

RUMBLE STRIP AND SINUSOIDAL (MUMBLE) STRIP NOISE STUDY ALONG SR 16 AND SR 20

March 1, 2019

INTRODUCTION

Delaware's Strategic Highway Safety Plan indicates that a high percentage of the fatal crashes in the state involve roadway departures with a disproportionately large percentage of the roadway departure crashes occurring on rural roadways. Studies have shown that the installation of longitudinal edge line rumble strips can significantly reduce the frequency of roadway departure crashes by alerting motorists through vibration and sound that their vehicle has left the travel lane. However, there are often concerns regarding noise impacts on surrounding residential land uses where rumble strips are being considered as a potential countermeasure to address roadway departure crashes. DelDOT's "Continuous Center Line and Longitudinal Edge Line Rumble Strips Design Guidance Memorandum" (effective May 16, 2011) states the following:

The intent of the rumble strip is to gain the attention of a driver. Naturally, the byproduct of this measure is noise. In isolated areas this is usually not a problem. However, when installed in a suburban or urban area, the noise from rumble strips may impact nearby residents. It is highly recommended to consider the noise implications of rumble strips if they are going to be located in a populated area.

Generally, continuous or bicycle-friendly longitudinal edge line rumble strips should not be applied on the shoulders of roadways within urban areas. In urban areas, the designer should consult with Engineering Support and Public Relations to determine if noise will be a concern.

Despite the demonstrated effectiveness of rumble strips to reduce roadway departure crashes, the noise generated by vehicle tires striking a strip continues to be of concern. To address the public concern, researchers worked towards revising the rumble strip design to reduce the external noise generated while maintaining or increasing the noise and vibration produced in the vehicle passenger cabin. The sinusoidal or 'mumble' strip design has been shown to achieve this goal. While the traditional rumble strip consists of a cylindrical groove carved out of the pavement surface with flat sections between the grooves, the sinusoidal strip profile resembles a mathematical sine wave curve. The continuous, smooth wave design is effective at reducing the noise generated by the tire wall hitting the pavement as the tire travels up and down over the oscillating strip.

This noise study is as an extension of the *DelDOT SR 24 Longitudinal Edge Line Rumble Strip Noise Study (2012)*, which assessed the impact of the noise generated by a rumble strip to roadside land uses. It investigates the external noise produced when a vehicle strikes a *mumble strip* and compares that to the external noise level produced by a *rumble strip*. The findings will influence DelDOT's use of mumble strip as a roadway departure warning device and assist in identifying sections of roadway where such warning devices are in compliance with DelDOT's Noise Policy in order to mitigate crash trends without significantly impacting residents along these roadways.

PREVIOUS DELDOT RUMBLE STRIP NOISE STUDIES

2006 Noise Study: In 2006, DelDOT performed a noise study to evaluate the noise impacts of edge line rumble strips along a rumble strip test area on I-495 at the 12th Street interchange. This location was selected because it was surrounded by industrial land uses, was easily accessible compared to other locations along I-495 and was not heavily wooded or wet (such conditions may absorb or reverberate sound making isolating noise from the rumble strip challenging). The results of the 2006 study indicate the following:

- Noise level increases at the test area due to a vehicle striking the rumble strip were clearly perceptible at 100 feet from the source, barely perceptible at 250 feet from the source, and not readily perceptible at 400 feet from the source. The study concluded that it was not likely that the noise would be perceptible at a location 100 feet farther (i.e., 500 feet) from the rumble strip.
- The maximum ambient noise, which represented the noise readings throughout the study period excluding the ten-second intervals surrounding the period when the rumble strip was struck, exceeded the peak noise level when the rumble strip was struck, indicating that truck noise on the interstate was louder than the noise generated by the rumble strip. However, spikes in the ambient noise level readings may have been attributed to trucks accessing the 12th Street ramps.
- DelDOT's Noise Policy (June 1995) at the time of the study stated that predicted exterior noise levels for a residence must approach or equal 67 dBA or experience a substantial increase (>10 dBA) to qualify as a traffic noise impact. Generally, peak noise levels at 400 feet did not approach or equal 67 dBA, nor was there a "substantial increase" in the noise levels at 250 feet or 400 feet.
- The study concluded that rumble strips should not be considered along I-495 where residences are located within 500 feet of the proposed rumble strip. For sections of I-495 with noise-sensitive adjacent land uses other than residences, proximity to rumble strips should be considered on a case by case basis.
- Highway traffic noise levels depend on several variables including traffic volumes, speeds, pavement type, percentage trucks, tires, horizontal and vertical roadway alignments, roadside terrain, vegetation, and other topography. For these reasons and due to the small sample size, the results of this study should not be applied to other roadways of varying characteristics.

Study Challenges and Lessons Learned

- While noise monitoring was conducted during the evening hours when non-highway generated noise levels were at a minimum, the test area experienced noise from sources such as the Cherry Hill Landfill and other industrial buildings that may be higher than typical residential areas along I-495.
- Noise meters were located along I-495 at distances of 50 feet, 100 feet, 250 feet, and 400 feet from the outside rumble strips. The noise meters located at 250 feet and 400 feet from the source straddled the 12th Street on-ramp to northbound I-495 and large trucks using this ramp occasionally created spikes in the noise readings. While a 500-foot location was desirable, due to heavy vegetation and wetlands in the area, testing could only be conducted at maximum distances of 400 feet.
- The previous study was completed using a sedan (Honda Civic) for the test vehicle. However, it is likely that larger vehicles would have generated higher noise levels when striking the rumble strip.

