Traffic Noise Generated by Rumble Strips

Requested by
Dana York, Environmental Services

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The Caltrans Division of Research and Innovation (DRI) receives and evaluates numerous research problem statements for funding every year. DRI conducts Preliminary Investigations on these problem statements to better scope and prioritize the proposed research in light of existing credible work on the topics nationally and internationally. Online and print sources for Preliminary Investigations include the National Cooperative Highway Research Program (NCHRP) and other Transportation Research Board (TRB) programs, the American Association of State Highway and Transportation Officials (AASHTO), the research and practices of other transportation agencies, and related academic and industry research. The views and conclusions in cited works, while generally peer reviewed or published by authoritative sources, may not be accepted without qualification by all experts in the field.

Executive Summary

Background

External noise caused by traffic crossing rumble strips, while having beneficial safety effects for drivers, is a cause of concern for Caltrans and other departments of transportation (DOTs) because it generates complaints from homeowners and may affect protected wildlife species. Caltrans is testing two potentially quieter forms of rumble strip: the sinusoidal rumble strip and the 5/16-inch milled rumble strip with thermoplastic stripe. To conduct an evaluation of these and other designs, it needs data on noise emissions by various kinds of vehicles driving over these and other types of rumble strips, and information about reliable instrumentation for collecting such data. Internal as well as external noise data are necessary to weigh the effectiveness of rumble strip designs in alerting drivers against their external noise reduction benefits.

To assist Caltrans in these efforts, we gathered information about internal and external noise levels caused by vehicles moving over rumble strips by:

- Conducting a literature search using transportation databases and the web.
- Contacting selected DOTs (including members of the TRB Committee on Transportation Related Noise and Vibration) about their experiences with various rumble strip designs.

Summary of Findings

The literature search and consultation with DOTs and other experts confirmed that there is little recent research by transportation agencies measuring exterior or interior noise levels for rumble strips or alternative rumble strip designs. The Danish Road Institute has conducted only one study on sinusoidal rumble strips since its 2007 paper, showing that emulsion sealing makes no difference in the noise levels of sinusoidal rumble strips. Arizona, Colorado and Missouri have not performed rumble strip noise research; Dana Lodico of Lodico Acoustics LLC and William Bowlby of Bowlby & Associates, Inc. both noted that there is still not a lot of information available on rumble strip noise.

A 2009 synthesis report consists of a literature search and AASHTO RAC Survey concerning centerline rumble strip design and noise issues. In this report, researchers concluded that as of 2009, no agency had reported a useful low-noise rumble strip design or noise mitigation measures. States generally handle rumble strip noise complaints by removing the rumble strips, persuading residents of their safety benefits or limiting their use near residential areas.

However, some state DOTs have conducted recent rumble strip noise testing:

- Results from a Michigan study showed a 16.2-decibel increase in exterior noise levels 95 feet from the road for a test vehicle driven at 70 mph over edge-line rumble strips, and a 25-decibel increase for another test at 50 feet.
- With informal testing, Jon Evans of the New Hampshire DOT found that 3/8-inch-deep rumble strips were 1 to 2 decibels quieter than 1/2-inch-deep rumble strips.
- Ohio is taking noise measurements for milled rumble strips and will share results as soon as they are available (as early as March 2012).
- Washington is analyzing rumble strip noise and will provide data as early as March 2012.

The existing literature shows that milled rumble strips increase external noise levels by 5 to 19 decibels, and increase noise levels inside vehicles by 5 to 15 decibels. Wider groove widths produce greater noise levels. External noise from sinusoidal rumble strips is 3 to 7 decibels quieter than rectangular strips, which increase noise levels by only 0.5 to 1 decibels. A 2004 report by the European Commission suggests that thermoplastic rumble strips decrease external noise levels by as little as 4 decibels. In **Related Research**, we present reports and journal articles about alternative rumble strip designs, including Rippleprint and Rumblewave—both used in the United Kingdom and said to generate little or no external noise while producing adequate interior noise.

When it comes to safety and the alerting effect of rumble strips to drivers, available research shows that increasing groove depth and width as well as rumble strip length increases interior noise and vibration. Milled, rolled, button, profiled and formed rumble strips can produce adequate changes in sound for drivers of passenger vehicles provided the appropriate design is used, but only milled rumble strips produced an adequate change in sound for drivers of commercial vehicles. Available research also shows that rumble strips have significant safety benefits.

Gaps in Findings

- There is still little research on noise levels for rumble strips, especially for alternative designs such as sinusoidal and thermoplastic rumble strips.
- Two DOTs—Ohio and Washington—are testing rumble strip external noise levels but were not yet ready to share results.
- We were unable to reach an appropriate contact at Delaware DOT, which is making use of thermoplastic rumble strips.

Next Steps

Moving forward, Caltrans might consider:

- Contacting Ohio and Washington DOTs for noise testing results available as early as March.
- Contacting Delaware DOT concerning its use of thermoplastic rumble strips.
- Contacting Jon Evans of New Hampshire DOT concerning a possible NCHRP proposal on rumble strip noise and alternative designs.
- At the recommendation of Jon Evans, contacting Bill Thompson of Maine DOT about possible rumble strip research.
- If applicable, making inquiries about the use of Rippleprint and Rumblewave in the United Kingdom.

Contacts

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Consultation with Experts

Danish Road Institute

Hans Bendtsen and Jørgen Kragh recommended "Traffic Noise at Rumble Strips," published in 2007 and cited on page 12 of this Preliminary Investigation. (This paper is also widely cited in the literature and in Caltrans' request for this Preliminary Investigation.) According to Mr. Kragh, the only research conducted by the institute on rumble strips since the publication of this paper measured noise levels from passenger cars rolling on sinusoidal rumble strips with and without emulsion sealing. Noise levels were essentially the same whether or not the strip surface had been sealed. (Full results are only available as an internal memo in Danish.)

Kansas DOT

Kansas is reviewing its files to see if it has noise data that might be useful to Caltrans. According to Mike Fletcher, Kansas has only collected data comparing peak noise from vehicles passing over rumble strips to regular road noise.

Michigan DOT

At the recommendation of Thomas Hanf, Tom Zurburg provided results of technical investigations that were initiated by citizens' complaints of rumble strip noise. The investigations are focused on ambient noise versus rumble strip noise.

> **M-53 Noise Measurements of the Edge Line Rumble Strip**, Michigan Department of Transportation, October 14, 2010.
> See Appendix A.
> Results showed a 16.2-decibel increase in noise (over daytime freeway noise)—from 71 to 87.2 decibels—for a test vehicle driven over edge-line rumble strips at 70 mph and measurements taken at 95 feet perpendicular from the rumble strips.
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> **Rumble Strip, Center Line, M-63, Noise Measurements Hagar Shores, Michigan**, Michigan Department of Transportation, November 23, 2009.
> See Appendix B and Appendix C.
> Pass-by noise measurements were taken 50 feet perpendicular to the centerline rumble strip at address number 5945 on M-63 south of Hagar Shores, MI. The vehicle used for these pass-by measurements was a 2005 Ford F-350 driven under controlled conditions. There was a significant 25-decibel increase between the ambient noise and a short strike of the rumble strip in this residential area.

New Hampshire DOT

According to Jon Evans, New Hampshire DOT received noise complaints in 2007 after the agency began installing centerline rumble strips in passing zones. (Shoulder rumble strips are crossed so infrequently that they don't receive complaints.) But these complaints decreased when residents learned about the safety benefits. Nevertheless, Mr. Evans conducted rudimentary noise tests for centerline rumble strips with a depth of 3/8 inch (instead of the usual ½ inch). Using two vehicles (a Chevy Malibu and a Chevy Suburban) at 65 mph, he found that at a distance of 10 feet from the rumble strip, both vehicles produced noise levels that were approximately 1 to 2 decibels lower for the 3/8-inch rumble strip than the 1/2-inch rumble strip. There wasn't a measurable difference between the vehicles.

Mr. Evans also proposed studying alternative designs but received little support from the New Hampshire Commissioner's Office. If he can get some support, he will submit an NCHRP proposal in the future, although a discussion with Mark Ferroni of the Federal Highway Administration (FHWA) indicated that an NCHRP research proposal a few years ago was never pursued because of lack of support.

In 2009, Bill Thompson of Maine DOT (william.thompson@maine.gov) was seeking information about noise mitigation for rumble strips in residential neighborhoods, but Mr. Evans doesn't know if Maine developed or tested alternative rumble strip designs.

New York State DOT

Christopher Menge of Harris Miller Miller & Hanson Inc. and Noel Alcala of Ohio DOT recommended the following study, which was provided by Terry Smith of New York State DOT:

> **Interstate Route 87 Rumble Strip Noise Study**, Technical Memorandum, New York State Department of Transportation, January 2001.
> See Appendix D and Appendix E.
> This study included an analysis of the loudest-hour equivalent sound levels and the maximum sound levels generated by vehicles on rumble strips that were 4 inches wide, 1/2 inch deep and 12 inches apart.
>
> Close-in sound level measurements of individual vehicles traveling over rumble strips at 55 mph were approximately 7 to 10 dBA for automobiles, medium trucks and heavy trucks (at 50 feet over soft ground with cruising throttle). In the community, maximum received sound levels of individual vehicles passing over the rumble strips range from approximately 47 to 64 dBA, while typical background noise levels (L90) range from 49 to 60 dBA.
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> For the close-in measurements, two microphones were placed approximately 5 feet from the edge of the shoulder along Interstate 87. One microphone was positioned at the center of the southernmost rumble strip and another microphone was placed 300 feet south of this last rumble strip adjacent to a portion of highway with standard pavement.

See also "A Case Study on the Effect of Rumble Strip Noise in a Community" on page 11 of this Preliminary Investigation.

Ohio DOT

Noel Alcala said Ohio DOT will soon be taking noise measurements adjacent to milled rumble strips on Ohio's IR80 turnpike and will share results with Caltrans as soon as they are available (as early as March 2012).

Washington State DOT

According to Larry Magnoni, Washington State DOT has been analyzing rumble strip noise. The analysis is not including the effect of heavy vehicles because they produce a lot of noise. Instead, the DOT has purposefully tested the Ford Hybrid, since its quietness helps isolate tire-rumble strip noise. Tim Sexton performed the study and is currently formatting results so that they can be shared. These results should be available in March 2012.

Other Responses

The following states have not performed rumble strip noise research:

- Arizona (according to Fred Garcia).
- Colorado (according to Jill Schlaefer).
- Missouri (according to Rob Meade).

Dana Lodico of Lodico Acoustics LLC and William Bowlby of Bowlby & Associates noted that there is a lack of information available about rumble strip noise. Other contacts referred to several studies listed in **Related Research**.

Synthesis Reports

Centerline Rumble Strips: A Review of Residential Location Policies, Noise Issues, and Typical Designs, Literature Search & AASHTO RAC Responses, AASHTO Research Advisory Committee, October 16, 2009.
http://research.transportation.org/Documents/RAC%20Surveys%20of%20Practice/CenterlineRumbleStrips_Review_10_16_09.pdf (or see Appendix F)
This report includes a literature search (pages 3-5 of the PDF), links to state policies (pages 5-6 of the PDF) and AASHTO Research Advisory Committee (RAC) survey responses from 22 states and two provinces (pages 11-19 of the PDF) concerning noise issues with centerline rumble strips. Selected conclusions from the report include the following:

- So far, no agency has reported a useful low noise rumble strip design or noise mitigation measures.
- Michigan, Missouri and Washington seem to have the most experience with centerline rumble strips.
- States agree that residential areas need to be considered when installing rumble strips, and some have prohibited by policy (written or unofficial) rumble strip installation near residential areas.
- One state policy prohibits rumble strip installation where posted speeds are less than 50 mph. This provision avoids many residential areas.
- Several states (including Michigan) have removed rumble strips in certain locations due to residential complaints.
- Several states say an explanation of their safety benefits or endorsement by law enforcement can defuse complaints.

AASHTO RAC results are summarized in the following table. (See pages 11-19 for full results.)

State/Province	Centerline Rumble Strip Use	Noise Complaints/Issues	Use of Alternative Rumble Strip Designs	Guidance
Alaska	No response	No response	N/A	N/A
Arkansas	Selected no passing zones with safety problems and a speed limit of 45 mph or greater	No response	Possibly reduce width from 16 inches to 12 inches, depth from 1/2 inch to 3/8 inch for 45 mph -55 mph	N/A
British Columbia	No passing zones in rural areas (and shoulder strips)	No. Strips are used only in rural areas with breaks near private driveways.	N/A	Limit use in residential areas. Design guidance
Connecticut	Route 6 in 1999 (removed). Currently no centerline.	Removed because of noise complaints	N/A	N/A

Delaware	Along several miles of US 301 since the late ’90s; bicycle friendly edge-line strips on SR 1.	No for US 301 (few residential areas on this corridor). Yes for transverse thermoplastic centerline strips near residential areas. No for edge-line strips.	Thermoplastic	Limit use near residential areas. Edge-line detail
Florida	No centerline	N/A	N/A	N/A
Georgia	Yes	Yes – in limited number	N/A	Limit use near residential areas.
Idaho	Several miles in non-urban environment	No	N/A	N/A
Indiana	No	N/A	N/A	N/A
Iowa	One section of rural roadway with plans to expand to 250 miles of roadway	Yes	N/A. Suggests contacting Michigan, Washington and Missouri.	Limit use near residential areas.
Maryland	None near residential areas; some near rural houses with their agreement.	No	N/A	Limit use near residential areas.
Massachusetts	Three roads initially	No data	N/A	N/A
Michigan	5,700 miles of rural highways with a speed limit of 55 mph (to avoid residential areas) by 2010	Yes	3/8-inch cut	3/8-inch rather than 1/2-inch cut Limit use in residential areas.
Minnesota	No response	No response	Brad Estochen of MnDOT is working on a rumble strip noise study.	See NCHRP Guidance. (See MnDOT Report and here.)
Missouri	Major roads for several years. 1,000 miles by 2011. (5,600 miles including edge-line)	No significant issues	N/A	Install only for greater than 50 mph Engineering policy

Montana	Centerline: Two locations not near residential areas Shoulder: Most of the Interstate system	N/A	N/A	Limit use near residential areas.
Nevada	No	N/A	N/A	N/A
New Hampshire	Route 16 since 2004. Route 9 since 2006.	Route 16: Some complaints initially. Route 9: Substantial number of complaints initially. Explanations usually defuse complaints.	Research proposal to examine alternative designs on hold. Issue has come up in Minnesota, Iowa and New York; discussed research proposal with Mark Ferroni of the FHWA Resource Center.	Be careful in maintaining passing zones through areas with rumble strips and nearby residences. Design: It's possible that breaking up strip patterns by varying their distance will solve the problem of frequency, which may be more important than noise level.
New York	Three locations	No data	N/A	N/A
North Dakota	Few installations—one through a residential area	Few from residents; more complaints from motorcyclists. Explanations usually defuse complaints.	N/A	N/A
Ohio	No			
Oregon	Not on urban highways	Strips are removed when noise is an issue.	N/A	Profiled striping could be used instead of rumble strips where noise is an issue.
Saskatchewan	Limited use on rural highways	Yes. Do not use in proximity to some rural areas because of complaints.	N/A	Limit use near rural areas.
Texas	Selected areas with safety problems	Some complaints after installation	3/8-inch cut	3/8-inch cut in residential areas Design

Guidance for the Design and Application of Shoulder and Centerline Rumble Strips, *NCHRP Report 641*, June 2009.
http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_641.pdf
This report presents findings of a Colorado study of noise levels from 12 milled rumble strip configurations for four different vehicle types (pages A-42 to A-44 of the report). In general, wider and deeper cuts in milled rumble strips will generate higher levels of vibration and noise for all types of vehicles. The report also presents data about stimuli levels necessary for rumble strips to be effective (pages 114-118 of the report).

Centerline Rumble Strips, *NCHRP Synthesis 339*, February 2005.
http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_syn_339.pdf
This report notes that Arizona uses narrow strips to reduce residential noise (page 12 of the report) and presents the results of Kansas field tests (in 2000) of external and interior noise for several types of rumble strips and various kinds of vehicles (pages 12-14 of the report). Researchers conclude that either the continuous 12 inch or alternating pairs 12 inches apart and pairs 24 inches apart provided the optimum required response to alert drivers. They also cite a 2000 Transportation Association of Canada showing that for environmental noise, rumble strips terminated approximately 200 meters before residential or urban areas produced tolerable noise impacts on residences. At an offset of 500 meters, the noise from rumble strips was negligible. A depth of 8 millimeters provides sufficient noise and vibration to alert drivers without creating excessive noise in the surrounding area.

Related Research

Rumble Strip Exterior Noise

"Centerline Rumble Strips: Study of External Noise," *Journal of Transportation Engineering*, Vol. 137, No. 5, May 2011: 311-318.
Abstract at http://trid.trb.org/view/2011/C/1105427
From the abstract: Two types of vehicles [a 2006 Ford Taurus (sedan) and 2008 Chevrolet Express (15 passenger van)] were driven over two different patterns of milled-in [centerline rumble strips (CLRS)] and over smooth asphalt pavement at two different speeds. Researchers collected the noise levels at three distances from the road at 10 different locations. Results indicated that vehicle type, speed, CLRS presence, and distance affect exterior noise levels. CLRS noise levels were statistically greater than smooth pavement noise levels, and the difference would be perceived by human ears at distances up to 45 meters.

Effects of Centerline Rumble Strips on Safety, Exterior Noise, and Operational Use of the Travel Lane, Daniel Edgard Karkle, Kansas State University, 2011.
http://krex.k-state.edu/dspace/bitstream/2097/13137/1/DanielKarkle2011.pdf
From the abstract: From the external noise study performed, it was found that external noise depends on vehicle speed, type of vehicle, and distance. Both football and rectangular CLRS substantially increased the levels of external noise at distances up to 45 m (150 ft). Therefore, before installing CLRS, the distance from houses or businesses should be considered. A distance of 60 m (200 ft) was recommended as the limit of the potential exterior noise problem area.

Evaluation of External Noise Produced by Vehicles Crossing Over Centerline Rumble Strips on Undivided Highways in Kansas, Rohit Makarla, Osmania University, 2009.
http://krex.k-state.edu/dspace/bitstream/2097/2360/5/RohitMakarla2009.pdf
From the abstract: Researchers collected noise levels at three distances: 50, 100, and 150 feet, measured orthogonally from the center line, in 8 different open space locations. Results indicate that vehicle type,

vehicle speed, pavement type, location and distances affect the levels of noise. In addition, both football and rectangular CLRS produced significantly higher levels of noise as compared to the smooth asphalt pavement. A 15 passenger van produced higher levels of noise in comparison with a sedan. Moreover, [the] lower the vehicle speed, noise levels were lower. At every 50 feet of distance, the noise levels dropped significantly. CLRS do increase levels of noise relative to smooth pavement at distances up to 150 feet.

