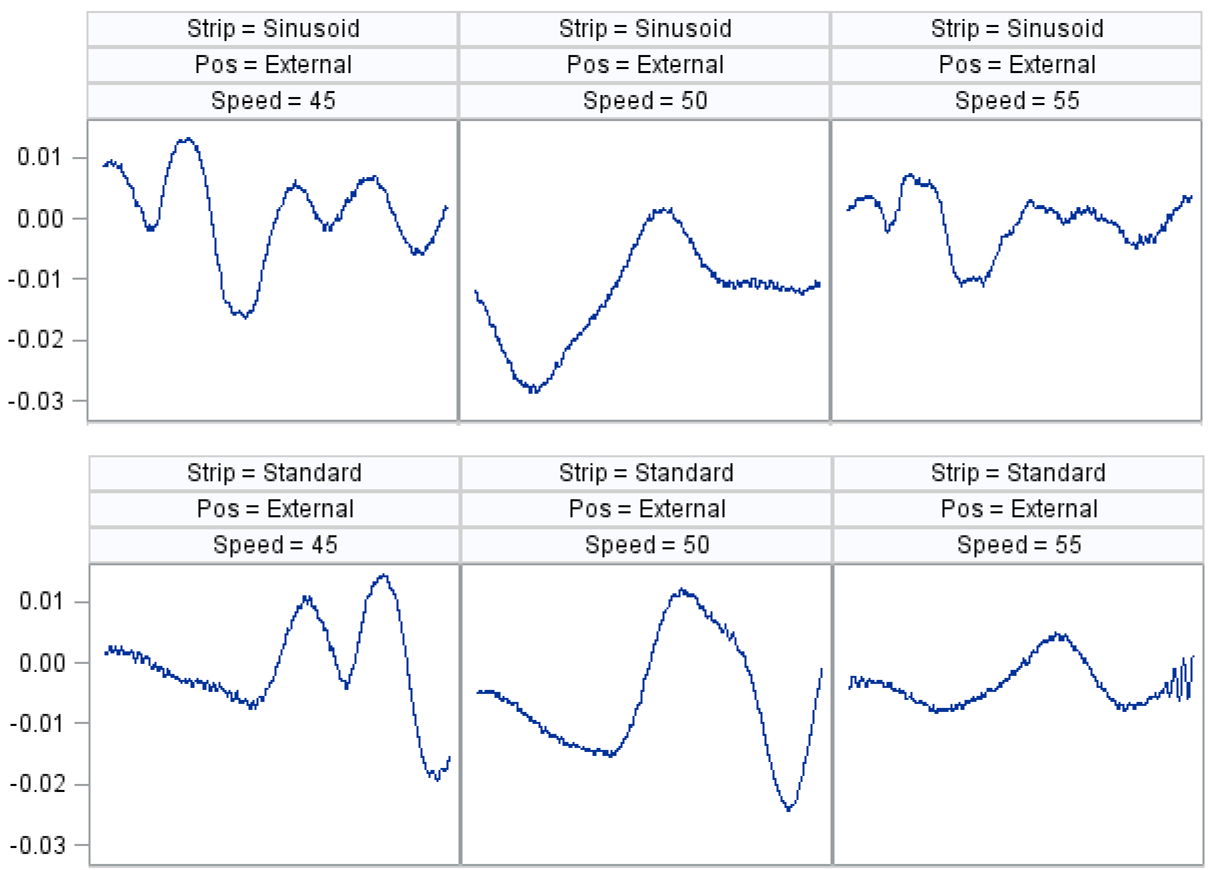

Figure 8. Rumble Strips Exterior Frequency Data

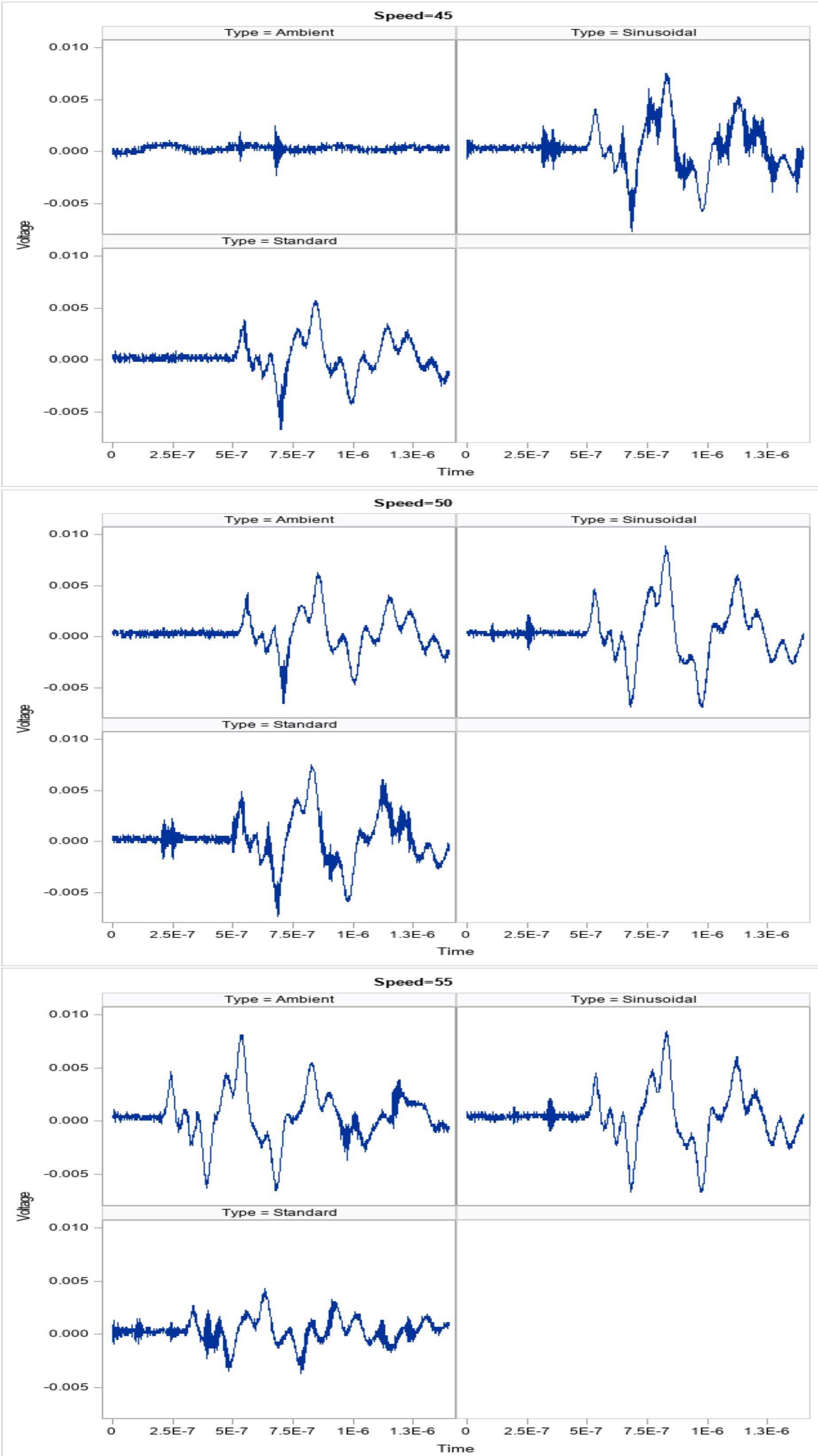

Figure 9: Rumble Strips Interior Frequency Data

Summary

An evaluation of two rumble strip designs – sinusoidal and rounded – was conducted at a test site along NC-71 in the study area near Shannon, North Carolina on adjacent roadway segments. This evaluation found that the standard rumble strip was generally louder than the sinusoidal rumble strip and that the distance away from the roadway impacted the difference. At a distance of 50 feet from the edge of the roadway, the loudness of the designs was similar, however at further distances of 100 feet and 200 feet, the sinusoidal design was 3 dBA and 9 dBA quieter, respectively. As a comparison, many states expect noise walls to reduce noise levels by 7 to 10 dBA (19 of 23 states studied had a minimum noise reduction goal of 7 dBA)(El-Rayes et al 2018), so the change in noise level at 200 feet by the sinusoidal design is similar to the addition of a noise wall. These results are expected given the results of the frequency analysis because sounds with higher frequency (as generated by striking the sinusoidal rumble strip) do not carry as far as the lower frequency standard rumble strip strike. The standard rumble strip, when struck, produced a frequency of 122.5Hz at the roadside, exterior locations, which had a much lower pitch than the 525Hz sound produced by the sinusoidal rumble strip. The evaluation also included a dump truck during the testing (with a sound meter located at 50 feet from the edge of the road) which did not find a substantial difference between the rumble strip designs.

Frequencies of the standard rumble strike are lower on the outside of the vehicle than sinusoidal, while the inverse is true for the interior. The objectively measurable difference on the interior of the vehicle indicates the sinusoidal strip is actually louder. A health benefit, in the form of lower risk of hypertension, may exist to roadway residents where the sinusoidal design is applied instead of the standard design based on research that has shown that lower frequencies (below 125Hz), such as those generated by standard rumble strips, are more harmful.