2012 Noise Study: In 2012, DelDOT performed a noise study investigating the external noise impacts of edge line rumble strips on two-lane rural roadways. The results of the 2012 study indicate the following:

- The study measured noise levels produced by a passenger and a heavy (dump truck) vehicle traveling over an edge line rumble strip for a length of 400 feet. The noise level was measured at four distances perpendicular to the roadway; 50 feet, 250 feet, 500 feet, and from 1,000 feet. The noise produced by vehicles passing over a rumble strip was compared against noise from normal roadway travel to ascertain the change in noise level.
- The average noise level increases due to a vehicle striking the rumble strip were approximately 12 dBA at 50 feet, 3 dBA at 250 feet, and less than 1 dBA at 500 feet. Noise levels recorded by the sound level meter at 1,000 feet were indistinguishable from background noise. For reference, noise level changes between 2 and 3 dBA were barely perceptible.
- The study found that the noise produced by a vehicle striking an edge line rumble strip do not meet the qualifications for 'noise impact' as defined by DelDOT's Noise Policy at distances of 250, 500, or 1,000 feet from the rumble strip; however, a minivan driving across the rumble strip does generate a noise impact (i.e., > 66 dBA and > 12 dBA increase) at a residence located 50 feet from the outside of the rumble strip.
- The dump truck generated more noise on smooth pavement than the minivan; therefore, the contribution of the dump truck itself to the cumulative noise level was relatively large, making the contribution from the tires striking the rumble strip less noticeable. This affect was much more pronounced at 50 feet than at distances farther from the rumble strip.

Conclusion

- The noise generated by vehicles driving across rumble strips are not typically perceptible from distances 275 feet or greater from adjacent residences. Noise impacts should be given special consideration when installing rumble strips adjacent to residences within these distances from the outside of the proposed rumble strip. Additionally, engineering judgment should be used when installing rumble strips in areas that differ from the conditions of this study.

RESEARCH

A review of recent studies and publications was conducted to obtain guidance on the installation of rumble strips in close proximity to residential areas. However, very little guidance exists regarding this topic other than to apply engineering judgment. The following guidance was found in FHWA's "Highway Traffic Noise: Analysis and Abatement Guidance":

Highway traffic noise is not usually a serious problem for people who live more than 500 feet from heavily traveled freeways or more than 100 to 200 feet from lightly traveled roads. In quiet settings, however, such as rural areas, people notice highway traffic noise over greater distances.

Additionally, NCHRP Report 641 - "Guidance for the Design and Application of Shoulder and Centerline Rumble Strips" states:

It has been noted that some residents claim to be able to hear the noise generated from the rumble strips from up to 1.2 mi (2 km) away. Studies have also shown that when rumble strips are terminated 656 ft (200 m) prior to residential or urban areas, tolerable noise impacts are experienced; also at a distance of 1,640 ft (500 m), the noise generated from rumble strips is negligible.

A study conducted for ITE, "Optimal Continuous Shoulder Rumble Strips and the Effects on Highway Safety and the Economy" (May 2003) measured noise levels 200 feet from the roadway. The study compared the noise level of a typical truck on the travel way (69 dB) and the noise level of a testing van on a rumble strip (60 dB). The study concluded that the impact of rumble strip noise on the environment was minimal and could be ignored because it was a random event. The exterior sound level of rumble strips was 9 dB lower than that of a truck traveling on a highway. Although this study indicates that rumble strip noise does not exceed the noise created by typical trucks, several studies were found where rumble strips were either removed or moved farther from the travel lanes to reduce the frequency of vehicles striking the rumble strip and address residents' complaints.

A cooperative research project conducted by Kansas DOT, Kansas State University Transportation Center, and University of Kansas, "Promoting Centerline Rumble Strips to Increase Rural, Two-Lane Highway Safety" (December 2010) quantified the level of exterior rumble strip noise impacts on roadside residences and businesses. As part of this project, two different types of vehicles (a sedan and a 15-passenger van) were driven over two different types of center line rumble strips (rectangular and football-shaped), at several different locations, at two speeds (40 and 65 miles per hour), and at distances of 50, 100, and 150 feet from the center line. The study concluded that the difference between noise levels generated by vehicles driving over the rumble strips is at least 5 dB greater than the noise levels generated by vehicles driving over a smooth surface. Additional key findings include: the lower the speed of the vehicle, the lower the noise generated by the rumble strip, heavier vehicles produce more noise, and the greater the distance from the noise source, the lower the noise. A 5dB difference in noise is considered noticeable; therefore, installing rumble strips will affect the noise levels for residents located 50 feet, 100 feet, and 150 feet from the noise source. The project also included a residential survey, which indicated that 90 percent of respondents feel that the noise generated from center line rumble strips is noticeable but not a concern and 100 percent of respondents felt that the potential safety benefits of the rumble strips are worth some level of annoyance created by exterior noise impacts. Research and Innovative Technology Administration University Transportation Centers Program's "Use of Center Line Rumble Strips to Improve Safety on Two-Lane Highways" determined that distances within 200 feet from the center of the roadway with center line rumble strips are potential exterior noise concern areas for the conditions studied as part of the Kansas DOT study.