"Exterior Noise Created by Vehicles Traveling Over Rumble Strips," Melissa Dayle Finley, Jeffrey David Miles, *TRB 86th Annual Meeting Compendium of Papers CD-ROM*, Paper #07-2555, 2007. Abstract at http://trid.trb.org/view/2007/C/802275
From the abstract: Researchers measured the exterior noise produced by two types of vehicles traveling over five types of rumble strip applications at two different speeds. Only 13 percent of the peak rumble strip noise levels were above the highest noise level measured for a commercial vehicle driving along the roadway not hitting the rumble strips. However, over half of the rumble strip conditions produced changes in the exterior noise greater than 4 decibels. In general, the increase in exterior noise was greater at 70 mph than at 55 mph and lower for the commercial vehicle than for the sedan. Button rumble strips produced the smallest increase in exterior noise (4-5 dB), while milled and rolled rumble strips yielded the largest increase in exterior noise (up to 19 dB for milled rumble strips with 12-inch spacing). For milled rumble strips, the amount of additional exterior noise increased as the rumble strip width increased and decreased as the rumble strip spacing increased. The change in the exterior noise level was also affected by the pavement type (chip seal versus hot-mix asphalt).

Shoulder Rumble Strips and Bicyclists, Janice Daniel, Report No. FHWA-NJ-2002-020, New Jersey Department of Transportation, June 2007.
http://transportation.njit.edu/nctip/final_report/RumbleStrip.pdf
This report provides research on exterior and interior noise levels. A summary of literature found on studies of rumble strip noise levels is presented on page 7 of the report.

Analysis of Noise Concerns Regarding Rumble Strips, Aaron Milsaps, Texas A&M University, August 2005.
http://swutc.tamu.edu/publications/technicalreports/compendiums/473700-00003-10.pdf#page=109
This study determined that rumble strip noise increases as length is increased or spacing decreased. Through the development of a strategy to accurately estimate the intensity of the noise at the nearby residences and businesses, it was found that only one residence at the four locations investigated surpassed the FHWA standard for consideration of noise abatement.

"Noise and Vibration Effects of Rumble Strips," Tiehallinnon Selvityksia, *Finnra Reports*, Vol. 3200933, Issue 21, 2005.
http://alk.tiehallinto.fi/julkaisut/pdf/3200933-vtaristavatviivat.pdf
This study measured interior and exterior noise levels for three types of rumble strip and four types of vehicle, including a truck, two passenger cars and a motorcycle. Milled rumble strips caused the largest noise increase in vehicles as well as in the road environment—an average 10-decibel increase in interior noise and up to 17 decibels in exterior noise for a vehicle traveling 80 kilometers per hour. The increase of environmental noise was largely dependent on the density of the center-to-center interval of the milled markings. Rumble strips made by pressing generated an average growth of 5 decibels of interior noise and 8 decibels exterior noise. Kamflex strips generated an average increase of 8 decibels for inside noise and an average increase of 3 decibels for exterior noise. Researchers concluded that the thickness of the strip correlates with the noise effect, especially inside a vehicle.

"A Case Study on the Effect of Rumble Strip Noise in a Community," Christopher J. Bajdek, Jason C. Ross, Laura H. Chan, *TRB 2003 Annual Meeting CD-ROM*, Paper #03-3817, 2003.
http://www.ltrc.lsu.edu/TRB_82/TRB2003-001817.pdf
From the abstract: Rumble strips were found to have 5 to 10 dB greater noise emission levels than vehicles on standard pavement. The study also utilized the sound propagation algorithms in the Federal Highway Administration's Traffic Noise Model to project rumble strip noise levels at four community locations. Three alternative mitigation measures to reduce the effect of rumble strip noise in the community were investigated, including: the installation of a barrier along the right-of-way, the installation of a parapet along the median, and the relocation of the closest rumble strips. The results of the study indicated that the relocation of the rumble strips was the most effective mitigation measure.

"US Experience with Centerline Rumble Strips on Two-Lane Roads: Pattern Research and North American Usage," Eugene Russell, Margaret Rys, Troy Brin, *Proceedings of the 2003 Mid-Continent Transportation Research Symposium*, August 2003.
http://www.ctre.iastate.edu/pubs/midcon2003/RussellRumble.pdf
In this study, researchers found that patterns with higher densities of rumble strip indentations produce higher average decibel levels. Longer rumble strips generally produce higher average decibel levels, but there is no consistency among the longer lengths, probably as a result of the vehicle tires not remaining in full contact with the shorter rumble strip patterns (page 7 of the report).

"Rumble Strip Noise," J.S. Higgins, W. Barbel, *Transportation Research Record*, Vol. 983, 1984: 27-36.
Abstract at http://pubsindex.trb.org/view/1984/C/218425
This paper was recommended by Roger Wayson of Volpe.
From the abstract: The Illinois Department of Transportation (IDOT) placed rumble strips near the north end of the Edens Expressway to alert drivers that they were approaching a signalized intersection. The intersection was a high accident location, and previous safety measures were not significantly effective in lowering the number or severity of the accidents. Many complaints about noise were received from adjacent property owners after the strips were placed. When a berm that was placed between the residents and the strips did not reduce the complaints, IDOT requested assistance from the Demonstration Projects Division of FHWA to study berm effectiveness and rumble strip noise. Two types of strip construction were compared, the formed and the cut types. Several different configurations were also analyzed. Outside measurements were taken at three sites, and inside noise measurements were taken from the tractor of a semitrailer unit. Vibration measurements were taken from the steering column of the truck. The results indicated that the formed type of strip provided better driver perception than did the cut type at all speeds tested. Outside noise did not significantly vary with the different types and configurations of the rumble strips. The strips appear to have reduced the number and severity of accidents at the Edens Expressway location.

Rumble Stripe Noise Study, Minnesota Department of Transportation, undated.
http://www.dot.state.mn.us/trafficeng/safety/rumble/powerpoints/Mndot%20Rumble%20Stripe%20Noise%20Study.pdf
This study collected noise data 50 feet from roadsides and used it to model exterior noise levels for rumble strips at various distances and traffic volumes. It also found interior noise levels of 15 dBA at all speeds.

Alternative Rumble Strip Designs

"Speed Reduction Techniques for Rural High-to-Low Speed Transitions," *NCHRP Synthesis 412*, 2011.
http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_syn_412.pdf
From page 16 of the report: The U.K. Department for Transport (2005) developed and tested a quieter alternative to conventional transverse rumble strips known as a rumblewave surface. The rumblewave surface delivers the auditory and tactile stimulus to vehicle occupants in an attempt to elicit a slower travel speed, but does not generate as much ground vibration or noise for the surrounding community. Its profile produces the largest increases in interior noise and vibration for a range of vehicle types but creates little increase in exterior noise levels.

Related Resource:

> **Rumblewave Surfacing**, Department for Transport (U.K.), January 2005.
> http://assets.dft.gov.uk/publications/traffic-advisory-leaflets/ficadvisoryleaflet105rum4122.pdf
> *From the brief:* This leaflet describes a traffic calming surface profile that has been developed as a quieter alternative to conventional rumble strips, and is considered suitable for residential areas.

"Evaluation of Football Shaped Rumble Strips Versus Rectangular Rumble Strips," Margaret Rys, Lucas Gardner, Eugene Russell, *Journal of the Transportation Research Forum*, Vol. 47, No. 2, 2008: 41-54.
http://scholar.googleusercontent.com/scholar?q=cache:HiVaNRSE9s8J:scholar.google.com/+%22rumble+strip%22+noise&hl=en&as_sdt=1,22&as_ylo=2001&as_vis=1
From the abstract: Researchers at Kansas State University (KSU) conducted research on football-shaped highway rumble strip designed by an independent firm in Kansas. Test strips were installed along a Kansas highway, and the KSU research team conducted several tests to evaluate the new football shaped rumble strip versus the rectangular rumble strip. The comparison consisted of water and debris collection, interior sound and vibration production, and the opinions of bicyclists. Based on the literature review, the limited tests performed, and the surveys conducted, it can be concluded that no significant difference was found between the two types of rumble strips.

Traffic Noise at Rumble Strips, Jørgen Kragh, Bent Anderson, Inter-Noise Paper 2007, Issue 156, 2007.
http://www.vejdirektoratet.dk/publikationer/VIrap156/index.htm
See Appendix G for a copy of this paper provided by Jørgen Kragh.
Hans Bendtsen and Jørgen Kragh of Danish Road Institute pointed to this frequently cited paper comparing sinusoidal and milled rumble strips. A pilot study was conducted by the Danish Road Institute to test rumble strips generating low noise levels in the environment. Five types of rumble strips made by milling indentations in the pavement of a two-lane road were tested for noise at 25 meters from the road. Sinusoidal indentations led to only a 0.5- to 1-decibel increase in noise levels over regular road noise and cylinder indentations to an increase of 2 to 3 decibels; rectangular indentations were 3 to 7 decibels louder than sinusoidal indentations and 2 to 5 decibels louder than cylinder segment indentations.

Related Resource:

> **Low Noise Rumble Strips on Roads—Pilot Study**, Jørgen Kragh, Danish Road Institute, undated.
> http://www.adc40.org/presentations/summer2007/08%20Rumble_strip_presentation_23Jul07.pdf

Traffic Management and Noise Reducing Pavements - Recommendations on Additional Noise Reducing Measures, SILVIA Project, European Commission, October 2004.
http://www.trl.co.uk/silvia/Silvia/pdf/Main_Outputs/SILVIA-DTF-DRI-008-11-WP5-020205.pdf

This report suggests that thermoplastic rumble strips increase external noise levels by 4 decibels. (See pages 6, 37 and 76 of the report.)

Rippleprint. A New Concept in Traffic Calming, J. Tyler, *Acoustics Bulletin*, Vol. 28, Issue 1, 2003: 32-33.
Abstract at: http://trid.trb.org/view/2003/C/646135
From the abstract: A new traffic calming surface was recently launched. Described as a 'noise-optimized' system, Rippleprint is a major step forward in traffic calming techniques. Traditional traffic calming surfaces such as rumble bars and strips create significant levels of exterior noise disturbance to nearby residents, but the noise generated when driving over Rippleprint is said to be virtually indistinguishable from a regular road surface. Instead, the internal vehicle resonances are excited by significant horizontal vibrations, which are readily transmitted into the vehicle's interior through the vehicle suspension. The result is claimed to be an increase in noise and vibration in the cab, but little discernible increase in noise outside.

See also:

- **Product page**: http://www.prismogroup.com/products/safety/rippleprint/index.html
- **Development of a Novel Traffic Calming Surface 'Rippleprint,'** Transportation Research Laboratory, Report 545, October 2002.
  http://trid.trb.org/view/2002/C/733339

Interior Noise & Safety

Rumble Strip Design Parameter Determination Based on Dynamic Jerking, Chiu Liu, Zhongren Wang, *International Journal of Pavement Research and Technology*, Vol. 4, Issue 1, 2011: 67-70.
http://www.ijprt.org.tw/files/sample/V4N1_8.pdf
The analysis shows that the optimal rumble strip width lies at approximately 180 millimeters, and the ranges of the design parameters can be selected to control the jerking magnitude to alarm a driver in an errant vehicle.

"Closed-Course Test and Analysis of Vibration and Sound Generated by Temporary Rumble Strips for Short-Term Work Zones," *Transportation Research Record*, Vol. 2169, 2010: 21-30.
Abstract at http://trid.trb.org/view/2010/C/911061
From the abstract: The purpose of this research was to compare the attention-getting characteristics of several temporary rumble strips with permanent rumble strips. Two types of devices were tested and compared with permanent rumble strips: portable plastic rumble strips and adhesive rubberized polymer rumble strips. These devices were tested for their ability to generate steering wheel vibrations and in-vehicle and roadside sound. Analysis revealed that the portable plastic rumble strips were more effective on cars than on trucks for generating in-vehicle vibration and increasing the in-vehicle sound level. Further, they were generally better than the adhesive rumble strips in matching the characteristics of the tested permanent rumble strip. This was also true for the configurations that contained fewer than six portable plastic rumble strips. If the vibration and sound generated by the permanent rumble strips is considered the standard performance, various configurations of the portable plastic rumble strips can be implemented in short-term work zones and provide results similar to those of permanent rumble strips.

"Development of Recessed Pavement Markings That Incorporate Rumble Strips," *Journal of the Eastern Asia Society for Transportation Studies*, Vol. 8, 2010: 2032-2047.
http://www.easts.info/publications/journal_proceedings/journal2010/100292.pdf
From the abstract: In winter in Hokkaido [Japan], pavement markings are damaged from snow removal, and every spring, markings need to be reapplied. The authors propose a system of pavement markings whose recessed design prevents scraping damage from snowplows and whose incorporation of rumble strips increases driving safety. To determine the optimum design for recessed pavement markings, trial

installation used 2 intervals between grooves. Driving tests found that recessed markings with long intervals generate more noise and vibration than recessed markings with short intervals, making the former more noticeable than the latter.

Impact of Rumble Strips on Road Accidents, Liikenneviraston Tutkimuksia Ja Selvityksia, Research Reports of The Finnish Transport Agency, Issue 41/2010, 2010.
http://alk.tiehallinto.fi/julkaisut/pdf3/lts_2010-41_taristavien_tiemerkintojen_web.pdf
From the abstract: This report analyzes the effects of shoulder and centreline rumble strips on accident rates. Centreline rumble strips showed a reduction of 10% in off-road left and head-on personal injury accidents on two-lane roads, when combining results obtained by different methods. All police-reported off-road right accidents increased by 4%, but it seems that only property damage accidents increased, not personal injury accidents. Based on the results, centreline rumble strips reduce all motor vehicle accidents (accidents without animals or unprotected road users) by approximately 3%.

"Statistical Model of In-Vehicle Sound Generated from Highway Rumble Strips," *International Journal of Vehicle Noise and Vibration*, Vol. 5, No. 4, 2009: 308-328.
Abstract at: http://trid.trb.org/view/2009/C/914678
This study estimated a model of in-vehicle sound intensity, frequency, and duration using seemingly unrelated regression. The statistical model indicates that increasing the vehicle speed; rumble strip length, width, and groove depth and using a milled versus a rolled rumble strip pattern, all increase the in-vehicle sound level relative to the ambient level. A rumble strip on the right-side of the travel lane, increasing the vehicle angle of departure, increasing the centre-to-centre spacing of the grooves, a concrete roadway surface, and a wet roadway surface, all decrease the in-vehicle sound relative to the ambient sound.

"Factors That Influence the Effectiveness of Rumble Strip Design," *Transportation Research Record*, Vol. 2030, 2007: 1-9.
Abstract at: http://trid.trb.org/view/2007/C/802346
This study focuses on the impact of vehicle speed, vehicle type, pavement type and rumble strip design (for example, application method and dimensions) on the level of sound change that motorists perceive when they traverse rumble strips. The factors investigated in this study and their impact on sound change are as follows:

- Width, length and spacing should be adequate to allow for maximum tire displacement while the vehicle tires are traversing rumble strips. Sound levels will increase as strip width and length increase until the tires are able to obtain maximum displacement. For raised rumble strips, sound will increase as spacing increases until maximum tire displacement is reached.
- Provided that width, length and spacing are not limiting maximum tire displacement, sound increases as rumble strip depth or height increases.
- Milled, rolled, button, profiled and formed rumble strips can produce adequate changes in sound for drivers of passenger vehicles provided the appropriate design is used.
- Only milled rumble strips produced an adequate change in sound for drivers of commercial vehicles.
- As the roughness of the pavement surface increases or as the speed of a vehicle increases, so does the ambient noise, which means that more aggressive rumble strip designs are necessary.

Safety Effects of Centerline Rumble Strips in Minnesota, Marc Briese, Minnesota Department of Transportation, December 2006.
http://www.lrrb.org/pdf/200844.pdf
This study showed that centerline rumble strips dramatically decrease encroachments of vehicles on horizontal curves—from 40 percent to 50 percent—and decreased crash rates. However, testing of 6-inch grooves showed that they did not provide adequate noise vibration for larger vehicles (page 2-5). Minnesota DOT estimates a cost-benefit ratio for systematic installation of centerline rumble strips on trunk highways with average daily traffic greater than 3,000 between 45:1 and 90:1.

Guidelines for the Application of Removable Rumble Strips, Eric Meyer, Kansas Department of Transportation, August 2006.
http://ntl.bts.gov/lib/26000/26900/26960/KU023_Report.pdf
From the abstract: This study compared removable rumble strips for use in work zones to asphalt strips in terms of the levels of in-vehicle noise, vehicle-body vibration, and roadside noise, their effect on vehicle speeds, and their cost, durability, and installation and removal processes. Sound and vibration levels were measured with a sound/vibration analyzer, microphone, and accelerometer. Speeds were monitored with pneumatic hoses and automatic traffic recorders. Additional tests were performed to explore the effects of changes in deployment configuration with respect to the sound and vibration levels produced by the orange rumble strips. Of the configurations tested, 6 strips with a center-to-center spacing of 0.6 m (2 ft) was the preferred configuration based on the sound and vibration levels produced. The results of the comparisons indicated that the removable rumble strips tested are similar to asphalt rumble strips in terms of the sound and vibration levels produced and the speed reductions observed. With certain limitations, these removable rumble strips are a viable alternative to asphalt rumble strips.

Placement and Design of Milled Rumble Strips on Centre Line and Shoulder: A Driver Simulator Study, Anna Anund, Magnus Hjälmdahl, Håkan Sehammar, Göran Palmqvist, Birgitta Thorslund, VTI Report 523A, 2005.
http://www.vti.se/en/publications/pdf/placement-and-design-of-milled-rumble-strips-on-centre-line-and-shoulder--a-driving-simulator-study.pdf
Investigators tested various rumble strip designs for driver response, safety and noise levels. Rumble strips had clear alerting effects and consistently produced corrective action, regardless of design.

"Evaluation of Milled Centerline Rumble Strip Patterns," *Journal of the Transportation Research Forum*, Vol. 57, No. 4, 2003: 135-147.
Abstract at: http://trid.trb.org/view/2003/C/682677
From the abstract: This study evaluates 12 different patterns for milled centerline rumble strips to determine the optimal pattern and dimensions for installation on Kansas highways. The patterns were installed at an isolated location for testing and evaluated based on vehicle interior noise level, steering wheel vibration level and exterior noise level. The tested patterns were generated based on the installations of other states. Seven vehicles of various sizes negotiated these rumble strips at varying speeds while the decibel levels at the driver's location, as well as steering wheel vibration, were recorded and analyzed. Based on the results of these tests, two patterns were chosen for further testing in an actual highway setting.

"The Effect of Rumble Strip Configuration on Sound and Vibration Levels," *ITE Journal*, Volume 72, No. 12, December 2002: 28-32.
Abstract at: http://trid.trb.org/view/2002/C/732390
From the abstract: This article examines the effects that changes made to rumble strip configurations have on the levels of sound and vibration produced. Sound and vibration data were collected and analyzed in order to compare 3 rumble strip cross-sections and 12 different layouts with respect to their ability to produce audible and tactile stimuli. Vehicle sound and vibration were measured for different configurations and then analyzed to study the relationships between various configuration parameters and the level of sound and vibration generated.