Sound data were collected inside the vehicle at multiple speeds (45, 50, and 55 MPH) at the test location. The data include the decibel values when the vehicle hit the strips at each speed and the ambient noise level at each speed. The sinusoidal rumble strips result in a lower sound level than the standard design inside the vehicle at each of the speeds. However, both the standard and sinusoidal rumble strips produce a noise level that is substantially higher (more than double) than the ambient noise level – suggesting that both designs should provide a sufficient warning to drivers of errant vehicles. Further research may be useful to explore the impacts of rumble strip design characteristics, such as, the width and depth.

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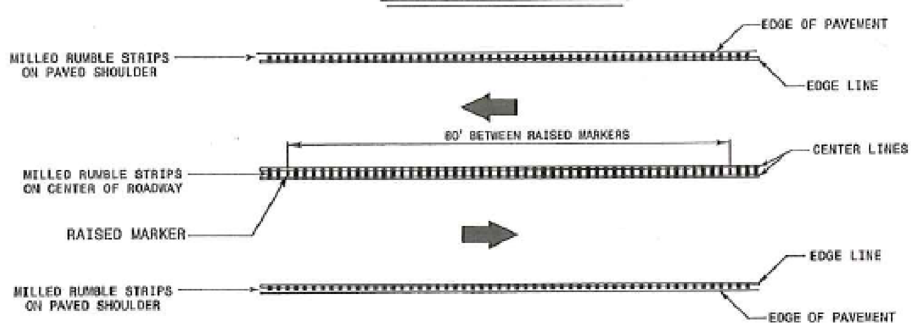
Appendix A: NCDOT Milled Rumble Stripe Specifications

PROJECT REFERENCE NO.	SHEET NO.
WBS - 2017CPT.05.01.10781.1	

DOCUMENT NOT CONSIDERED FINAL UNLESS ALL SIGNATURES COMPLETED

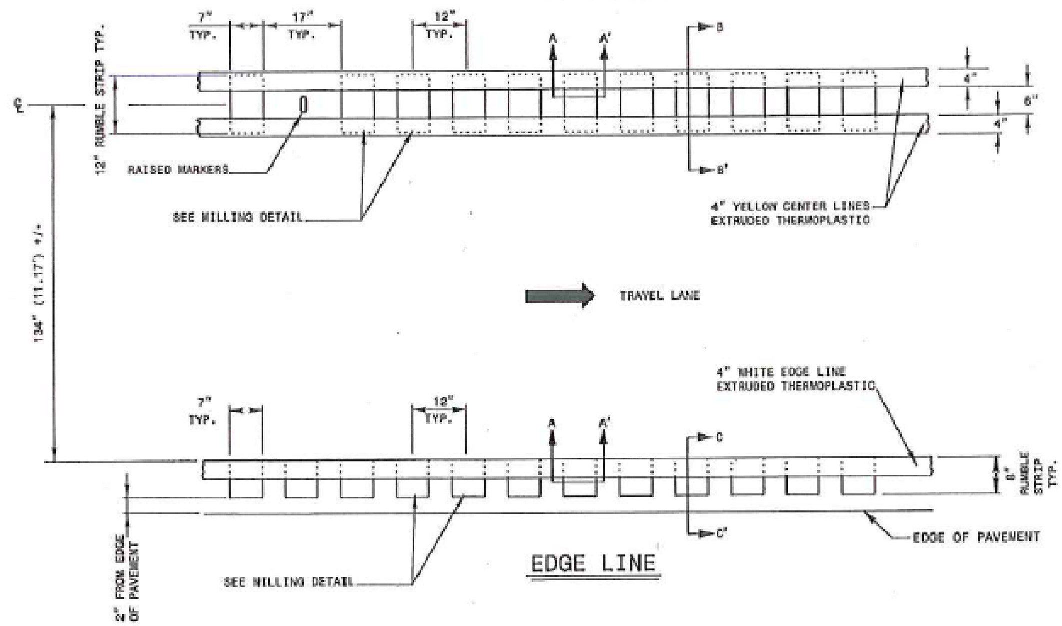
LANE TREATMENT



NOTES:

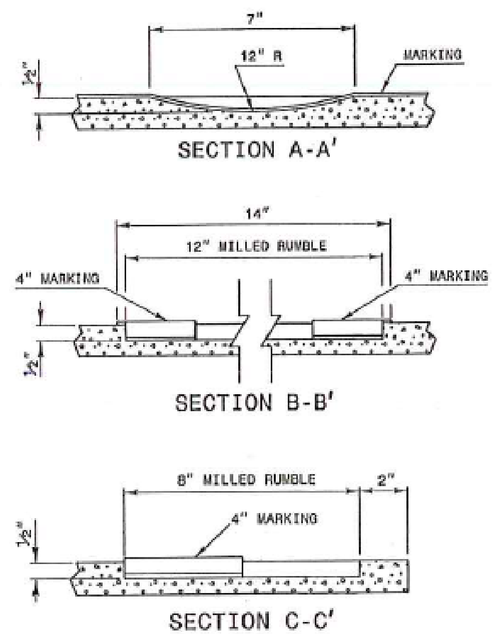
1) USING A VACUUM IN THE SAME OPERATION, REMOVE ALL DEBRIS FROM THE MILLINGS JUST PRIOR TO PLACING ANY PAVEMENT MARKINGS.
2) ENSURE GLASS BEADS ARE SPREAD UNIFORMLY OVER THE ENTIRE SURFACE OF PAVEMENT MARKING.
3) RAISED MARKERS SHALL BE INSTALLED ON 80' INCREMENTS. DO NOT MILL RUMBLE IN SECTION WHERE RAISED MARKERS WILL BE INSTALLED.
4) LOCATE EDGE LINES/RUMBLES FROM CENTER OF ROADWAY WIDTH.

CENTER LINES



EDGE LINE

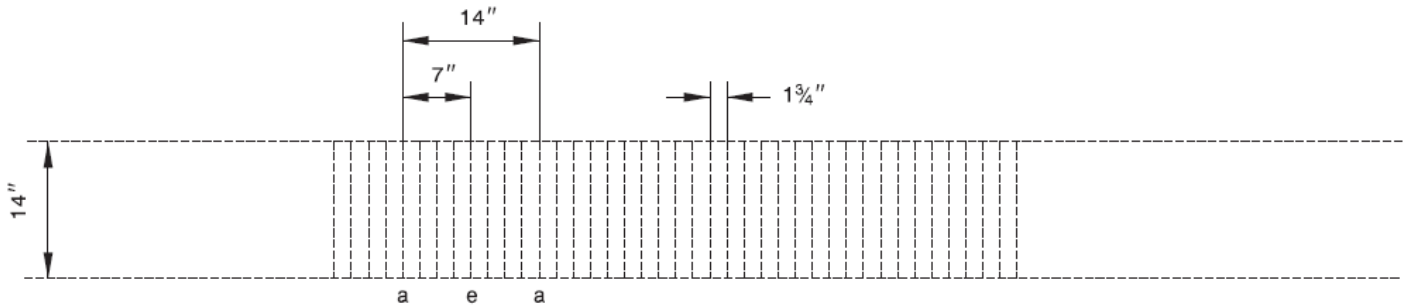
MILLING/MARKING DETAILS



CENTER AND EDGE LINES
MILLED RUMBLED STRIPE

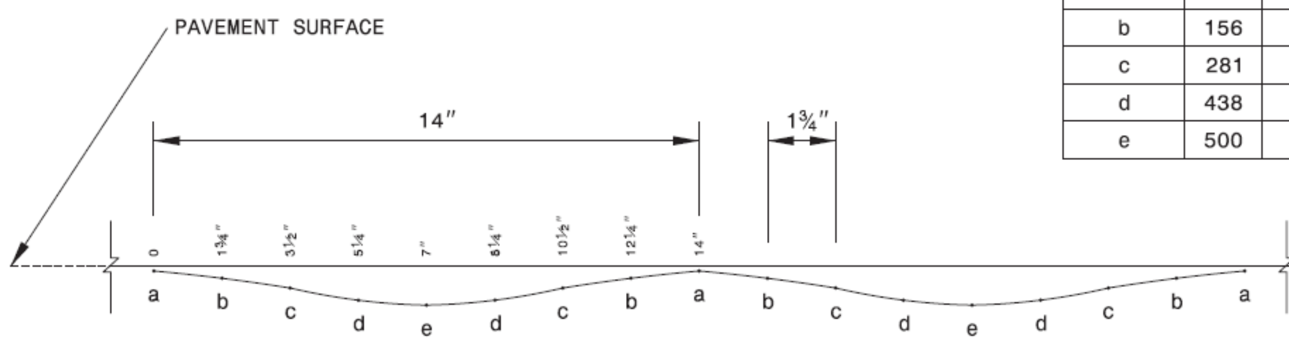
Appendix B: NCDOT Sinusoidal Milled Rumble Strip Specifications

PROJECT REFERENCE NO.	SHEET NO.



PLAN

	DEPTH	
LOCATION	MIL	INCHES
a	62.5	1/16″
b	156	5/32″
c	281	9/32″
d	438	7/16″
e	500	1/2″



PROFILE

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SINUSODIAL MILLED RUMBLE STRIPS

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MODIFIED BY: DATE:
CHECKED BY: DATE:
FILE SPEC.: sinusodial rumble strips.dgn