A study conducted by CalTrans, "Design and Acoustic Evaluation of Optimal Sinusoidal Mumble Strips versus Conventional Ground-In Rumble Strips" (April 2018), evaluated the effectiveness of sinusoidal or 'mumble' strips whose profile mimics the mathematical sine wave. An iteration of the conventional rumble strip, the mumble strip is intended to reduce external noise produced by tires passing over a warning strip while increasing internal vibrations to warn drivers of an impending roadway departure. The improved designed was developed to address the main disadvantage of the conventional rumble strip, the exterior noise generated and its effect on adjacent land uses as well as potential sensitive wildlife populations. By having a smoother and lower frequency profile, the mumble strip results in less excitation of the tire as it

slaps against the pavement, thus reducing roadside noise levels. The sine wave profile is in contrast to the abrupt, cylindrical shaped grooves intermingled with flat surfaces of the rumble strip profile. This comparison is evident in Figure 1 and Figure 2 below.

The study is considered unique in the mumble strip research field since it studied external automotive noise along with internal vibrations while considering highway engineering principles. It evaluated mumbles strips from multiple factors: assessed why the profile of a sine wave is effective at achieving the stated goal; performed a sensitivity analysis on the design focusing on finding the optimal amplitude (depth of groove into pavement) and wavelength (distance between high points of the wave); considered the impact of the design on bicyclists; measured noise and vibration from four points, internal and external to the vehicle; tested the effectiveness of mumble strips over five different vehicle types; and, considered the influence of travel speed.

Four vehicle types were used in the study, with one of the vehicle types conducting the test at three different speeds (60, 40, and 20 miles per hour). The vehicle types represent differing tire size, length between axles, and weight. The steering column vibration, interior noise level, and roadside noise level of the conventional rumble strip was compared to two other warning strip designs; the sinusoidal mumble strip and the raised pavement marker.

The study found the mumble strip to perform as intended addressing the concerns of traditional rumble strips. On average, the passenger vehicle striking the mumble strip reduced the generated exterior noise by 6 dBA (which is considered readably noticeable to the human ear) while the heavy vehicle reduced the generated noise by 3 dBA (a change considered imperceptible to the human ear). However, the mumble strip was found to produce pronounced tonal sounds at a lower frequency advising that the impact of the lower frequencies is unknown. While the design of the mumble strip used for the study had an amplitude or pavement depth of 5/16 inches and a wavelength of 14 inches, the study proposes that a depth of ¼ inch and a wavelength of 16 inches may further reduce exterior noise¹.



Source: Caltrans, "Design and Acoustic Evaluation of Optimal Sinusoidal Mumble Strips versus Conventional Ground-In Rumble Strips". April 2018. Figure 10.

Figure 1: Example of an Installed Mumble Strip

¹ Note DelDOT's standard detail for sinusoidal strips shows a wavelength of 14" and trough depth of 5/16"



Source: Caltrans, "Design and Acoustic Evaluation of Optimal Sinusoidal Mumble Strips versus Conventional Ground-In Rumble Strips". April 2018. Figure 11.

Figure 2: Example of an Installed Rumble Strip

HIGHWAY NOISE FUNDAMENTALS

The extent to which individuals are affected by noise sources is composed of several factors, including:

- The duration and frequency of sound
- The distance between the source of the sound and the receptor
- The intervening natural or man-made barriers or structures
- The ambient environment

The level of highway traffic noise depends primarily upon:

- Traffic flow conditions (volume and speed)
- The number of trucks in the flow of traffic
- The distance of receptor to the noise sources
- Shielding effects from intervening terrain and vegetation

Hourly noise levels are given in equivalent hourly average (Leq) of "A-weighted decibels" (dBA), which is an average of the perceived sound level. Because noise levels in an area fluctuate dramatically over time and the human response to noise is frequency dependent, the actual measured time variant noise levels are compiled into a Leq. The Leq is a single representative noise level that contains the same amount of sound energy as the fluctuating noise levels measured over the same time period, generally one hour. To compensate for the frequency dependency of the "human" response, the contributions of different frequencies are adjusted to correspond to the human sensitivity to these frequencies. Sound data that has been adjusted using this method is reported as dBA. Throughout this study, all noise level measurements are given in Leq dBA. Table 1 provides examples of common outdoor and indoor noise levels and their corresponding noise levels in decibels.

Table 1: Common Outdoor And Indoor Noise Levels ¹		
Common Outdoor Noise Levels	Noise Level Decibels	Common Indoor Noise Levels
	110	Rock Band
Jet Fly Over at 1,000 feet	100	Inside Subway Train (N.Y.)
Gas Lawn Mower at 3 feet		
Diesel Truck at 50 feet	90	Food Blender at 3 feet
Noisy Urban Daytime	80	Garbage Disposal at 3 feet/ Shouting at 3 feet
Gas Lawn Mower at 100 feet	70	Vacuum Cleaner at 3 feet
Commercial Area		Normal Speech at 3 feet
	60	
		Large Business Office
Quiet Urban Daytime	50	Dishwasher Next Room
Quiet Urban Nighttime	40	Small Theater, Large Conference Room (Background)
Quiet Suburban Nighttime		Library
	30	
Quiet Rural Nighttime		Bedroom at Night, Concert Hall (Background)
	20	
		Broadcast & Recording Studio
	10	Threshold of Hearing
	0	
1. Adapted from <i>Guide on Evaluation and Attenuation of Traffic Noise</i> AASHTO-1974		

Typically, noise level changes between 2 and 3 dBA are barely perceptible, while a change of 5 dBA is readily noticeable by most people. A 10 dBA increase is usually perceived as a doubling of loudness, and conversely, noise is perceived to be reduced by one-half when a sound level is reduced by 10 dBA.