Evaluation of Milled-In Rumble Strips, Rolled-In Rumble Strips and Audible Edge Stripe, California Department of Transportation, May 2001.
http://www.dot.ca.gov/newtech/researchreports/reports/2001/milled-in.pdf
This study found that for five types of rolled and milled-in rumble strips, all provided adequate sound and vibration properties for light vehicles, but low to insignificant alerting values for heavy commercial vehicles. Inverted profile thermoplastic strips provided adequate alerting properties for light vehicles, but

raised profile thermoplastic strips had low to insignificant alerting properties. This study also concluded that vibrations felt through the steering wheel are negligible in their alerting properties compared to the noise level produced in the passenger compartment.

APPENDIX A

M-53 Noise Measurements of the Edge Line Rumble Strip
October 14, 2010

Project information:
On October 14, 2010, the Michigan Department of Transportation (MDOT) conducted noise measurements of the southbound M-53 edge line rumble strip in response to complaints of unwanted noise in the adjacent neighborhood.

Pass-by-noise measurements were taken at the ROW/backyard fence, 95ft. perpendicular to the M-53 edge line rumble strip, and directly east of the backyard at address number 43256 Donley Drive, Sterling Heights, Michigan. This residence is approximately 10 houses north of the complainant's residence at 43236 Donley Drive. The measurement site was selected because it allowed access to the ROW fence and it provided a safe location in which to drive the test vehicle over the rumble strip. The vehicle used for the pass-by measurements was a 2005 Ford F-350 driven under controlled conditions at 70 mph.

A three second pass-by short strike of the rumble strip resulted in an 87.2dBA noise level measurement at the ROW fence. An eight second pass-by long strike of the rumble strip resulted in an 87.6 dBA noise level measurement at the ROW fence.

Summary:

The edge line rumble strip along M-53 produces intermittent short term high levels of impulse noise. When the rumble strip was struck by the test vehicle, there was a 16.2 decibel increase over the daytime freeway noise. In general a 10 decibel increase in noise is perceived to sound twice as loud to the human ear. The 16.2 dBA increase in noise due to a rumble strip strike may be perceived as an increase of more than three times as loud as the daytime freeway noise level.

While a strike of the M-53 rumble stripe creates a significant increase in noise, there is no Federal Highway Administration (FHWA) or a Michigan Department of Transportation (MDOT) criterion which establishes a maximum allowable noise level.

<u>Summary Table of Noise Characteristics at the M-53 Measurement Site</u>

Noise Type	Decibel Level	Time Period
MDOT Impact Level	66	One hour average
Background (freeway)	71	One hour average
Pass-by short rumble strike @ 95'	87.2	Approximately 3 seconds
Pass-by long rumble strike @ 95'	87.6	Approximately 8 seconds

General Noise Characteristics:
The residential area in this location appears to receive typical freeway traffic noise levels. Daytime freeway noise level decibels were measured at 71 dBA's along the ROW/backyard

fence. Traffic volumes were moderate. The freeway traffic noise level of 71 dBA exceeds MDOT's impact level of 66 decibels.

In terms of time characteristics of noise, a smooth continuous flow of noise (such as from a fan) is more comfortable or acceptable than impulsive noise (such as from a jack-hammer or rumble strips) or intermittent noise (such as from occasional passing trucks or an occasional rumble strip hit), even though all of these noises might be judged as unwanted. There is evidence that noise levels that change markedly with time or more identifiable than noise levels that remain constant, and noises that are more identifiable tend to be ore annoying. The time at which the unwanted noise occurs is a factor, rumble strip noise or an automobile horn in your neighbor's driveway that awakens you at 2 a.m. is more annoying than the same sound 12 hours later.

Rumble Strip, Center Line, M-63, Noise Measurements
Hagar Shores, Michigan November 23, 2009

Project summary:
MDOT has initiated noise measurements of M-63 center line rumble strips in response to complaints of unwanted noise. Noise measurements will be taken before and after hot poured rubber is placed to reduce the amount of noise created by the rumble strips.

On November 23rd, 2009 pass-by noise measurements were taken 50ft perpendicular to the centerline rumble strip at address number 5945 on M-63 south of Hagar Shores, Michigan. The vehicle used for the pass-by measurements was a 2005 Ford F-350 driven under controlled conditions.

The residential area appears to be quiet when traffic is not present. Daytime ambient noise level decibels were measured in the upper 40's. Traffic volumes were light with single intermittent vehicles.

Pass-by traffic noise levels without rumble strips approached or exceeded the impact level of 66 decibels but only for short periods of time. The pass-by time period is below a one hour average which is the typical time standard for traffic noise studies.

Pass-by short strikes of the rumble strip resulted in noise level decibels in the mid 70's and was above the impact level. The short strike time period is below a one hour average which is the typical time standard for traffic noise studies.

Pass-by long strikes of the rumble strip resulted in noise levels in the upper 70's to low 80's which are above the impact level. The long strike time period is below a one hour average which is the typical time standard for traffic noise studies. The long strike pass-bys used for these measurements probably exceed the amount of time that a vehicle would typically be in contact with the rumble strip.

It cannot be assumed that the noise environment characteristics along this portion of M-63 will be the same at other rumble strip locations. The site characteristics, specifications for constructing rumble strips, and vehicle sizes and speeds will result in different noise levels.

Conclusion:
There is a significant 25 decibel increase between the ambient noise and a short strike of the rumble strip in this residential area. In general a 10 decibel increase in noise is perceived to sound twice as loud to the human ear. The 25 dBA increase in noise due to a rumble strip strike may be perceived as an increase of more than four times as loud as the ambient noise level.

The measured rumble strip noise levels are above the decibel portion of MDOT's noise impact level of 66 decibels. They do not meet MDOT's impact level criterion for "traffic noise" which includes a one hour average at or above 66 decibels. The rumble strip strikes happen intermittently and last for a matter of several seconds.

In terms of time characteristics of noise, a smooth continuous flow of noise (such as from a fan) is more comfortable or acceptable than impulsive noise (such as from a jack-hammer) or intermittent noise (such as from occasional passing trucks), even though all of these noises might be judged as unwanted. There is evidence that noise levels that change markedly with time are more identifiable than noise levels that remain constant, and noises that are more identifiable tend to be more annoying. The time at which the unwanted noise occurs is a factor: an automobile horn in your neighbor's driveway that awakens you at 2 a.m. is more annoying than the same sound 12 hours later.

The center line rumble strip at 5945 M-63 produces intermittent short term high levels of impulsive noise. When the impulse noise is created, there is a significant increase in noise level compared to the existing ambient noise level.

Summary Table of Noise Characteristics at the Measurement Site

Distances of 100' and beyond are calculated using the "inverse square law"

Noise Type	**Decibel Level**	**Time period**
Ambient (background)	50	One hour average
MDOT Impact Level	66	One hour average
Pass-by no rumble strip @ 50'	68	Approximately 15 seconds
Pass-by short rumble strike@ 50'	75	Approximately 15 seconds
Pass-by long rumble strike@ 50'	80	Approximately 15 seconds
Pass-by short rumble strike@ 100'	69	Approximately 15 seconds
Pass-by short rumble strike@ 200'	63	Approximately 15 seconds
Pass-by short rumble strike@ 400'	57	Approximately 15 seconds
Pass-by short rumble strike@ 800'	51	Approximately 15 seconds

Rumble Strip, Center Line, M-63, Noise Measurements
November 23, 2009

2nd and 7th Pass-by, no rumble strip, northbound @ 51mph and 55 mph
Decibel levels measured: 66.6dBA and 67.9dBA respectively

3rd and 6th Pass-by, rumble strip, northbound @ 50mph and 52 mph
Decibel levels measured: 77.2dBA and 78.6dBA respectively

5th and 8th Pass-by, rumble strip, southbound @ 55mph and 55 mph
Decibel levels measured: 79.1dBA and 82.0dBA respectively

9th Pass-by, short strike of rumble strip between driveways, southbound @ 55mph
Decibel levels measured: 74.6dBA

Ambient noise level measured at approximately 48dBA's.

1st and 4th pass-by measurements were not used due to extra noise from secondary sources.

Summary:
Pass-by noise measurements were taken 50ft perpendicular to the centerline rumble strip at address number 5945 on M-63 south of Hagar Shores, Michigan. The vehicle used for the pass-by measurements was a 2005 Ford F-350 driven under controlled conditions.

The residential area appears to be quiet when traffic is not present. Daytime ambient noise level decibels were measured in the upper 40's. Traffic volumes were light with single intermittent vehicles.

Pass-by traffic noise levels without rumble strips approached or exceeded the impact level of 66 decibels but only for short periods of time. The pass-by time period is below a one hour average which is the typical time standard for traffic noise studies.

Pass-by short strikes of the rumble strip results in noise level decibels in the mid 70's and is above the impact level. The short strike time period is below a one hour average which is the typical time standard for traffic noise studies.

Pass-by long strikes of the rumble strip results in noise levels in the upper 70's to low 80's which are above the impact level. The long strike time period is below a one hour average which is the typical time standard for traffic noise studies. The long strike pass-bys used for these measurements probably exceed the amount of time that a vehicle would typically be in contact with the rumble strip.

It cannot be assumed that the noise environment characteristics along this portion of M-63 will be the same at other rumble strip locations. The site characteristics, specifications for constructing rumble strips, and vehicle sizes and speeds will all result in different noise levels.

Conclusion:
There is a significant 25 decibel difference between the background (ambient) noise and a short strike of the rumble strip in this residential area. In general a 10 decibel increase in noise is perceived to sound twice as loud to the human ear. The 25 dBA increase in noise due to a rumble strip strike may be perceived as an increase of more than four times as loud as the ambient noise level.

The measured rumble strip noise levels are above the decibel portion of MDOT's noise impact level of 66 decibels. They do not meet MDOT's impact criterion for traffic noise which includes a one hour average at or above 66 decibels. The time period of the rumble strip strikes last for a matter of several seconds and the strikes happen intermittently.

In terms of time characteristics of noise, a smooth continuous flow of noise (such as from a fan) is more comfortable or acceptable than impulsive noise (such as from a jack-hammer) or intermittent noise (such as from occasional passing trucks), even though all of these noises might be judged as unwanted. There is evidence that noise levels that change markedly with time are more identifiable than noise levels that remain constant, and noise that are more identifiable tend to be more annoying. The time at which the unwanted noise occurs is a factor: an automobile horn in your neighbor's driveway that awakens you at 2 a.m. is more annoying than the same sound 12 hours later.

The rumble strips result in short term high noise levels, significant increases in noise levels, and impulsive noise. Even though these noise characteristics do not meet the "traffic noise" definition of noise impacts, they may create an unwanted noise environment.

Summary Table of Noise Characteristics at the Measurement Site

Distances of 100' and beyond are calculated using the "inverse square law"

Noise Type	**Decibel Level**	**Time period**
Ambient (background)	50	One hour average
MDOT Impact Level	66	One hour average
Pass-by no rumble strip@ 50'	68	Approximately 15 seconds
Pass-by short rumble strike@ 50'	75	Approximately 15 seconds
Pass-by long rumble strike@ 50'	80	Approximately 15 seconds
Pass-by short rumble strike@ 100'	69	Approximately 15 seconds
Pass-by short rumble strike@ 200'	63	Approximately 15 seconds
Pass-by short rumble strike@ 400'	57	Approximately 15 seconds
Pass-by short rumble strike@ 800'	51	Approximately 15 seconds

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TECHNICAL MEMORANDUM

To: Daniel P. Hitt, L.A., NYSDOT Region 1

William McColl, NYSDOT Environmental Analysis Bureau

Copies: Cathy Cowan, NYSDOT Consultant Management Bureau

Douglas E. Barrett, HMMH

From: Jason C. Ross and Christopher J. Bajdek

Date: 3 January 2001

Subject: Interstate Route 87 Rumble Strip Noise Study

NYSDOT PIN 1806.44.101

Reference: HMMH Project No. 294241.07

TABLE OF CONTENTS

1. Introduction

Under contract to the New York State Department of Transportation, Harris Miller Miller & Hanson Inc. (HMMH) conducted a noise study in Guilderland, New York to determine the effect of rumble strip noise on the adjacent community. The rumble strips are located on Interstate Route 87 (I-87) between the New York State Thruway exit ramp 24 and the Crossgates Mall exit ramp, while the community is located on the northbound side of I-87.

This report includes the results of close-in sound level measurements of individual vehicle pass-bys over both a rumble strip and a standard pavement section of the highway, ambient sound level measurements conducted in the community, computed loudest-hour equivalent sound levels with and without rumble strip noise, and computed noise reductions for three different noise mitigation measures. The three noise mitigation measures that were evaluated for this study include:

- placing a noise barrier along the right-of-way on the northbound side of I-87,
- replacing the four southernmost rumble strips with four rumble strips north of the on-ramp from the Thruway, and
- placing a 1.0-meter high parapet between the northbound and southbound lanes of I-87 adjacent to the existing rumble strips.

This study included an analysis of the loudest-hour equivalent sound levels and the maximum sound levels generated by vehicles on the rumble strips. To evaluate the benefit provided by each of the mitigation measures, maximum pass-by sound levels were calculated for each of the three vehicle classifications in 1/3 octave bands. To characterize the intrusiveness or audibility of these maximum pass-by sound levels, these noise events were then compared to typical background sound levels.

2. Summary of Findings and Conclusions

Close-in sound level measurements of individual vehicles traveling over rumble strips result in typical increases in sound levels of approximately 7 to 10 dBA for automobiles, medium trucks and heavy trucks (at 50 feet, over soft ground, with cruising throttle, and at 55 miles per hour). In the community, maximum received sound levels of individual vehicles passing over the rumble strips range from approximately 47 to 64 dBA, while typical background noise levels (L_{90}) range from 49 to 60 dBA.

Loudest-hour equivalent sound levels (L_{Aeq1h}) in the community are not increased due to the presence of the rumble strips, even though individual vehicles on the rumble strips can often be heard. For this reason, the conclusions of this study were based on an analysis of the maximum sound levels due to vehicle pass-bys on the rumble strips, and a comparison of these levels with background sound levels. Table 1 provides a summary of the maximum pass-by sound levels with and without rumble strips, and background sound levels at each site in the community.

Table 1. Maximum Pass-by Sound Levels and Background Sound Levels in the Community

Computed Maximum Pass-by Sound Levels and Measured Background Levels [dBA]					
Site	Address	**Distance to Nearest Rumble Strip [meters]**	**"Ambient" L90 Sound Levels**	**Range of L_{Amax} With Rumble Strips**	**Range of L_{Amax} With Standard Pavement**
1	52 Providence Street	205	60	56 to 64	46 to 54
2	53 Providence Street	180	58	56 to 64	46 to 56
3	55 Mercer Street	170	55	54 to 64	45 to 57
4	36 Mercer Street	330	49	47 to 57	37 to 48

Table 2 provides a summary of the approximate noise reductions that could be achieved with each of the mitigation measures under evaluation. The amount of noise reduction shown in Table 2 is given with respect to the computed reduction in the maximum A-weighted sound level for individual vehicle pass-bys on the rumble strips. As shown in the table, the most effective measure to reduce the effect of the rumble strips in the community would be to relocate the four southernmost (closest) rumble strips. The construction of a noise barrier along the right-of-way would provide modest reductions in the maximum sound levels generated by the rumble strips, while the installation of a standard height parapet along the median would provide barely noticeable noise reductions.

Table 2. Computed Noise Reductions for Various Mitigation Measures

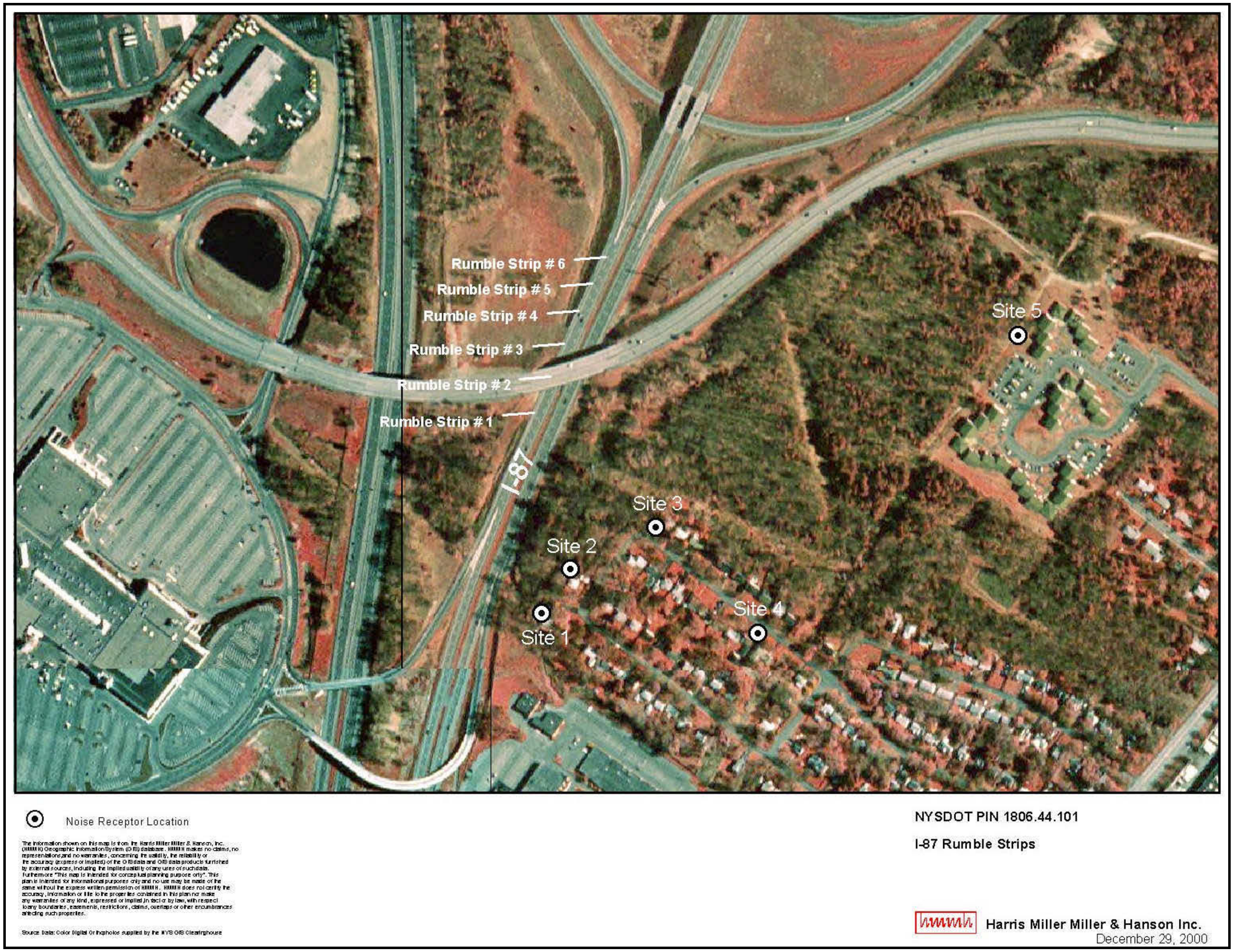
Mitigation Measure	Range of Reductions in $L_{A,max}$ for Individual Vehicle Pass-bys in the Community
Noise barrier along right-of-way	3 to 8 dB
Relocate four rumble strips	8 to 18 dB
Parapet along median	0 to 3 dB

3. Reference (Close-in) Rumble Strip Sound Levels

Sound level measurements near the rumble strips were conducted to determine the increase in sound level in 1/3 octave bands for vehicles passing over a rumble strip. For this noise study, a single rumble strip was defined as a set of 18 transverse grooves in the pavement that are 4 inches in width, ½ inch in depth, and spaced 12 inches apart. There are a total of six rumble strips spaced 120 feet apart on the southbound side of I-87 from approximately 480 feet north of the Washington Avenue overpass to120 feet south of the overpass. Figure 1 shows the approximate locations of the rumble strips on I-87 and their proximity to the community.

For the close-in measurements, two microphones were placed approximately 5 feet from the edge of shoulder along I-87. One microphone was positioned at the center of the southernmost rumble strip and another microphone was placed 300 feet south of this last rumble strip adjacent to a portion of highway with standard pavement. Trained acoustical consultants logged the instances that individual vehicles passed by the rumble strip portion of the highway, along with the lane of travel on southbound I-87 and the vehicle type. A pass-by event was determined to be an acceptable individual event based on the spacing between adjacent vehicles, the specific lane of travel on southbound I-87 and the volume of traffic on the northbound lanes of I-87. The vehicle pass-by had to be acceptable at both microphone positions to be included in the analysis. During the noise measurements, NYSDOT personnel measured vehicle speeds using a radar gun. Figure 2 shows the locations of the two reference (close-in) positions along the southbound side of I-87.

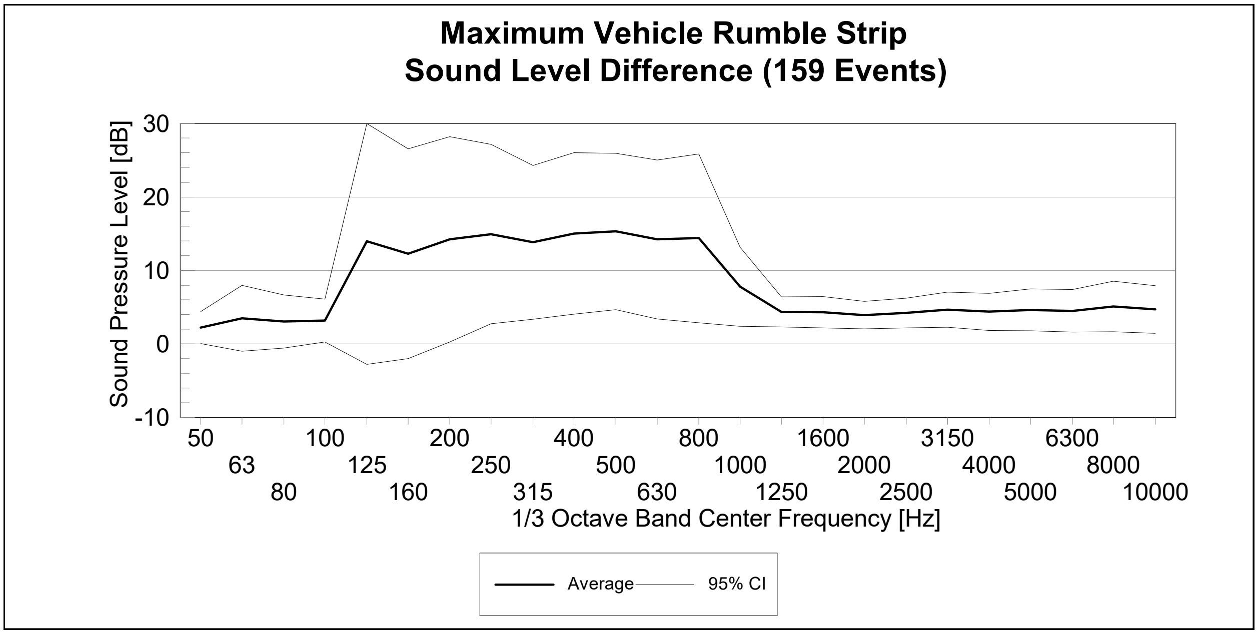
Figure 1. I-87 Rumble Strip Study Area



The maximum 1/3 octave band sound levels of 159 individual events were measured on Thursday, November 16, 2000 from approximately 13:00 to 15:00 using a two-channel digital audio tape recorder. The differences in sound levels caused by vehicles passing over the rumble strips were calculated for each of the acceptable pass-bys in 1/3 octave bands. Differences in maximum sound levels were analyzed for different groupings of vehicles based on vehicle type and lane of travel on southbound I-87. No significant correlations between vehicle type or lane of travel were found, thus, maximum pass-by sound level differences were grouped for all 159 vehicle events. The speeds of the vehicles mostly ranged between 40 and 65 miles per hour with an average of approximately 52 miles per hour. Figure 3 shows the average difference in the measured maximum sound levels for all 159 events and the 95 percent confidence intervals. The frequency of rumble strip noise is dependent on vehicle speed. These measurements include vehicles across a range of speeds and therefore show increases in sound levels across a broad frequency range from 125 to 1000 Hertz. (See Appendix A for a graph of sound level differences of all 159 events).

Figure 2. Rumble Strip Reference Measurement Site

Figure 3. Average Measured Rumble Strip Sound Level Difference with Confidence Limits

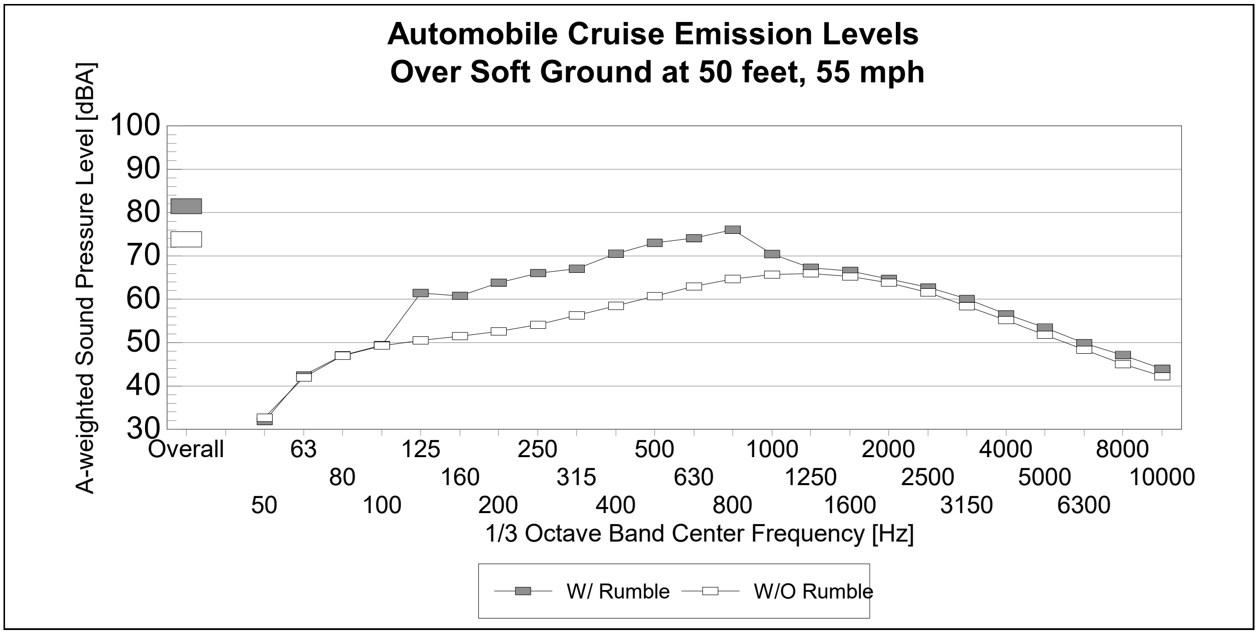


The measured difference in maximum vehicle pass-by sound levels was applied to the Federal Highway Administration Traffic Noise Model (TNM) version 1.0b database of vehicle sound level emissions for the purpose of evaluating the effect of rumble strip noise in the community. The TNM database of vehicle sound levels includes A-weighted sound pressure levels in 1/3 octave bands for both the low and high sub-sources of automobiles, medium trucks and heavy trucks over a range of speeds from 0 to 80 miles per hour. The low sub-source height for all vehicles is 0 feet. The high sub-source height for automobiles and medium trucks is 5 feet, while the high sub-source height for heavy trucks is 12 feet. For automobiles and medium trucks half of the sound energy from the rumble strips was added to both the low and high sub-sources. For heavy trucks, all of the sound energy from the rumble strips was added to only the low sub-source. Table 3 shows A-weighted overall vehicle emissions over soft ground at 50 feet for each vehicle type traveling at cruise throttle 55 miles per hour with and without rumble strip noise. Figure 4 shows 1/3 octave band sound levels of both rumble strip and standard pavement emissions for an automobile traveling at 55 miles per hour. (See Appendix B for graphs of close-in spectra for medium and heavy trucks on rumble strips and standard pavement).

Table 3. A-weighted Vehicle Sound Levels with and without Rumble Strips

A-weighted Vehicle Sound Levels Over Soft Ground at 50 feet and 55 miles per hour [dBA]		
Vehicle Type	**With Rumble Strips**	**Without Rumble Strips**
Automobiles	81	74
Medium Trucks	89	80
Heavy Trucks	94	84

Figure 4. Automobile Reference Spectrum with and without Rumble Strips



4. Ambient Sound Level Measurements in Community

Sound level measurements were conducted at five representative locations in the community adjacent to the rumble strips in Guilderland, New York. Figure 1 shows the I-87 study area and each of the community measurement sites. The purpose of these measurements was to characterize and quantify typical ambient sound levels during the evening hours when background levels are low and the rumble strips are more noticeable. To determine the intrusiveness of rumble strip noise in the community, comparisons were made of the maximum rumble strip sound levels and background sound levels at these sites. The background noise measurements were conducted for 34 to 41 minutes in duration each between 20:08 and 22:59 on Thursday, November 16, 2000.

Traffic volumes during this period were relatively low compared to daytime traffic volumes. During the measurements, sound propagation occurred under “upwind” conditions, i.e. the wind was blowing from the community to the rumble strips. As a result of the upwind conditions, the rumble strips were mostly inaudible at each measurement location in the community. Both L_{eq} and statistical sound levels in 1/3 octave bands were measured at each site. Figure 5 shows the measured background sound levels at Site 3 – the community location closest to the rumble strips. Typically, L_{90} sound levels are considered to be most representative of the background noise environment. Table 4 shows the locations, measurement periods, A-weighted L_{90} sound levels, wind speeds and wind directions of the five community measurement sites. (See Appendix C for photographs and ambient sound level measurements for all five measurement site locations).

Figure 5. Ambient Sound Level Measurements at Site 3

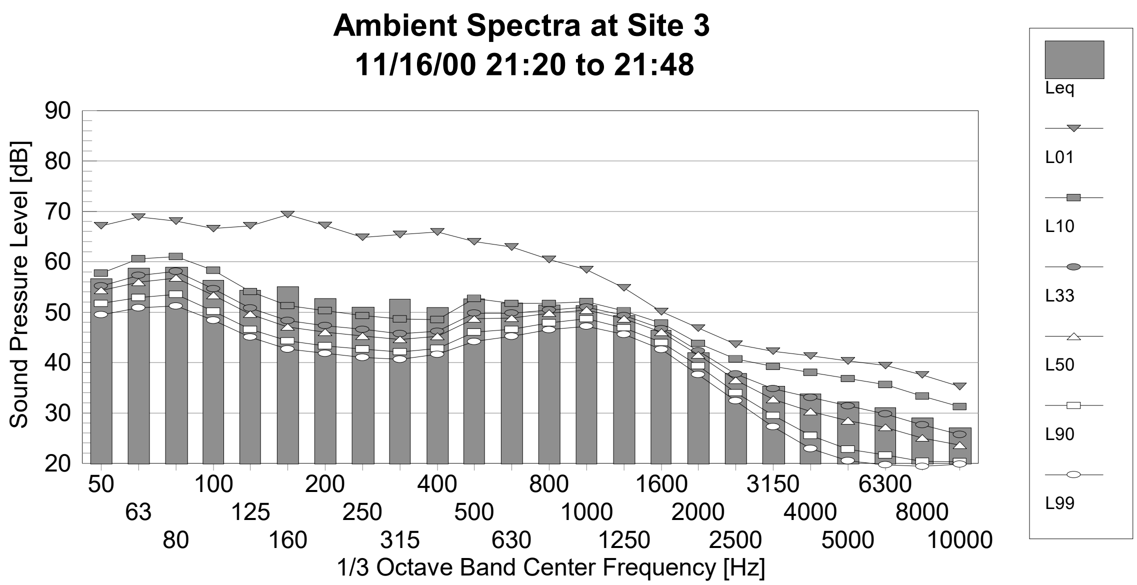


Table 4. Background Noise Measurement Data

Background Noise Measurement Data					
Site	Address	Ambient Measurement Period	"Ambient" L90 Sound Levels [dBA]	Wind Speed [mph]	Wind Direction [degrees]
1	52 Providence Street	20:08 to 20:48	60	4 to 6	220
2	53 Providence Street	20:21 to 20:55	58	4 to 6	220
3	55 Mercer Street	21:20 to 21:48	55	3 to 5	120
4	36 Mercer Street	21:13 to 21:54	49	3 to 5	120
5	Freedom Quad, SUNY Student Housing	22:19 to 22:59	48	2 to 4	180

5. Loudest-Hour Equivalent Sound Levels in the Community

5.1 Hourly Sound Levels and Noise Barrier Insertion Loss Without Rumble Strips

A "Type II" noise barrier planning study was performed for this study area in October 2000 by McFarland-Johnson, Inc., Bowlby & Associates, Inc., and Konheim & Ketcham, Inc[1]. Type II studies evaluate traffic noise and abatement options for existing roadways. Because the rumble strips were installed after the Type II study was completed, the Type II study did not include the effect of rumble strip noise levels on the community. That study examined noise impact based on an assessment of loudest hour equivalent sound levels, L_{Aeq1h}, and an evaluation of noise barriers wherever noise impacts were expected to occur.

The Type II study concluded that noise impact would occur at three single-family residences based on a comparison of the loudest-hour equivalent sound levels to Federal Highway Administration's Noise Abatement Criteria. To mitigate these impacts, a 410-meter long, 3.7-meter tall noise barrier was evaluated. This barrier located along the northbound side of I-87 would provide an insertion loss of more than 7 dB at three residences, and benefit a total of five residences. This noise barrier would cost approximately $376,650 or $75,330 per benefited residence. Consequently, this barrier is not considered cost-effective according to NYSDOT policy of $50,000 per benefited residence.

Table 5 shows loudest-hour L_{Aeq1h} sound levels with and without the noise barrier calculated at Sites1, 2 ,3, and 4 using the Federal Highway Administration Traffic Noise Model (TNM) version 1.0b based on the McFarland-Johnson report[1].

Table 5. Loudest Hour Equivalent Sound Levels without Rumble Strip Noise (from Ref. 1)

A-weighted With and Without Barrier Loudest Hour L_{aeq1h} Sound Levels and Insertion Loss [dBA]			
Site	**Without Barrier**	**With Barrier**	**Insertion Loss**
1	69	61	8
2	68	62	6
3	64	61	3
4	59	56	3

5.2 Hourly Sound Levels and Noise Barrier Insertion Loss With Rumble Strips

To determine L_{Aeq1h} hourly equivalent sound levels and barrier insertion loss for vehicles traveling over the rumble strips, a modified version of TNM was used. The general equation contained within the TNM is given by[2];

$$L_{Aeq1h} = EL_i + A_{traff(i)} + A_d + A_s$$

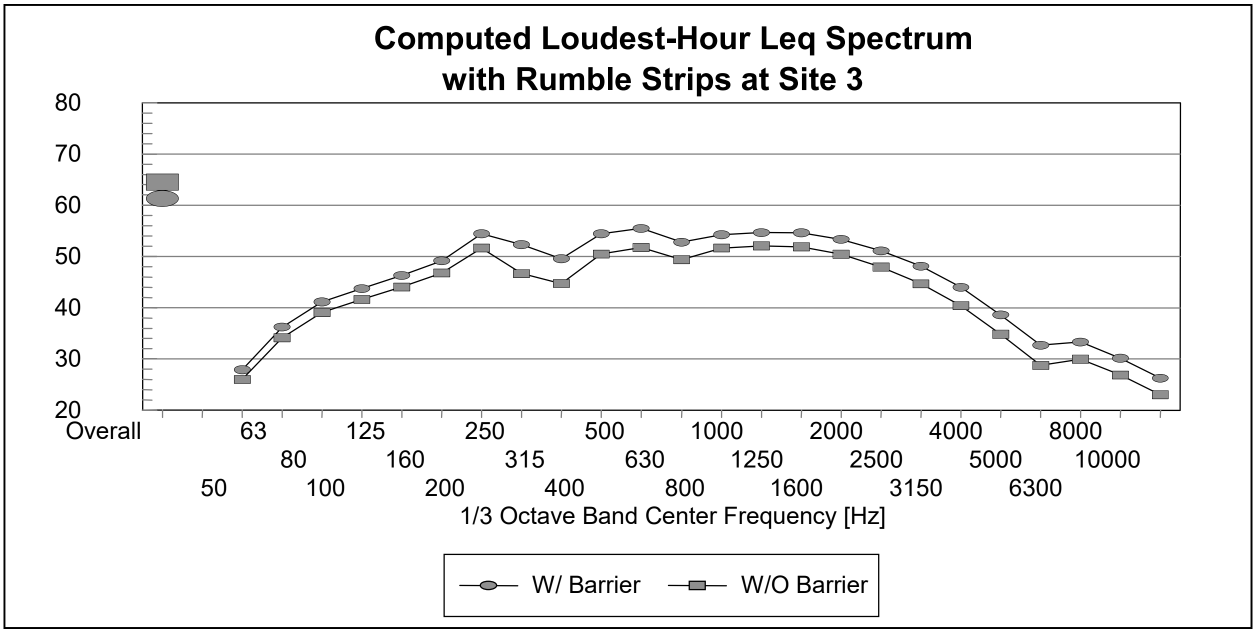
where El_i represents free field vehicle emission levels for each vehicle type, $A_{traff(i)}$ represents traffic flow adjustments for vehicle speed and volume, A_d represents distance adjustments between the roadway and receiver based on roadway length and A_s represents sound level attenuation due to ground effects, shielding and atmospheric absorption.

Using a modified version of TNM, A_s attenuation factors calculated by the vertical geometry portion of TNM were extracted. From the TNM database, El_i 50-foot free field vehicle emission levels in 1/3 octave bands were extracted for all three vehicle types, vehicle sub-sources and all vehicle speeds represented in the loudest hour traffic. Vehicle emission levels were calculated with and without rumble strips as discussed in the foregoing *Reference Rumble Strip Sound Levels* section. In a spreadsheet, A_d distance adjustments and $A_{traff(i)}$ traffic adjustments were recalculated in the same manner as in TNM version 1.0b.