DELDOT'S NOISE POLICY

FHWA requires states to adopt their own policies on the abatement of highway traffic noise and provides guidance and criteria for the evaluation of traffic noise impacts and noise abatement opportunities for communities adjacent to highways. All federal or federal-aid highway projects authorized under Title 23, United States Code are subject to DeIDOT's Highway Transportation Noise Policy, revised in July 2011. The policy is not mandatory for projects that are 100 percent State-funded or when FHWA approvals are not necessary.

Per DeIDOT's Noise Policy, whenever traffic noise impacts are identified, DeIDOT will consider and evaluate noise abatement for feasibility and reasonableness. The following conditions are identified as traffic noise impacts:

- Predicted (design-year) build condition noise levels approach or exceed the Noise Abatement Criteria levels shown in Table 2 (i.e., predicted exterior noise level for a ground-level residence must approach or equal 67 dBA to qualify as a traffic noise impact). DeIDOT considers the noise abatement criteria to be approached if traffic noise levels are within one decibel of the values shown.
- Predicted (design-year) noise levels substantially exceed existing noise levels. DeIDOT considers a substantial increase to be at least 12 dBA.

DelDOT Noise Abatement Criteria contained in DelDOT's Noise Policy apply to Type I projects, defined under 23 CFR 772 as:

- (1) The construction of a highway on a new location; or,*
- (2) The physical alteration of an existing highway where there is either:*
 - i. A substantial horizontal alteration; being a project that halves the distance between the traffic noise source and the closest receptor between the existing condition to the future build condition; or,*
 - ii. A substantial vertical alteration; being a project that removes the shielding therefore exposing the line of sight between the receptor and the traffic noise source. This is done by either altering the vertical alignment of the highway or by altering the topography between the highway traffic noise source and the receptor.*
- (3) The addition of a through-traffic lane(s). This includes the addition of a through traffic lane that functions as a High Occupancy Vehicle lane, High Occupancy Toll lane, bus lane, or truck climbing lane; or,*
- (4) The addition of an auxiliary lane, except for when the auxiliary lane functions as a turn lane; or,*
- (5) The addition or relocation of interchange lanes or ramps added to a quadrant to complete an existing partial interchange; or,*
- (6) Restriping existing pavement for the purpose of adding a through-traffic lane or auxiliary lane, except for when the auxiliary lane functions as a turn lane; or,*
- (7) The addition of a new or substantial alteration of a weigh station, rest stop, ride-share lot, or toll plaza; or,*
- (8) If a project is determined to be a Type I project under this definition, then the entire project area as defined in the NEPA environmental documentation is a Type I project.*

Table 2: Noise Abatement Criteria (NAC) Hourly A-Weighted Sound Level in Decibels (dBA)

Activity Category	Activity Criteria ¹ Leq(h) ²	DelDOT Approach Criteria	Evaluation Location	Activity Description
A	57	56	Exterior	Lands on which serenity and quiet are of extraordinary significance and serve an important public need and where the preservation of those qualities is essential if the area is to continue to serve its intended purpose.
B ³	67	66	Exterior	Residential
C ³	67	66	Exterior	Active sport areas, amphitheaters, auditoriums, campgrounds, cemeteries, daycare centers, hospitals, libraries, medical facilities, parks, picnic areas, places of worship, playgrounds, public meeting rooms, public or nonprofit institutional structures, radio studios, recording studios, recreation areas, Section 4(f) sites, schools, television studios, trails, and trail crossings
D	52	51	Interior	Auditoriums, day care centers, hospitals, libraries, medical facilities, places of worship, public meeting rooms, public or nonprofit institutional structures, radio studios, recording studios, schools, and television studios
E ³	72	71	Exterior	Hotels, motels, offices, restaurants/bars, and other developed lands, properties or activities not included in A-D or F
F	--	--	--	Agriculture, airports, bus yards, emergency services, industrial, logging maintenance facilities, manufacturing, mining, rail yards, retail facilities, shipyards, utilities (water resources, water treatment, electrical), and warehousing
G	--	--	--	Undeveloped lands that are not permitted

¹ The Leq(h) Activity Criteria values are for impact determination only and are not design standards for noise abatement measures.

² The equivalent steady-state sound level which in a stated period of time contains the same acoustic energy as the time-varying sound level during the same time period, with Leq(h) being the hourly value of Leq.

³ Includes undeveloped lands permitted for this activity category.

Since the installation of rumble strips does not meet the definition of a Type I project listed above, DelDOT's and FHWA's noise abatement criteria do not directly apply to this study but do provide a basis for comparison. Under 23 CFR 772, the installation of rumble strips would be considered a Type III project and would not require a noise analysis. However, this does not preclude highway agencies from performing a noise analysis. 23 CFR 772 states that generally, if a project results in a new noise source, the highway agency should consider a noise analysis for the project.

STUDY METHODOLOGY AND RESULTS

Site Selection: Four locations with rumble strips were identified as potential locations for the noise measurements (see Figure 3). These locations were selected based on minimal background noise, continuous bicycle-friendly center line rumble strips and Sinusoidal edge line rumble strips (mumble strips) for at least 400 feet (i.e., not broken for turn lanes or driveways) and relatively unobstructed land for distances a minimum of 1,000 feet from the edge of pavement. The parcel numbers and land owner information for each location was obtained from the Sussex County Online Mapping website, as shown below. Prior to conducting the noise study measurements, DelDOT informed the property owners of DelDOT's intent to perform noise studies.