Loudest-hour sound levels with and without the rumble strips, and with and without the noise barrier were calculated at Sites 1, 2, 3, and 4. The results of these calculations show that the presence of rumble strips has no effect on either the overall hourly equivalent L_{Aeq1h} sound levels, or the noise barrier insertion loss based on the L_{Aeq1h} descriptor. This is due to the relatively short lengths of the rumble strips compared to the entire length of the road and the fact that the rumble strips are not located on the closest sections of the road to the community. Figure 6 shows 1/3 octave band sound levels calculated at Site 3 with rumble strip noise, with and without the right-of-way noise barrier. (See Appendix D for the loudest-hour equivalent sound level spectra with and without the barrier at all sites).

Since the presence of the rumble strips does not have an effect on loudest-hour equivalent sound levels with or without a barrier, any evaluation of noise mitigation measures based on the L_{Aeq1h} descriptor would be inconclusive. As described in the following sections, the effects of rumble strip noise in the community were then evaluated with respect to the maximum sound levels generated by vehicle pass-bys on the rumble strips.

Figure 6. Computed Spectrum at Site 3 With and Without Noise Barrier



6. Maximum Sound Levels Due to Individual Vehicle Pass-bys

As previously mentioned, loudest-hour equivalent sound levels in the community are not increased due to the presence of the rumble strips even though individual vehicles on the rumble strips can often be heard. Consequently, to evaluate the effect of rumble strip noise in the community, maximum sound levels generated by vehicles on the rumble strips were evaluated with respect to background noise levels.

6.1 Vehicle Pass-by Sound Levels With and Without Rumble Strips

In the evening to late night hours, due to significantly lower traffic volumes and lower ambient or masking sound levels, individual vehicles passing over the rumble strips may be audible. The intrusiveness of these maximum sound levels is characterized by comparing them with typical background sound levels.

Maximum pass-by sound levels were calculated with and without rumble strip noise using a modified version of TNM and the following equation;

$$L_{max} = El_i + A_{distance\ (ss)} + A_s$$

where $A_{distance\ (ss)}$ represents sound level attenuation due to spherical spreading from an omni-directional point source. Vehicle emission levels and sound level attenuation due to ground effects, shielding and atmospheric absorption were calculated similar to the hourly equivalent analysis. Traffic flow adjustments were not necessary since maximum pass-by sound levels only consider individual vehicles. It is important to note that these pass-by sound levels are for neutral atmospheric conditions with no wind, and that sound levels for either upwind or downwind conditions would likely cause these pass-by sound levels to be somewhat lower or higher, respectively.

Table 6 shows the maximum pass-by sound levels of automobiles, medium trucks and heavy trucks traveling at 55 miles per hour under cruise throttle with and without rumble strip noise. Maximum sound levels on standard pavement were calculated for the same rumble strip-to-receptor distance. Figure 7 and 8 show the maximum spectra for both automobiles and heavy trucks, as well as ambient L_{90} sound levels at Site 3. (See Appendix E for the computed spectra for all vehicle types at all sites with and without rumble strip noise).

The computed automobile pass-by spectrum without rumble strip noise is below background levels across nearly all frequencies at Site 3. However, with rumble strip noise, the automobile spectrum is 9 to 11 dB above the L_{90} in the 1/3 octave bands from 125 to 250 Hz, and would likely be audible. Heavy truck maximum pass-by sound levels without rumble strip noise are only slightly above background levels, while pass-bys with rumble strip noise are up to 17 dB above the background sound levels and clearly audible across a broad frequency range. All four sites calculated show similar results: that maximum pass-by sound levels with rumble strip noise for all vehicle types protrude above L_{90} levels, and maximum A-weighted sound levels with rumble strip noise range from 5 to 11 dB higher than maximum A-weighted sound levels without rumble strip noise.

Note that the measured background spectra for each site are representative of the noise environment in the community for upwind conditions (which were observed during the noise measurement program). Although measured L_{90} levels may vary under different weather conditions, the background spectra presented in this report are representative of the noise environment in the community during typical evening hours when rumble strip noise is likely to be more intrusive.

Table 6. Maximum A-weighted Sound Levels With and Without Rumble Strips

Maximum A-weighted Received Sound Levels With and Without Existing Rumble Strips [dBA]							
Site	Distance to Nearest Existing Rumble Strips [meters]	Automobile		Medium Truck		Heavy Truck	
		With Rumble	Without Rumble	With Rumble	Without Rumble	With Rumble	Without Rumble
1	205	56	46	64	53	63	54
2	180	56	46	64	54	63	56
3	170	54	45	64	54	62	57
4	330	47	37	57	46	53	48

Figure 7. Maximum Automobile and Background Spectra at Site 3

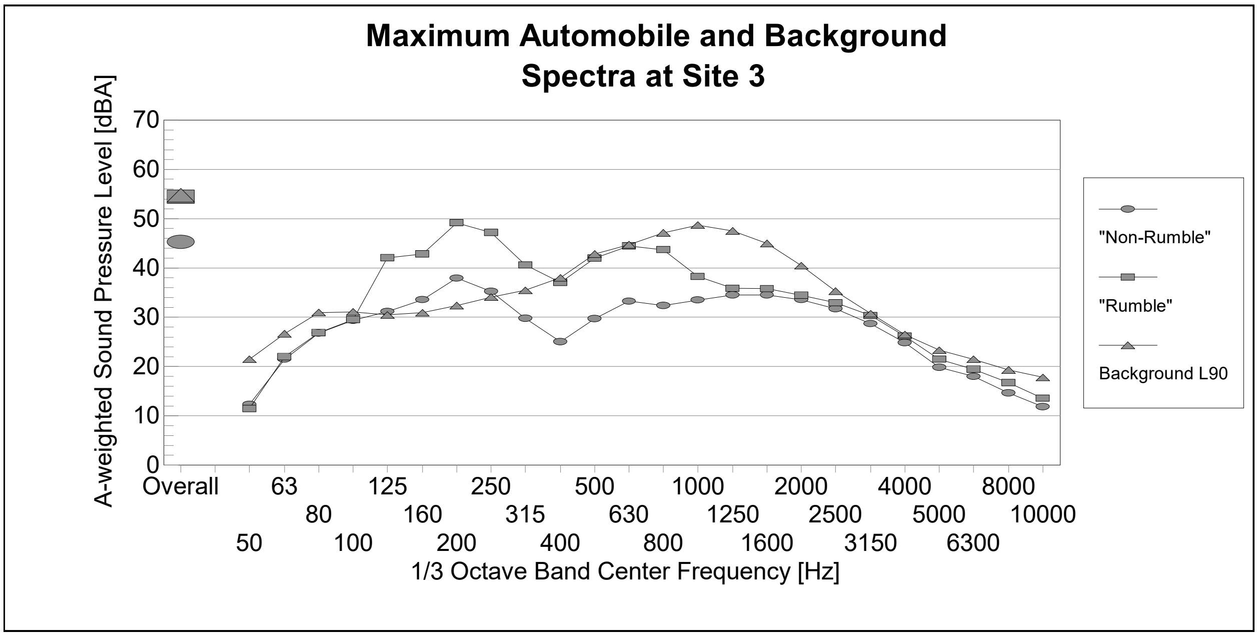
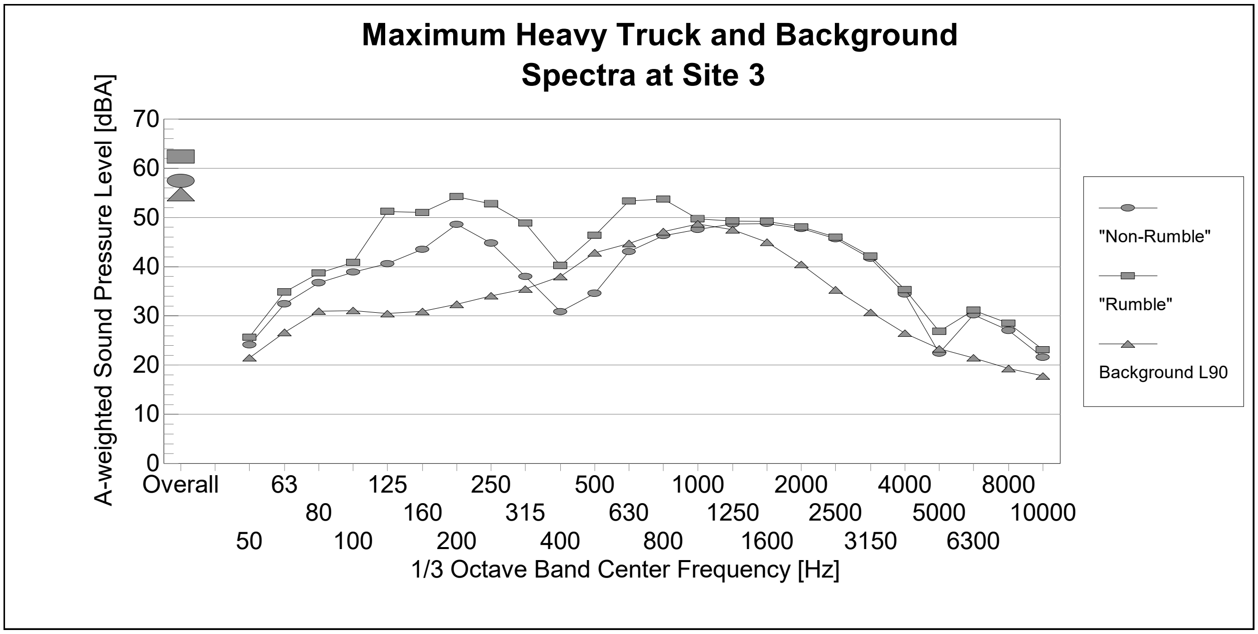


Figure 8. Maximum Heavy Truck and Background Spectra at Site 3



6.2 Vehicle Pass-by Sound Levels With and Without a Noise Barrier

Noise mitigation by means of a 410-meter long, 3.7-meter tall barrier was shown to provide from 3 to 8 dB of insertion loss for the loudest hour equivalent sound levels.[1] Of course, this noise barrier also would provide attenuation to maximum pass-by sound levels of individual vehicles. Table 7 shows maximum A-weighted sound levels at all sites for vehicles passing over the nearest rumble strip with and without the 410-meter long noise barrier. The noise barrier is expected to reduce maximum pass-by sound levels by approximately 3 to 8 decibels for all vehicle types and at all sites.

Figures 9 and 10 are maximum spectra of automobiles and heavy trucks passing over the nearest rumble strip with and without the right-of-way noise barrier, as well as the L_{90} spectrum at Site 3. These graphs show that a 3.7-meter tall noise barrier is not expected to lower maximum vehicle pass-by sound levels below the L_{90} sound levels. Generally, in the 125 to 315 Hz frequency bands, maximum vehicle pass-by sound levels would remain somewhat above the background levels even with a noise barrier. (See Appendix F for maximum pass-by spectra for all sites and all vehicle types with and without the right-of-way noise barrier).

Table 7. Maximum Rumble Strip Sound Levels With and Without Noise Barrier

Maximum A-weighted Received Sound Levels With and Without Right-of-way Noise Barrier						
	Automobile		Medium Truck		Heavy Truck	
Site	Without Barrier	With Barrier	Without Barrier	With Barrier	Without Barrier	With Barrier
1	56	48	64	57	63	55
2	56	50	64	59	63	57
3	54	50	64	59	62	59
4	47	42	57	51	53	49

Figure 9. Maximum Automobile Spectra With and Without Noise Barrier, and Background Spectrum

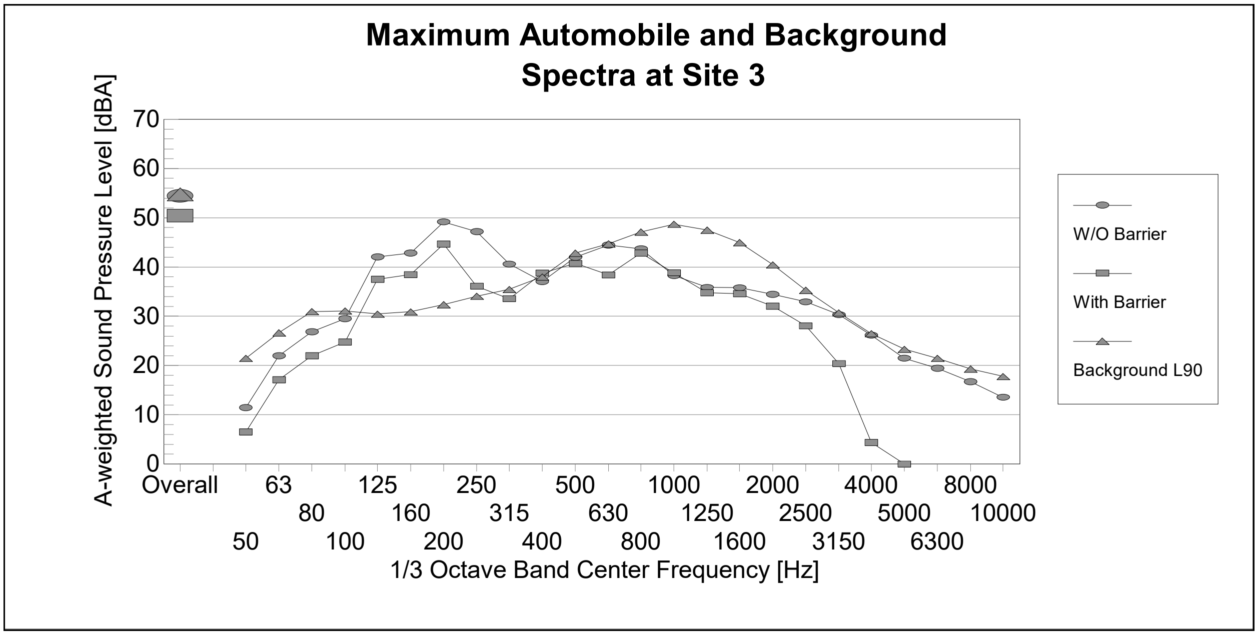
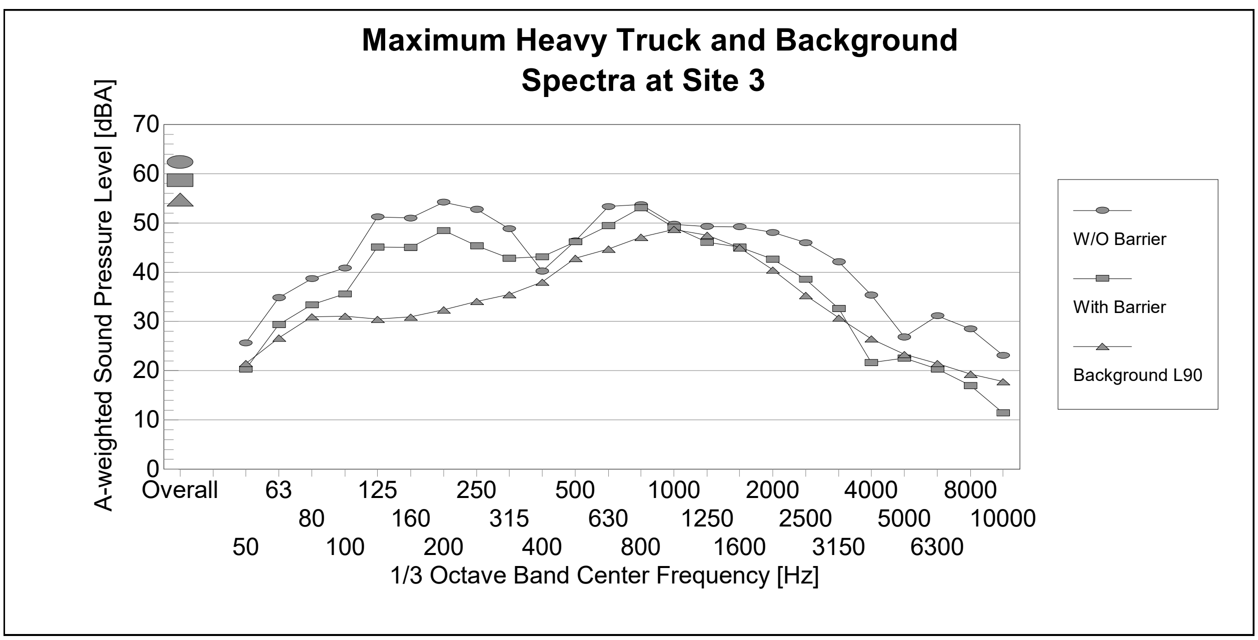


Figure 10. Maximum Heavy Truck Spectra With and Without Noise Barrier, and Background Spectrum



7. Alternative Mitigation Measures

In the previous section, the right-of-way noise barrier that was evaluated in the Type II study[1] would provide somewhat noticeable reductions in the maximum noise levels generated by vehicles on the rumble strips at various locations in the community. Two additional noise abatement measures were evaluated to mitigate the intrusiveness of rumble strip noise in the community as described in the following sub-sections.

7.1 Relocation of Four Southernmost Rumble Strips

One noise mitigation measure is to replace the four southernmost (closest) rumble strips (Rumble Strips #1, #2, #3, and #4 in Figure 1) with four rumble strips north of the on-ramp from the Thruway. Maximum pass-by sound levels were calculated for each vehicle type, for a speed of 55 miles per hour, over both the nearest existing rumble strip and nearest relocated rumble strip. Table 8 shows the maximum A-weighted sound levels at Sites 1, 2, 3, and 4 for vehicles on both the existing and relocated rumble strips. Figures 11 and 12 show the maximum pass-by spectra for both automobiles and heavy trucks on the existing rumble strips and the relocated rumble strips, as well as the background spectrum at Site 3. (See Appendix G for maximum sound level spectra for all vehicle types, and background spectra at all sites).

Table 8. Maximum A-weighted Sound Levels with Existing and Relocated Rumble Strips

Maximum A-weighted Received Sound Levels with Existing and Four Moved Rumble Strips [dBA]								
			Automobile		Medium Truck		Heavy Truck	
Site	Distance to Nearest Existing Rumble Strip [meters]	Distance to Nearest Moved Rumble Strip [meters]	Existing Location	Moved Location	Existing Location	Moved Location	Existing Location	Moved Location
1	205	365	56	47	64	56	63	54
2	180	330	56	38	64	46	63	46
3	170	280	54	44	64	53	62	52
4	330	420	47	34	57	43	53	44

In the community, the maximum A-weighted sound levels would be reduced by approximately 8 to 17 dB by relocating the four southernmost rumble strips. Maximum vehicle pass-by spectra are typically lower than the background spectrum across most of the 1/3 octave bands. As a result, rumble strip noise would become mostly inaudible at these sites under neutral (calm) wind conditions. The noise reduction provided by the relocation of the four southernmost rumble strips can be attributed in part to the increased distance between the closest rumble strip and the homes, and in part to the excess attenuation provided by the Washington Avenue bridge abutments that acts like a natural noise barrier.

Figure 11. Maximum Automobile Spectra for Existing and Relocated Rumble Strips, and Background Spectrum

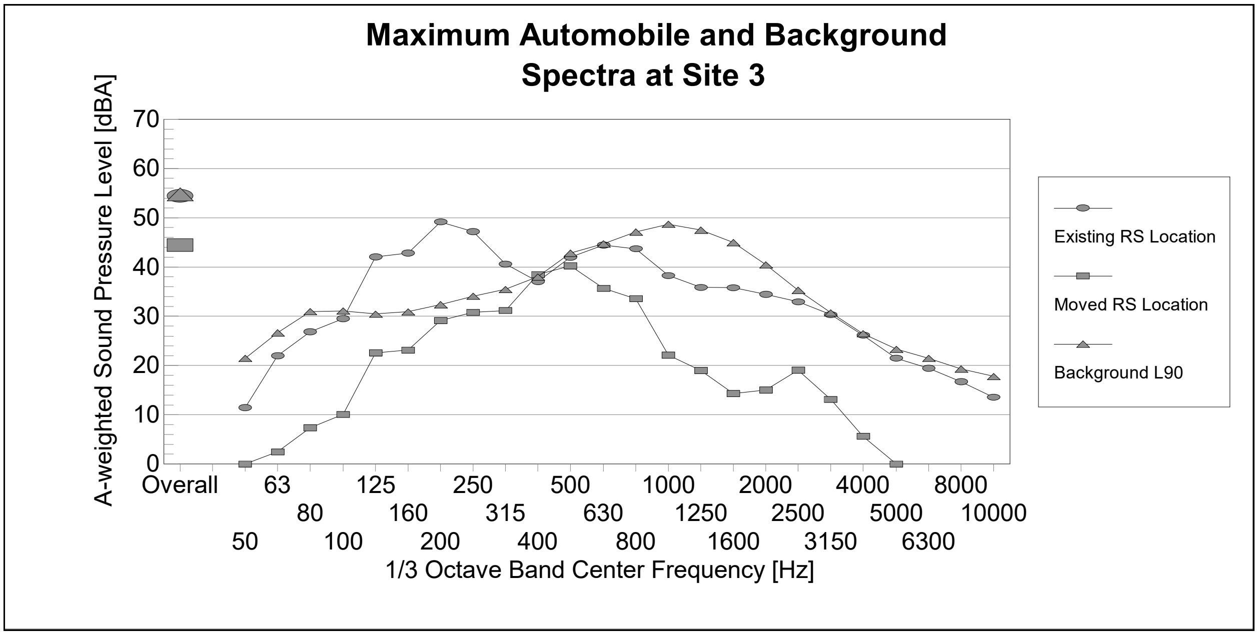
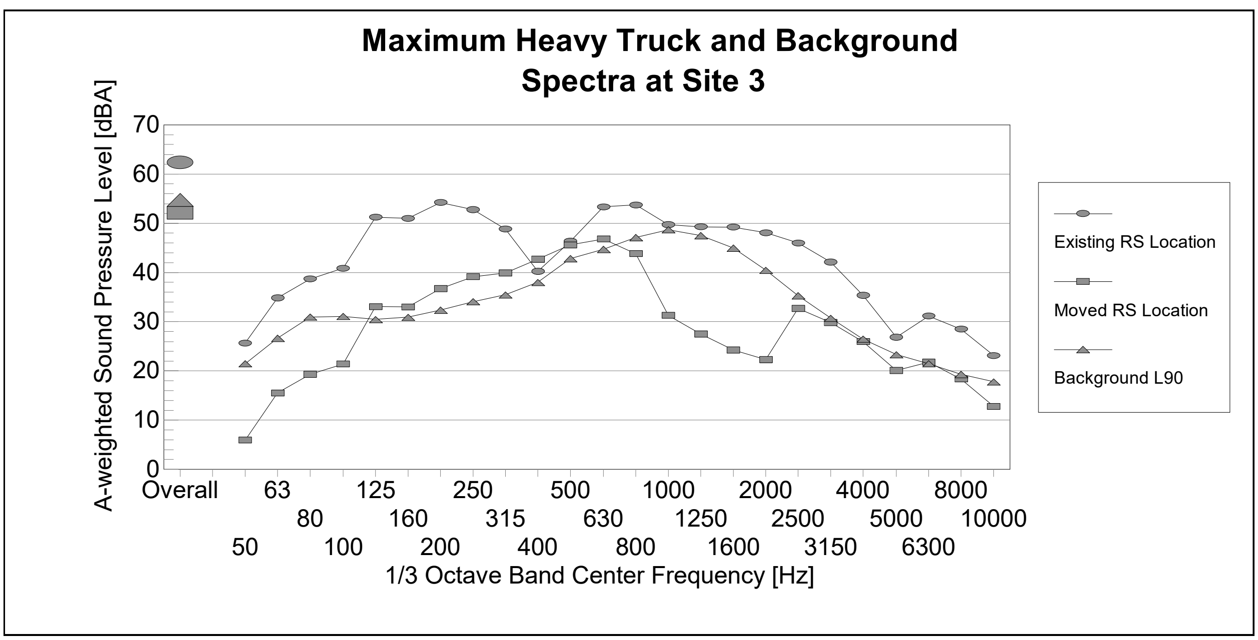


Figure 12. Maximum Heavy Truck Spectra with Existing and Relocated Rumble Strips, and Background Spectrum



7.2 Parapet along the Median

The other possible noise mitigation measure would be the installation of a 1.0-meter tall parapet along the median strip between the northbound and southbound lanes of I-87 adjacent to the existing rumble strips. This noise mitigation measure does not have an effect on the computed loudest-hour equivalent sound levels; however, a parapet along the median would have a small effect on the maximum sound levels due to vehicles on the rumble strips. Table 9 shows the maximum A-weighted sound levels for each vehicle type on the rumble strips both with and without a parapet. These results show that a parapet does affect the maximum pass-by sound levels of individual vehicles, although the effect would be barely noticeable. For all vehicle types, a parapet along the median would reduce maximum A-weighted sound levels by only 0 to 3 dB for vehicles in the middle lane of I-87 southbound. The noise reduction provided by a parapet along the median would vary for vehicles traveling in the other two lanes of I-87 southbound.

Table 9. Maximum A-weighted Sound Levels With and Without Parapet

Maximum A-weighted Pass-by Sound Levels With and Without Parapet						
	Automobile		Medium Truck		Heavy Truck	
Site	Without Parapet	With Parapet	Without Parapet	With Parapet	Without Parapet	With Parapet
1	56	53	64	62	63	62
2	56	55	64	64	63	63
3	54	53	64	62	62	62
4	47	47	57	56	53	53

Figures 13 and 14 show the maximum sound level spectra at Site 3 for automobiles and heavy trucks both with and without a parapet. These spectral graphs show that there would be a minimal benefit in the community with mitigation by means of a parapet. The audibility of the maximum rumble strip pass-by sound levels would be mostly unchanged. (See Appendix H for graphs of maximum rumble strip pass-by sound levels for all vehicle types and at all sites, with and without a parapet).

Figure 13. Maximum Automobile Spectra With and Without Parapet, and Background Spectrum

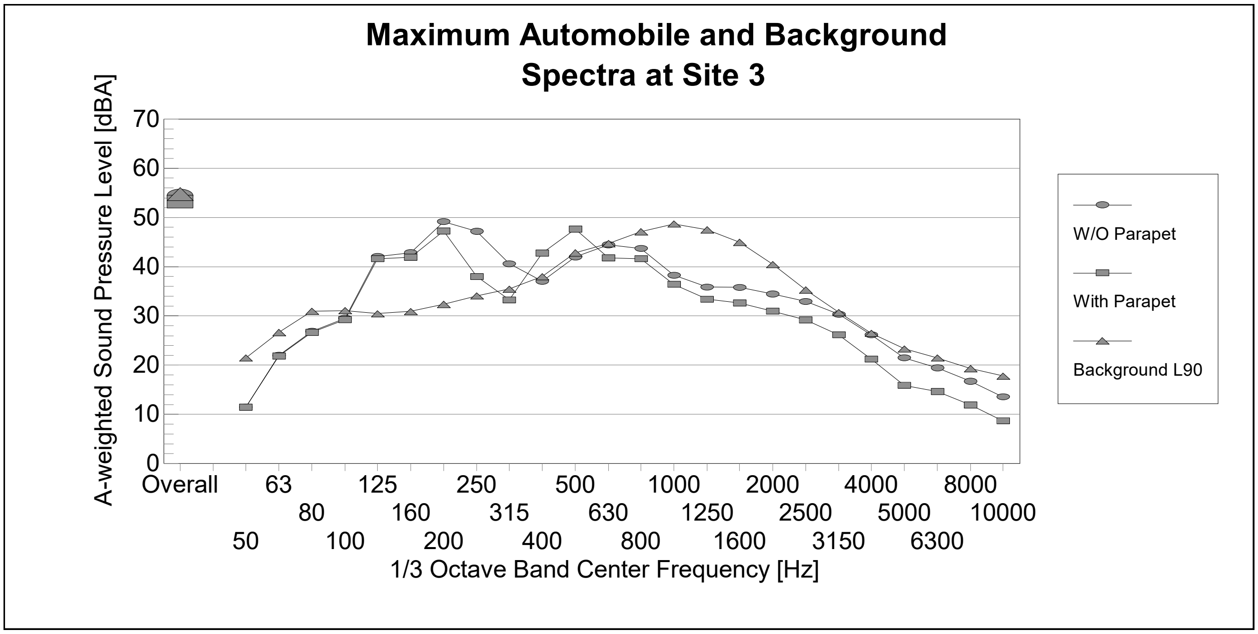
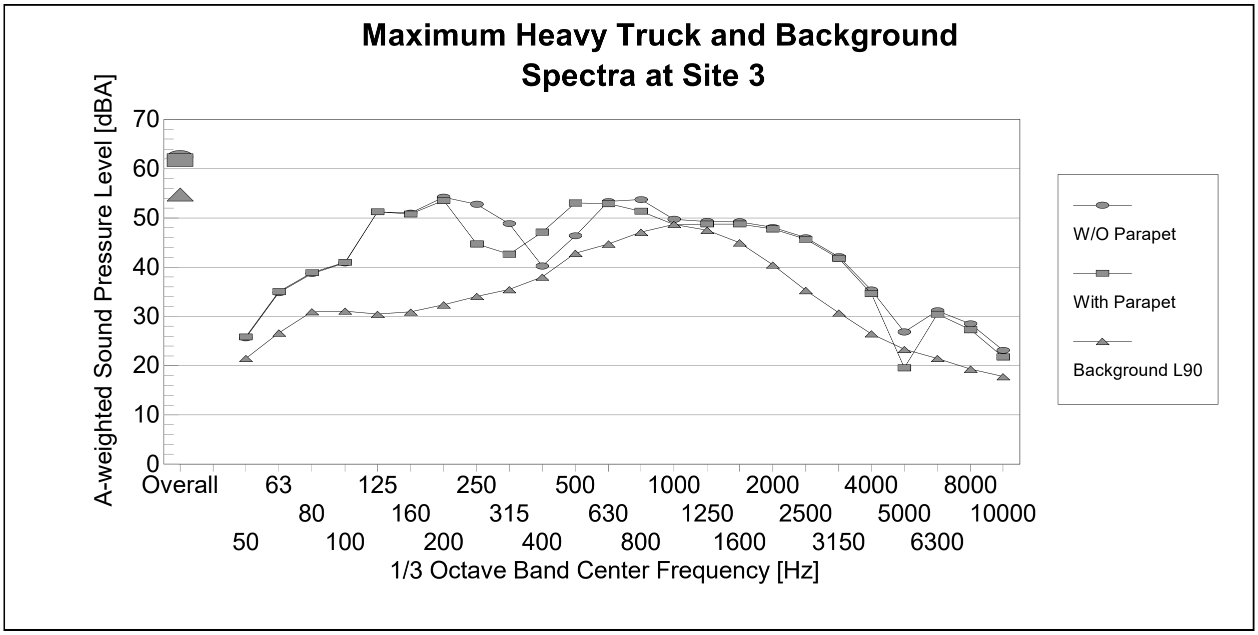


Figure 14. Maximum Heavy Truck Spectra With and Without Parapet, and Background Spectrum



References

[1] McFarland-Johnson, Inc., Bowlby & Associates, Inc., Konheim & Ketcham, Inc.. *Noise Barrier Planning Study NYSDOT Region 1 Toll-Free Limited-Access Highways (NY 85, I-/NY 87, I-88, I-90, I-787, I-890).* October 2000.

[2] Menge, Christopher W., Christopher F. Rossano, Grant S. Anderson, Christopher J. Bajdek, "FHWA Traffic Noise Model, Version 1.0: Technical Manual," Report No. FHWA-PD-96-010, February 1998.

Appendix A – Measured Sound Level Differences for 159 Vehicle Pass-bys on Rumble Strips and Standard Pavement

Appendix B – Close-in Spectra for Trucks on Rumble Strips and Standard Pavement

Appendix C – Photos of Community Sites and Measured Background Spectra

Appendix D – Loudest-Hour L_{Aeq1h} over Rumble Strips, With and Without Noise Barrier, and Background Spectra

Appendix E –Vehicle Pass-by Sound Levels, With and Without Rumble Strips, and Background Spectra

Appendix F –Vehicle Pass-by Sound Levels with Rumble Strips, With and Without Noise Barrier, and Background Spectra

Appendix G – Vehicle Pass-by Sound Levels over Existing and Relocated Rumble Strips, and Background Spectra

Appendix H –Vehicle Pass-by Sound Levels over Rumble Strips, With and Without Parapet, and Background Spectra

Rumble Strips: Effective Safety Measure or Just a Nuisance?

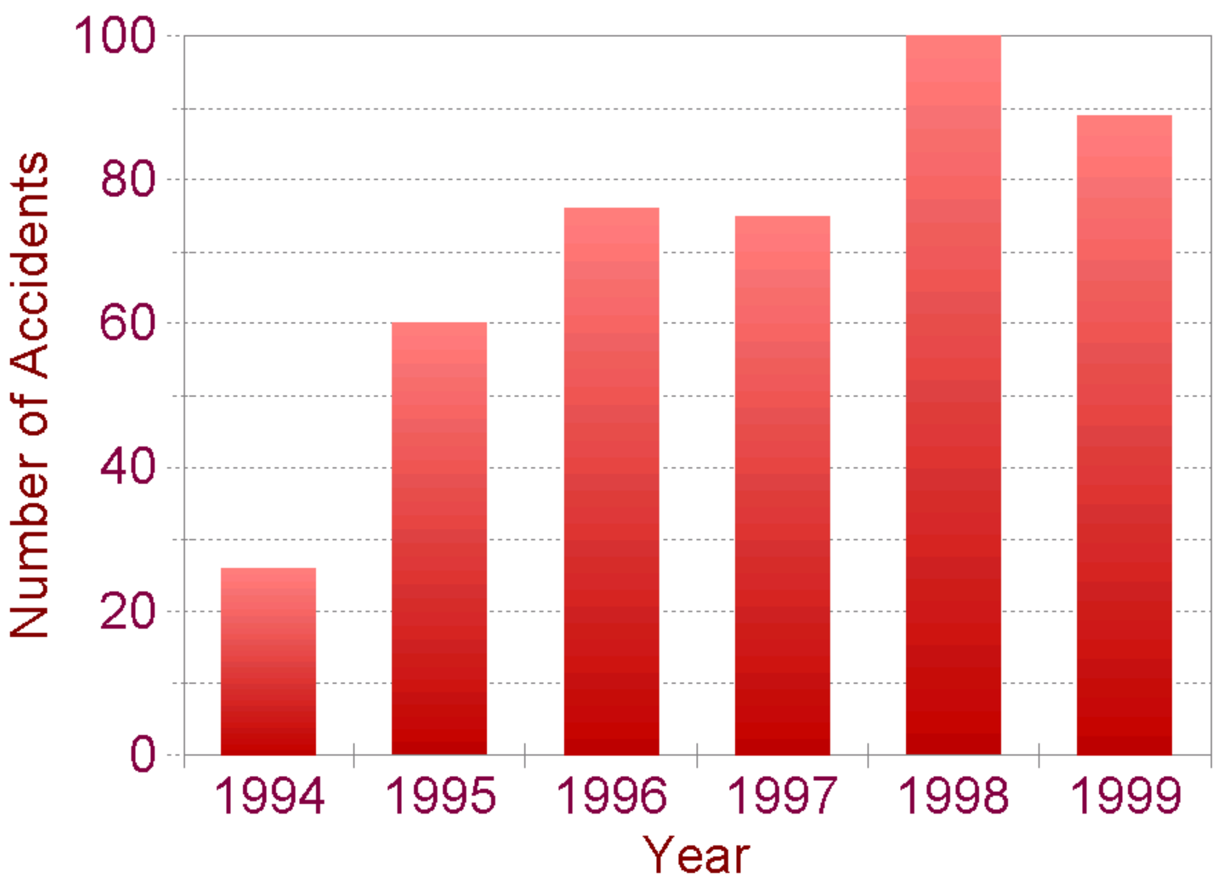
Christopher J. Bajdek and Jason C. Ross

Harris Miller Miller & Hanson Inc.

The Study Area

Accidents along I-87

http://www.hmmh.com/



Source: State information management system, as reported by Jill Bryce in the *Gazette Reporter*.

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Complaints from Community

http://www.hmmh.com/

Guilderland residents say rumble strips too loud

By JILL BRYCE
Gazette Reporter

GUILDERLAND — The rumble strips installed on the Northway near Crossgates Mall to decrease traffic speed and reduce accidents are creating so much noise, some residents are being kept awake at night.

McKownville area residents, particularly those on Warren, Mercer and Providence streets, have complained about the noise. They say it has seriously hampered their quality of life.

It has gotten so bad that Town Supervisor Kenneth Runion asked the state Department of Transportation to remove the strips. Runion said he has fielded about a dozen calls from residents.

"Our residents are unable to sleep at night due to the noise. They are also unable to open their windows due to the noise. Several residents have indicated the neighborhood is no longer habitable due to the noise," Runion wrote to DOT.

He visited the neighborhood and agrees with residents, noise from the rumble strips is unbearable. "In fact I tend to believe this intrusion could be considered a 'taking' by the state of New York of their properties," he said.

DOT regional engineer William Logan said when the rumble strips were put in, it was not known that there were homes nearby. He said the agency is very sensitive to the residents' complaints and the effectiveness of the strips in reducing speed and accidents is being evaluated.

"We want to evaluate the impact of these things. We cannot evaluate them until we go through the Christmas season, which is when most accidents occur. We have heard about complaints, we sympathize, but have to see if this works," he said.

An environmental consultant is beginning a noise analysis of the area. "We may reach a point that we find the rumble strips are very effective and then we will figure out what to do about the noise. If there is no difference in accidents, we will take them out."

Another option is to take the rumble strips out partially, off the thru lanes, but leave them on the exit ramp.

Accidents occur on the section of I-87 when motorists travel down the main lane and cut in at the last minute to get off at Crossgates, resulting in rear-enders.

Logan said about 100 accidents occur each year in the area and a high percentage involve teen-agers who drive over the crest at 60 mph, then must quickly slow down or stop.

The rumble strips installed by maintenance crews are grooves cut into the highway which create a noise when automobiles or trucks drive over them, similar to the ones on shoulders of many interstate highways.