Table 3: Test Locations

Location	Reference Road	Parcel Number	Property Owner
1: SR 16 West	Approximately 920 east of Oak Road, south side of SR 16	430-07.00-09.01	Webb Montilles J III
2: SR 16 East	Approximately 2,140 feet east of Truitt Road, south side of SR 16	230-25.00-29.00	Webb Family Farm
3: SR 20 East	Approximately 670 feet east of James Road, north side of SR 20	231-22.00-08.00	James Alden B TTEE REV TR
4: SR 20 West	Approximately 1,000 feet west of Pepper Road, north side of SR 20	231-18.00-27.00	Pepper Cecil A

Per DelDOT's "Continuous Center Line and Longitudinal Edge line Rumble Strips Design Guidance Memorandum" (effective October 2, 2014), continuous, milled, bicycle-friendly edge line rumble strips consist of 40-foot rumble strip segments alternating with 12-foot "gap" segments absent of grooves, as shown in Figure 4. Bicycle-friendly edge line rumble strip are installed 12-inches from the edge line and with a 3/8th-inch depth. Sinusoidal rumble ('mumble') strips consists of a wavelength (crest to crest) of 14-inches and a trough depth (max depth of groove into the pavement) of 5/16-inch as shown in Figure 6.

Continuous, milled, bicycle-friendly *edge line* sinusoidal rumble strips were installed at the test locations detailed in Figure 3 and at the depths detailed in . An image of the mumble strip installed at location 4 is shown in Figure 12. Continuous, milled *center line* rumble strips were installed at the four test locations per the specifications in Figure 5.

LOCATION OF STUDY SITES



Figure 3: Location of the Four Study Sites

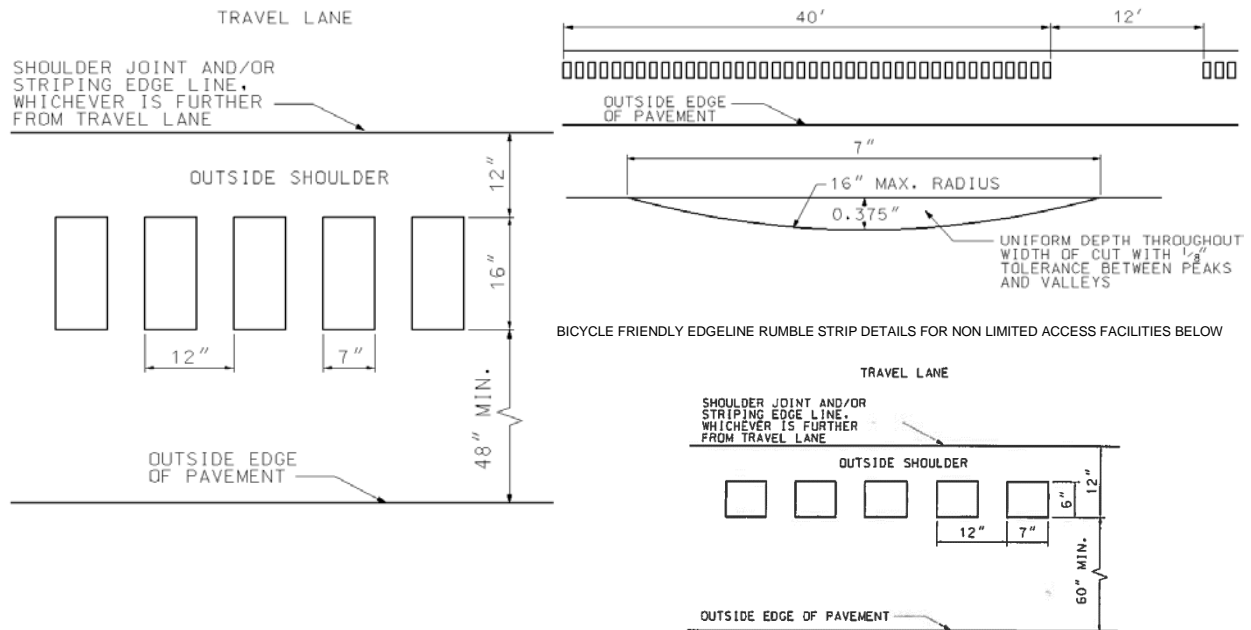


Figure 4: Conventional Edge Rumble Strip DelDOT Standard Detail

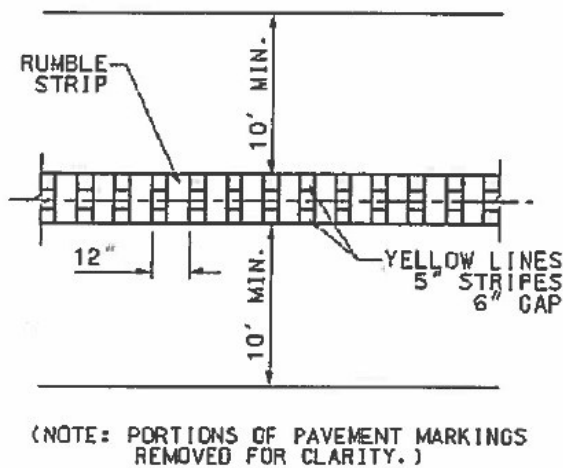


Figure 5: Conventional Center Line Rumble Strip DelDOT Standard Detail

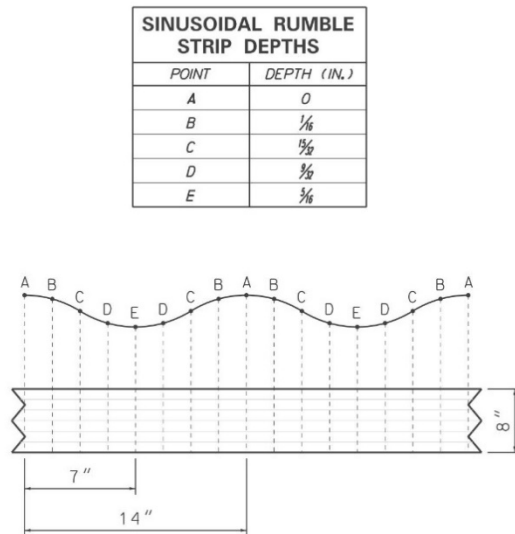


Figure 6: Sinusoidal Rumble ('Mumble') Strip DelDOT Standard Detail



Figure 7: Edge Line Sinusoidal Mumble Strip Installed on SR 20 (Location 4)

Noise Measurements: Noise measurements were conducted to quantify the noise generated by vehicles striking the center line rumble strips and the edge line mumble strips at the four locations discussed above. Since residents are most aware of the noise produced by the strips during periods when background traffic noise levels are lowest, testing was performed during off-peak hours (i.e., between 9 AM and 3 PM). Noise measurements were conducted at location 1 between 10:30 AM and 12:00 PM, location 2 between 1:30 PM and 3:00 PM, location 3 between 1:30 PM and 2:45 PM, and location 4 between 10:30 AM and 12:00 PM. Two test vehicles were used for the noise measurements: a 2015 Honda Odyssey minivan and a 3-axle DelDOT dump truck. Test vehicle speeds during the study were at the posted speed limit of 50 miles per hour. The noise measurements were conducted on a dry day with low winds (less than 10 miles per hour).

The study was conducted using ANSI S 1.4-1983 Type II sound level meters, which record noise levels in a variety of formats including Lp and Leq dBA. Based on the findings from the previous studies discussed above, noise meters were positioned orthogonally from the outside of the edge line mumble strips at 50 feet, 150 feet, 250 feet, and 500 feet at each study location to assess the exterior noise impacts of the strips on the surrounding areas. The noise meter placement was revised from the 2012 study, which placed the meters at 50 feet, 250 feet, 500 feet, and 1,000 feet.

The noise meters recorded the exterior noise levels during at least five base runs, at least five center line rumble strip runs, and at least five edge line mumble strip runs at each location. The base runs involved the test vehicles driving over smooth asphalt pavement through approximately 400-foot segments along SR 16 and SR 20 at locations 1 through 4 as discussed above. The rumble strip runs involved the test vehicles traveling over the center line rumble strips through the 400-foot test segments along SR 16 and SR 20 at the same locations. The mumble strip runs involved the test vehicles traveling over the edge line sinusoidal rumble strips through the 400-foot test segments along SR 16 and SR 20 at the same locations. The 400-foot test segments along SR 16 and SR 20 were marked with cones to help the drivers identify the test segments. Runs with increased background noise, such as when another vehicle was present within the marked test segments during the run, were discarded from the data set. Similarly, runs where the test run event could not be distinguished from background noise were also discarded from the data set.

INDIVIDUAL SITE FIELD SET UP | LOCATION 1 SR 16 WEST



Figure 8: Field Set Up for Location 1

INDIVIDUAL SITE FIELD SET UP | LOCATION 2 SR 16 EAST



Figure 9: Field Set Up for Location 2

INDIVIDUAL SITE FIELD SET UP | LOCATION 3 SR 20 EAST



Figure 10: Field Set Up for Location 3

INDIVIDUAL SITE FIELD SET UP | LOCATION 4 SR 20 WEST



Figure 11: Field Set Up for Location 4

Study Results: Noise levels were measured in one-second intervals at all four study locations. The five one-second intervals were averaged for each base run as the test vehicle traveled through the marked test segments. Following the base runs, the five one-second intervals during the time the test vehicles were driven across the rumble strips in the center of the road were averaged for each rumble strip run. Finally, the five one-second intervals during the time the test vehicles were driven across the mumble strips on the edge of the road were averaged for each mumble strip run. Table 3 shows the average noise levels for the base, rumble strip, and mumble strip runs for each test vehicle at 50, 150, 250, and 400 feet from the outside of the edge mumble strip, and the average increase for the rumble strips and mumble strips compared to the base runs. At location 3, the noise meter located 150 feet from the mumble strip did not record, therefore, the number of runs used in the average noise measurement for 150 feet was less than the other distances. The average noise level during the rumble strip run was compared to the average noise level during the base run for each vehicle and the difference between these two measurements were used to determine whether the noise generated from the test vehicle striking the rumble strips was perceptible at various distances from the rumble strip under test conditions. This same procedure was performed for the mumble strip runs to determine whether the noise generated from the test vehicle striking the mumble strips was perceptible at various distances from the mumble strip under test conditions.

Figure 12 and Figure 13 are graphical representations of the average noise level increase during the rumble strip runs and mumble strip runs as compared to the base runs for each offset from the outside of the rumble strip/sinusoidal rumble strip for the minivan and dump truck, respectively for this study and for the DeIDOT SR 24 Longitudinal Edge Line Rumble Strip Noise Study (2012).