At this point, it's not clear if the strips have reduced in speed, but Logan said he has seen motorists brake on the strips.

Chief James Murley said Friday the accident rate on the stretch of I-87 has increased in recent years since the Crossgates ramp exit was built. In 1994, it was 26 accidents; in 1995, 60 accidents; in 1996, 76 accidents; in 1997, 75 accidents; in 1998, 100 accidents; and in 1999, 89 accidents. Figures are from the state information management system.

He cited several reasons:

- Vehicles head south on the Northway and some, not as familiar with the exit, are in passing lanes and try to get over to the exit.
- Additionally, the traffic light on Ring Road, around the mall, changes to red and cars back up onto the Northway.
- Motorists getting off Thruway Exit 24 to get on the Northway and to Western Avenue also contribute to the congestion.

The rumble strips are the latest option being tested — The DOT has reduced the speed limit from 55 to 45 mph and installed flashing light boards on that section of road asking motorists to use alternate routes.

Overview of Noise Study

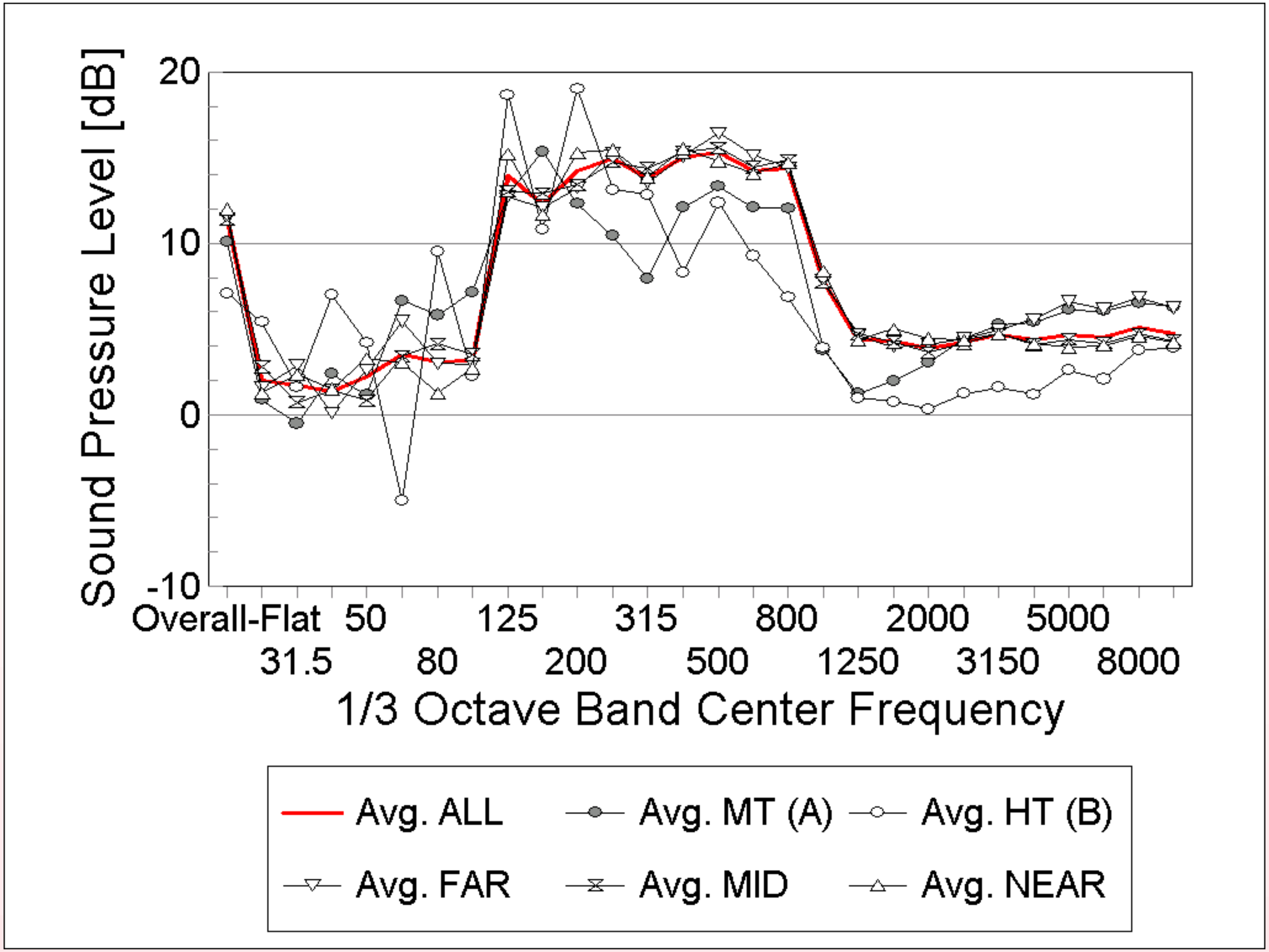
- **Evaluate the effect of rumble strip noise**
  - Noise measurements
    - Vehicle passbys
    - Background
  - Projections of rumble strip noise
    - TNM propagation algorithms
    - L_{Amax} in 1/3-octave bands
- **Evaluate three alternative abatement measures**
  - Barrier along right-of-way (northbound side)
  - Parapet along median
  - Relocation of rumble strips

What is a Rumble Strip?

A Closer Look at the Study Area

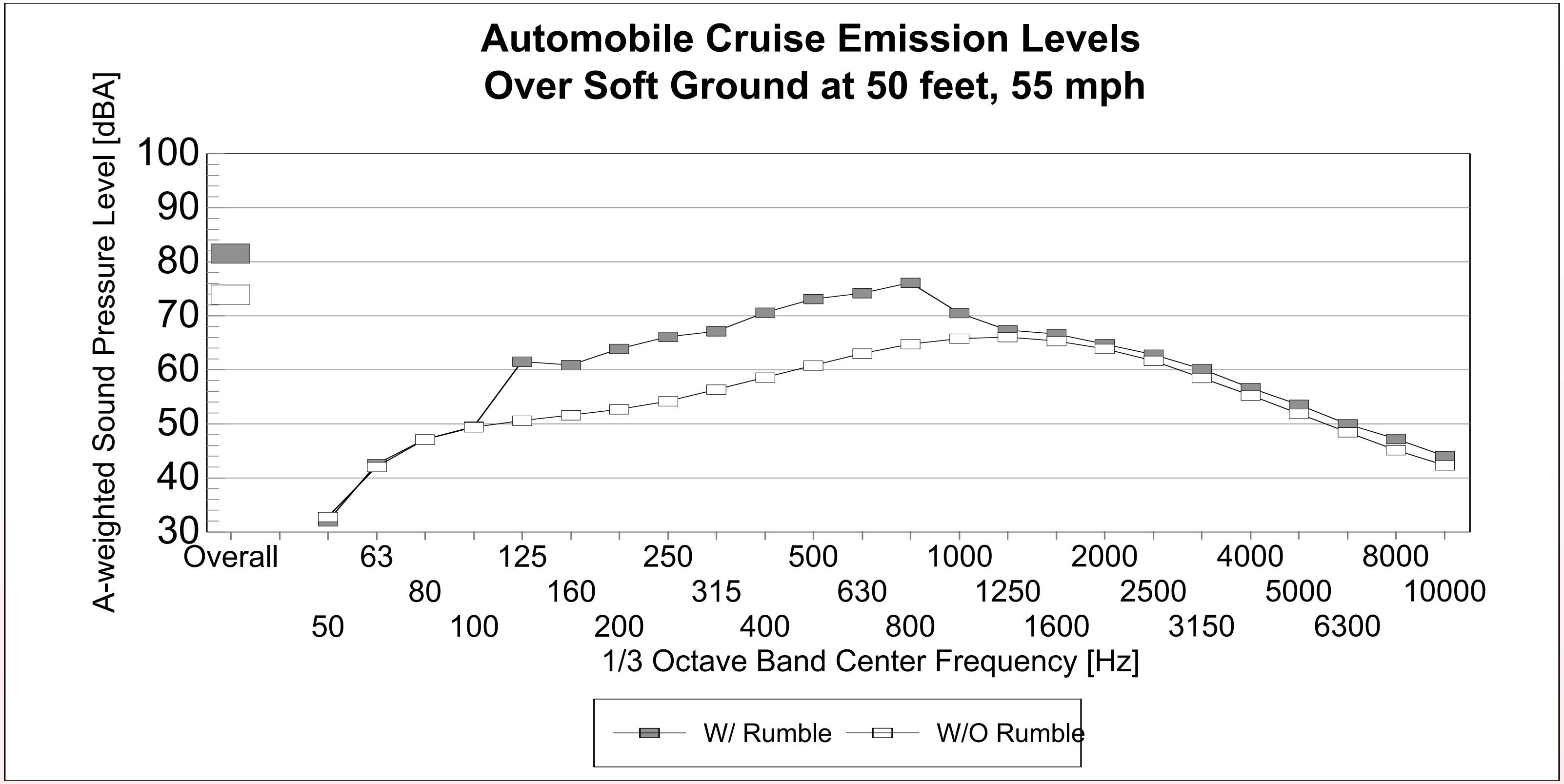
Close-in Measurements

Relative L_{max} for Vehicles on Rumble Strips



Reference Source Levels

http://www.hmmh.com/



Noise Model

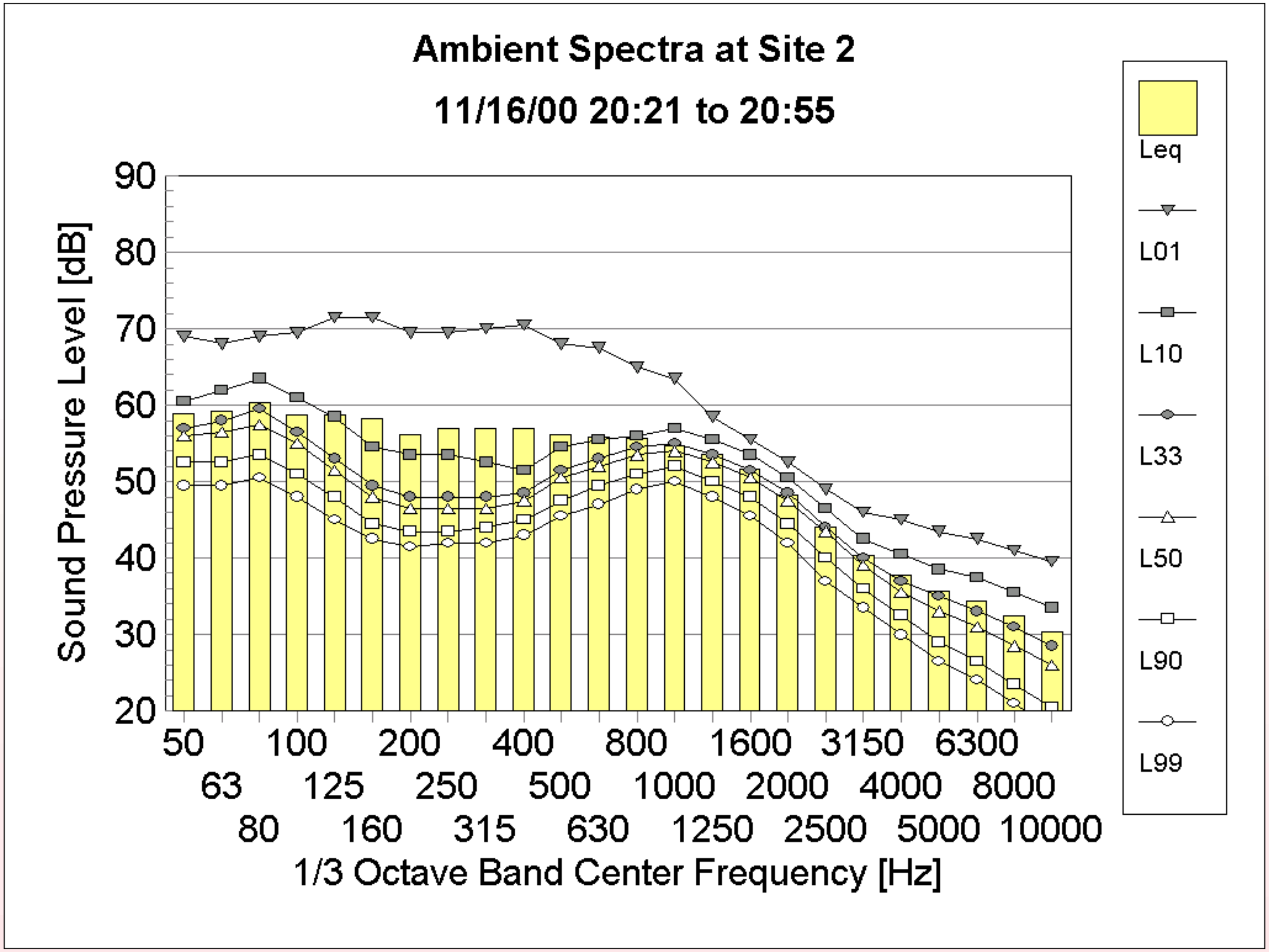
- **Equation for L_{Aeq1h}**
  - $L_{Aeq1h} = EL_i + A_{traff(i)} + A_d + A_s$
  - Where:
    - EL_i = free field emission level for vehicle i
    - $A_{traff(i)}$ = traffic flow adjustment
    - A_d = distance adjustment
    - A_s = attenuation due to ground, shielding, and atmosphere
- **Equation for L_{Amax}**
  - $L_{Amax} = EL_i + A_{distance(ss)} + A_s$
  - Where:
    - $A_{distance(ss)}$ = attenuation due to spherical spreading from omni-directional point surce

Computed L_{Amax} from Rumble Strip #1 minus Measured L_{90} at Community Locations

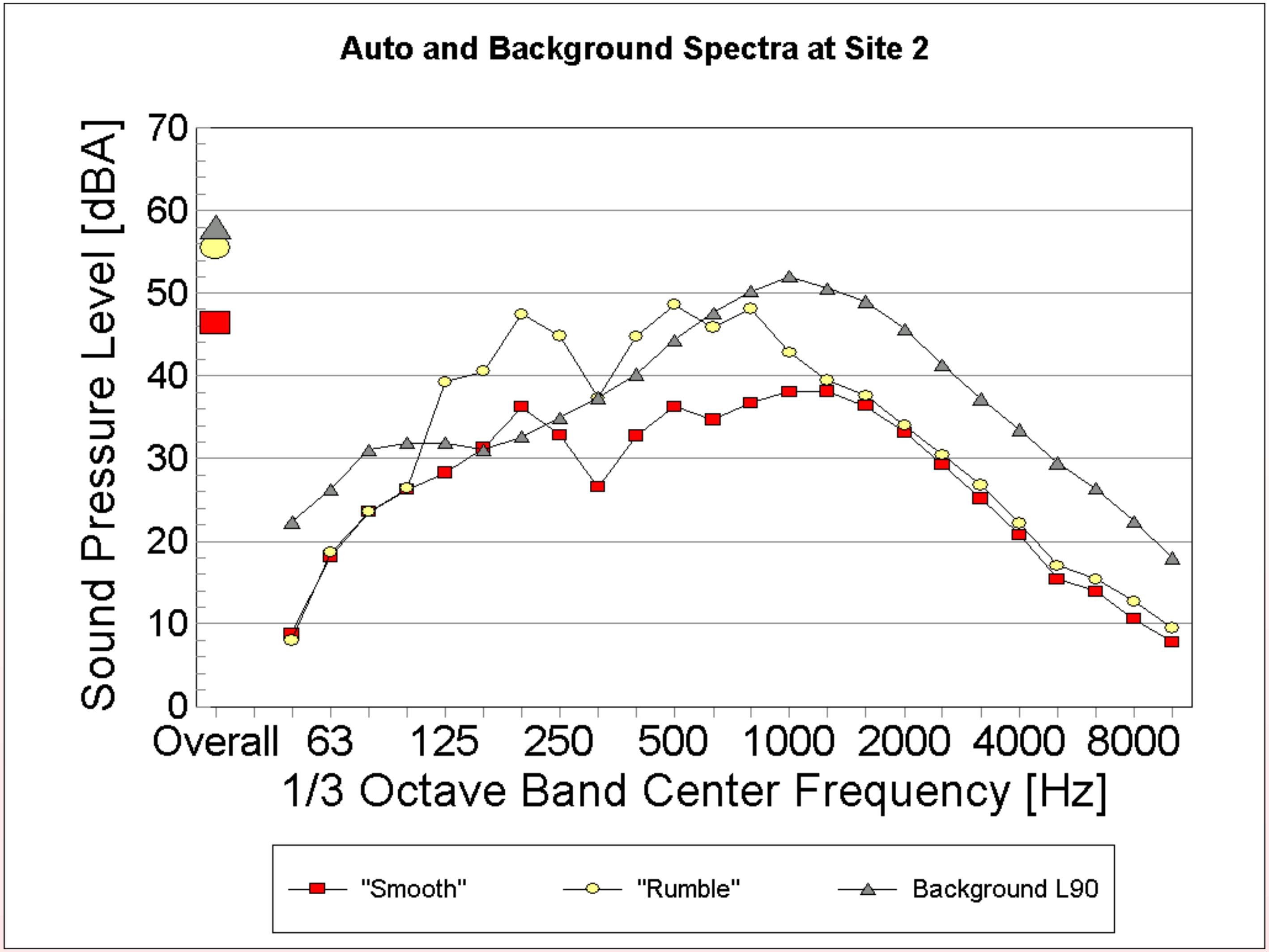
Site	Autos (dBA)		Medium Trucks (dBA)		Heavy Trucks (dBA)	
	Rumble Strip	Std. Pave.	Rumble Strip	Std. Pave.	Rumble Strip	Std. Pave.
1	-4	-14	+4	-7	+3	-6
2	-2	-12	+6	-4	+5	-2
3	-1	-10	+9	-1	+7	+2
4	-2	-12	+8	-3	+4	-1

Background Noise Levels at Site 2

http://www.hmmh.com/



Effect of Rumble Strip Noise at Site 2



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Noise Barrier along Right-Of-Way