Table 4: Summary of Base, Center Rumble Strip, and Edge Mumble Strip Noise Impacts

Noise Meter Offset from Outside of Mumble Strip	Base Run		Rumble Strip Run		Mumble Strip Run		Average Noise Level Increase Base vs Rumble (dBA)	Average Noise Level Increase Base vs Mumble (dBA)
	Average Noise Level (dBA)	Noise Level Range (dBA)	Average Noise Level (dBA)	Noise Level Range (dBA)	Average Noise Level (dBA)	Noise Level Range (dBA)		
Minivan								
50 feet	68.7	66.7 – 72.4	71.8	66.3 – 76.0	69.8	65.6 – 72.7	3.1	1.2
150 feet ¹	56.2	52.8 – 61.8	61.1	58.5 – 63.0	57.7	56.9 – 58.2	4.9	1.5
250 feet	53.4	48.0 – 63.4	56.2	51.2 – 58.7	54.4	49.5 – 56.8	2.8	1.0
400 feet	50.5	44.4 – 58.0	51.9	47.2 – 56.4	51.6	46.0 – 52.6	1.4	1.1
Dump Truck								
50 feet	73.0	71.2 – 74.1	76.7	76.1 – 77.3	74.4	73.0 – 77.2	3.7	1.4
150 feet ¹	63.3	60.4 – 65.2	66.5	65.3– 67.2	64.8	63.7 – 67.0	3.2	1.5
250 feet	58.2	55.4 – 60.6	60.6	56.9 – 63.4	59.5	55.1 – 62.4	2.5	1.3
400 feet	54.9	52.7 – 58.6	56.1	50.7 – 61.0	55.8	51.8 – 60.6	1.2	1.0

¹ The noise meter located at 150 feet was not recording at location 3; therefore, the number of runs used in the average noise measurement for this distance was less than the other distances.

Average Noise Level Increase - Minivan

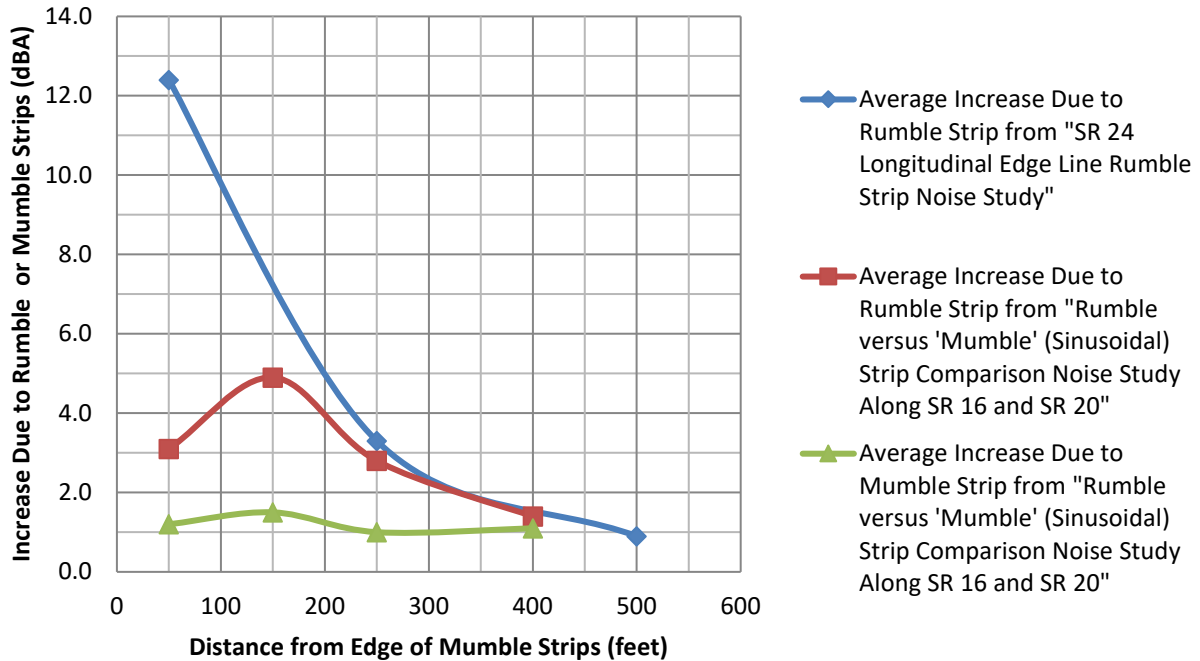


Figure 12: Average Noise Level by Run Type (Minivan)

Average Noise Level Increase - Dump Truck

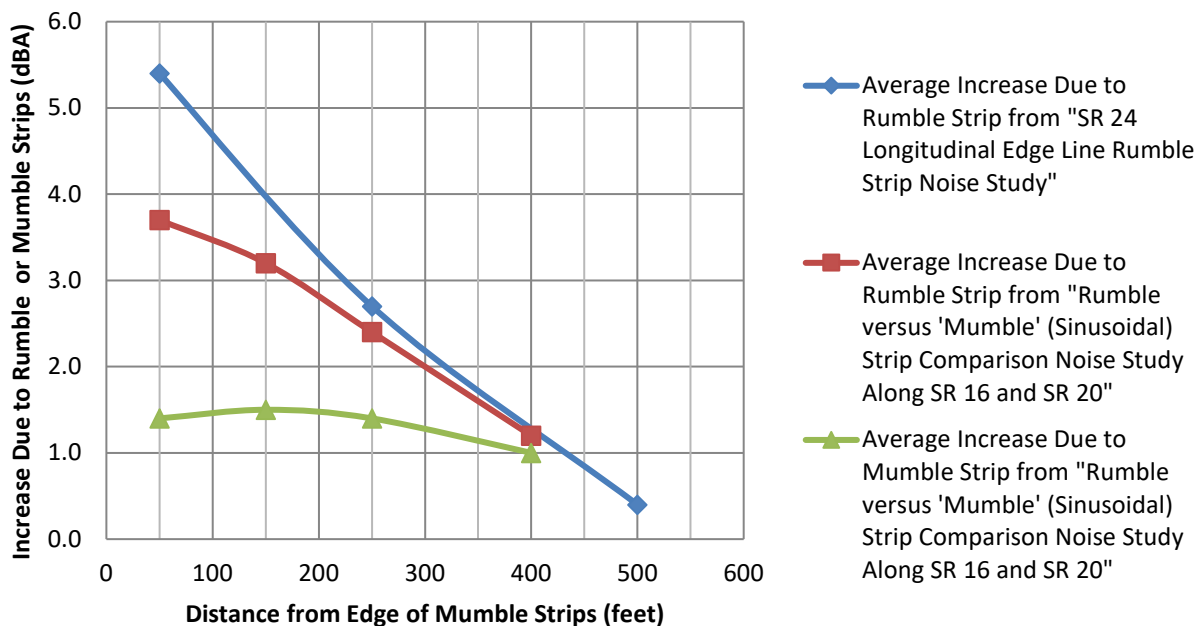


Figure 13: Average Noise Level by Run Type (Dump Truck)

As mentioned previously, noise level changes between 2 and 3 dBA are barely perceptible, while a change of 5 dBA is readily noticeable by most people. As shown, at 50 feet the increase in average noise level due to the test vehicle driving across the rumble strip was 3.1 dBA for the minivan and 3.7 dBA for the dump truck; both average noise level increases are typically perceptible by most people (i.e., >3 dBA increase). At 150 feet, the increase in average noise level due to the test vehicle driving across the rumble strip was 4.9 dBA for the minivan and 3.2 dBA for the dump truck; again, both average noise level increases are typically perceptible by most people (i.e., >3 dBA increase). At 250 feet the increase in average noise level due to the test vehicle driving across the rumble strip was 2.8 dBA for the minivan and 2.5 dBA for the dump truck; both average noise level increases are barely perceptible by most people (i.e., 2-3 dBA increase). At 400 feet, the increase in average noise level due to the test vehicle driving across the rumble strip was 1.4 dBA for the minivan and 1.2 dBA for the dump truck; both average noise level increases are not typically perceptible by most people (i.e., <2 dBA increase). These results are similar to those found in the *DelDOT SR 24 Longitudinal Edge Line Rumble Strip Noise Study (2012)*.

The average noise level increases in this study area due to the test vehicles (minivan or DelDOT dump truck) striking the centerline rumble strips were 2.5 dbA to 2.8 dBA at 250 feet from the outside of the edge line mumble strip and 1.2 dBA to 1.4 dBA at 400 feet from the outside of the edge line mumble strip (noise level changes between 2 and 3 dBA are barely perceptible). Interpolation between these two values indicates that average noise level increases due to a vehicle (minivan or dump truck) driving across the rumble strips would not exceed 2 dBA at 335 feet. The average noise level increases due to a vehicle (minivan or dump truck) driving across the rumble strips would not exceed 3 dbA at 250 feet. These results are very similar to those found in the *DelDOT SR 24 Longitudinal Edge Line Rumble Strip Noise Study (2012)* and confirms the conclusion that noise generated by vehicles driving across rumble strips will not typically be perceptible from distances 275 to 350 feet or greater from adjacent residences.

As shown, the increase in average noise level due to the test vehicle driving across the mumble strip ranged from 1.0 dBA to 1.5 dBA for both the minivan and the dump truck and at all offsets from the outside of the rumble strip. The increase in noise levels due to striking the mumble strip are not typically perceptible by most people. Personnel monitoring the sound level meters at the 50-foot offset and at other offsets confirmed that the noise generated from the test vehicle striking the mumble strips could not be distinguished from the noise generated from the test vehicle driving over smooth asphalt pavement. Further, personnel at the 50-foot offset and at other offsets could not identify by hearing whether the test vehicle was successfully striking the mumble strip. The increase in average noise level due to the test vehicle driving across the mumble strip was less than the increase in average noise level due to the test vehicle driving across the rumble strip for both test vehicles and for all offsets tested.

CONCLUSION

According to DelDOT's Noise Policy, predicted exterior noise levels at a residential location must approach or equal 67 dBA or experience a substantial increase (i.e., 12 dBA or more) to be considered a noise impact. The results of this study indicate the substantial increase impact criterion (i.e., 12 dBA or more) is not met for the test conditions, and that the average noise levels do not approach or exceed 67 dBA at distances of 250 feet or 400 feet from the outside of the rumble strip. The average noise levels during the base run, rumble strip run, and mumble strip run for both test vehicles exceed 66 dBA at 50 feet from the outside of the rumble strip. At 150 feet, the average noise level from the dump truck driving over the rumble strip was 66.5 dBA, all other base runs, rumble strip runs, and mumble strip runs were less than 66 dBA.

As mentioned previously, noise level changes between 2 and 3 dBA are typically barely perceptible by most people. The average noise level increases in this study area due to the test vehicles (minivan or DelDOT dump truck) striking the edge line sinusoidal rumble (mumble) strip were less than 2 dBA at all offset distances where noise measurement data was collected (50 feet, 150 feet, 250 feet, and 400 feet). Therefore, the noise generated by vehicles driving across sinusoidal rumble (mumble) strips will not typically be perceptible from distances 50 feet or greater from adjacent residences. Additionally, engineering judgement should be used when installing or rumble strips or sinusoidal (mumble) strips in areas that differ from the conditions of this study.