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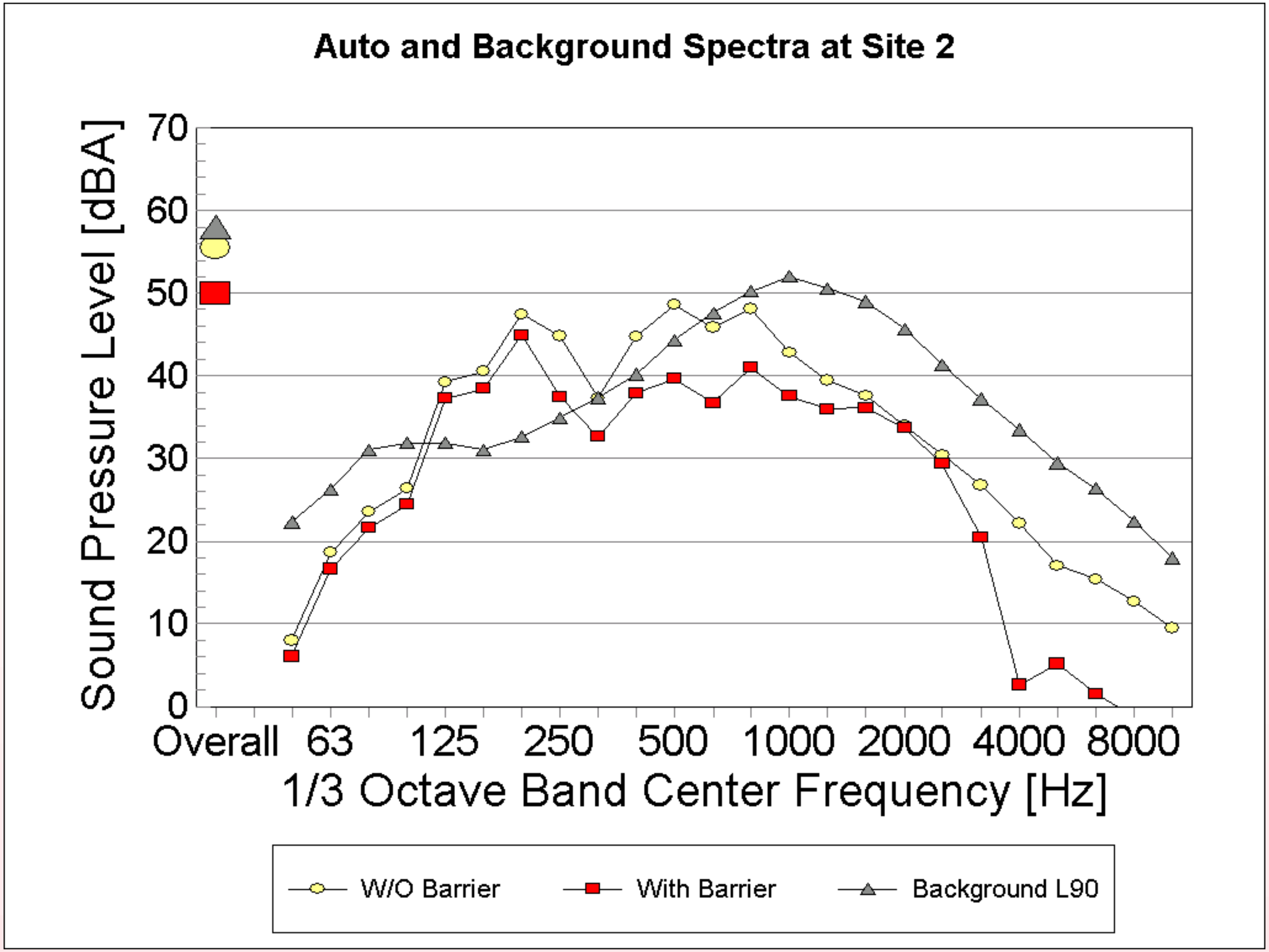
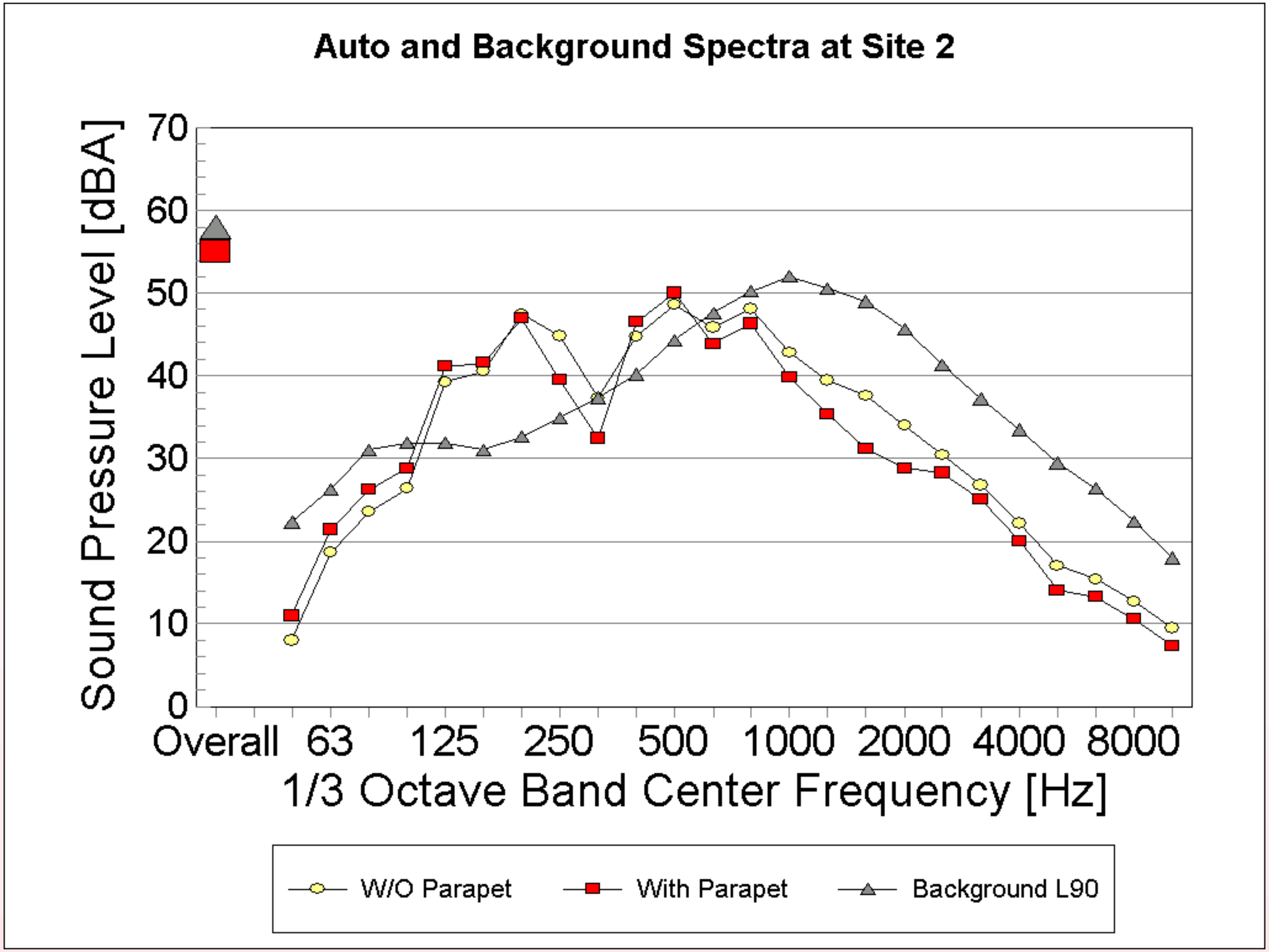


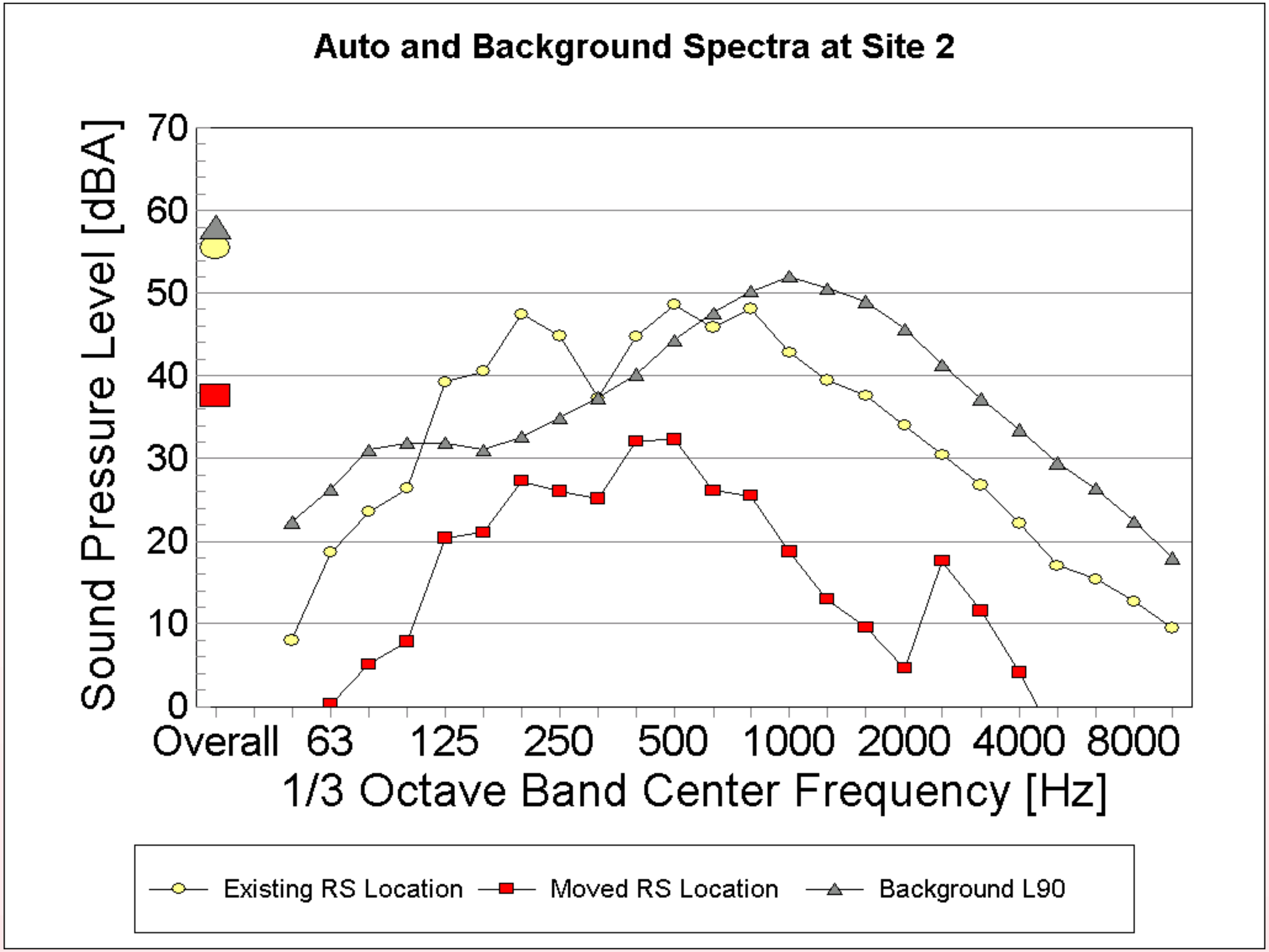
Parapet along Median

http://www.hmmh.com/



Relocation/Removal of 4 Southern Rumble Strips

http://www.hmmh.com/



Summary of Reductions in Vehicle Passby L_{Amax}

Abatement Measure	Range of Reductions in L_{Amax} in the Community
Noise Barrier along R-O-W	3 to 8 dB
Parapet along Median	0 to 3 dB
Relocation/Removal of 4 Southern Rumble Strips	8 to 18 dB

Closing Remarks and Acknowledgements

http://www.hmmh.com/

- **NYSDOT removed the 4 southern rumble strips**
- **Prior to NYSDOT action, community believed "it would not be enough"**
- **Safety issues are still a concern**
- Bill McColl at NYSDOT provided insight into safety issues

Centerline Rumble Strips

A Review of Residential Location Policies, Noise Issues, and Typical Designs
Literature Search & AASHTO RAC Responses

Contents

Summary of Findings

- A new NCHRP report, Guidance for the Design and Application of Shoulder and Centerline Rumble Strips, will contain much new information on this subject. The report will be published in late October or early November as NCHRP 641 (see http://144.171.11.40/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=458, for project info). We have, however received an advance copy of the report for our use. A full review of this report should wait until it is published, however, some important takeaways are listed below. These conclusions should not be forwarded or disseminated until the final report is published:
  - "... the safety benefits of centerline rumble strips on horizontal curves and tangents are similar. Thus, it is concluded that the safety effectiveness of centerline rumble strips is the same for both roadway alignments.
  - "Even though numerous studies have been conducted to investigate the optimum dimensions of rumble strips, there is no clear absolute answer to the issue. …In general, for milled rumble strips, wider and deeper cuts will generate higher levels of vibration and noise for all types of vehicles because of tire-drop capabilities; however, tire drop is dependent upon the properties of the tire, the speed of the vehicle, and the spacing of the cuts.
  - "Although the noise produced by shoulder and centerline rumble strips is intermittent, transportation agencies continue to receive complaints from nearby residents. To address these complaints, some agencies have increased the offset of the rumble strip from the edgeline to decrease the incidence of vehicles falsely traversing the rumble strips. Other transportation agencies have completed removed the rumble strips. Another alternative is to construct noise barriers. 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 (Bahar and Parkhill, 2005). A recent survey to determine the opinions of residents in areas where centerline rumble strips had been placed showed that the majority of residents find the external noise produced from centerline rumble strips acceptable or tolerable and that the potential driver safety outweighed the effect of the external noise (Gardner et al., 2006)."
  - "Most transportation agencies install centerline rumble strips within the boundaries of the centerline markings or a portion of the rumble strips may extend slightly into the travel lane. Only two transportation agencies install centerline rumble strips on either side of the centerline pavement markings"
  - Typical dimensions for milled centerline rumble strips are as follows:
    - Length: 12 or 16 in (305 to 406 mm)
    - Width: 7 in (178 mm)
    - Depth: 0.5 in (13 mm)
    - Spacing: 12 in (305 mm)
  - The report makes a recommendation for bicycle tolerable rumble strips as follows:
    - Width: 5 in (127 mm)
    - Depth: 0.375 in (10 mm)
    - Spacing: 11 or 12 in (280 or 305 mm)
- Michigan, Missouri, and Washington probably have the most experience with centerline rumble strips.
- All agree that nearby residential areas need to be taken into consideration when installing rumble strips, and some have prohibited by policy (written or unofficial) rumble strip installation near residential areas. Some consider centerline rumble strips as still experimental.
- So far no agency has reported a useful low noise rumble strip design or noise mitigation measures.
- One state policy is that rumble strips are not installed where posted speeds are less than 50 mph. It is thought that this provision avoids many residential areas.
- In one Michigan location, rumble strips were removed in 2009 because horse owners complained that horses do not like them. In that specific population, it was felt that a frightened horse

jumping into a travel lane poses more of a problem to passing motorists than an errant cross-over driver.

- There has been some concern that drivers who are familiar with edgeline rumble strips may automatically veer left, rather than right, when hitting a centerline rumble strip. This has been documented in a driving simulator, but not documented in the field. (See Kansas DOT/Kansas SU report cited below.) The new NCHRP report mentions this concern as well.
- A 2002 DelDOT study stated that "the use of CRS potentially transfers a head-on collision problem further down the roadway to locations without CRS".
- One state reports that resident's complaints about nearby rumble strips were reduced after law enforcement personnel strongly endorsed the rumble strips.
- The University of Minnesota completed a study on centerline rumble strips this past summer. The report, an Assessment of Centerline Rumble Strips in Minnesota, includes information on other states experiences with centerline rumble strips.
- MinnDOT is doing a noise study of rumble strips, which is to be completed this fall.
- A study in Denmark in 2007 found that sinusoidal rumble strips caused less noise than cylindrical indentations, by about 5 decibels.
- In 2001 Colorado DOT published a report on bicycle friendly rumble strips. The link to the report is below under State policies.

Sources

Assessment of Centerline Rumble Strips in Minnesota, Executive Summary and Project Task Summary Attachments,[(includes Attachments:A) Literature Review Results Summary, B) Winter Weather State Survey Results Summary, C) Data Summary and Evaluation Results Summary],

NCHRP 17-32 Guidance for the Design and Application of Shoulder and Centerline Rumble Strips
http://144.171.11.40/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=458

Transportation Research Board, NCHRP Synthesis 339, Centerline Rumble Strips, 2005.
http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_syn_339.pdf

FHWA: Low Cost Treatments for Horizontal Curve Safety CHAPTER 5. RUMBLE STRIPS
http://safety.fhwa.dot.gov/roadway_dept/horicurves/fhwasa07002/ch5.cfm

TX A&M: Positive Effects of Road Surface Discontinuities- Francesca La Torre
http://nautarch.tamu.edu/preview/ivey/SOARIChapter4.%20Positive%20Discontinuities.Revision020408.doc

Swedish National Road and Transport Research Institute, (VTI): Road users' opinion about rumble strips in the centre of 2-lane roads – Discussion within focus groups with motorcyclists and commuters, and road side interviews.http://www.vti.se/templates/Report____2797.aspx?reportid=11053

Influence of Roadway Surface Discontinuities on Safety State of the Art Report Sponsored by the Surface Properties–Vehicle Interaction Committee, Transportation Research Board, May 2009
http://roads.dicea.unifi.it/TRB/final%20report_ec134.pdf

"THE EFFECT OF RUMBLE STRIPS ON EXTERIOR NOISE
A key disadvantage of rumble strips is the noise generated outside the vehicle. This can be disturbing to the inhabitants surrounding the road infrastructures. Two studies have recently been published, (one based on a United States experience (*see Finley TRB report*), and one based on a Danish experience (*see Kragh report*). Both investigate the influence of different rumble strip designs on exterior noise. (Kragh et al.) shows that a change in the rumble strip design can seriously affect the noise levels measured at 25 m from the travelled lane. When a sinusoidal

indentation is used only a 0.5–1 dB increase in the noise level is expected as compared to a "rectangular" indentation that can produce 3–7 dB higher noise levels. Much higher noise level increases have been found by Finley and Miles (*13*). They show noise levels that increase from 4–5 dB (when using "button rumble strips") to 19 dB when milled rumble strips with 12-inch spacing are considered. Noise is an issue in some urban areas. Even high macrotexture pavements are apparently an issue due to higher noise, and high textures have long been encouraged from a tire–pavement friction perspective. All noise/vibration guidance methods, generally reduce accident rates and are considered good practice where environmental issues related to increased noise are not determining factors."

Finley, M. D., and J. D. Miles. Exterior Noise Created by Vehicles Traveling Over Rumble Strips. Presented at the 86th Annual Meeting of the Transportation Research Board, Washington, D.C., 2007.

"Researchers measured the exterior noise produced by two types of vehicles traveling over five types of rumble strip applications at two different speeds."

"Overall, rumble strips do increase the exterior noise level. Thus, practitioners should consider the impact on the public living and working near roadways before installing rumble strips. Based on the findings included herein, practitioners should specifically consider the rumble strip application, pavement type, rumble strip width, and rumble strip spacing. Researchers recommend that future research projects investigate the following:

1. frequency of hits received and the duration of these events for various types and applications of rumble strips, and

2. minimum sound thresholds in the surrounding environment required before alternatives need to be considered."

Finley, M. D., and J. D. Miles. Evaluation of Factors that Impact the Effectiveness of Rumble Strip Design, Presented at the 86th Annual Meeting of the Transportation Research Board, Washington, D.C., 2007.

- Regarding rumble strip dimensions (e.g., width, spacing, length, and depth/height): "Each dimension plays a specific roll in generating sound when traversed by vehicle tires, and the current standard rumble strip design is the only one proven to provide adequate increases in sound to alert all drivers."

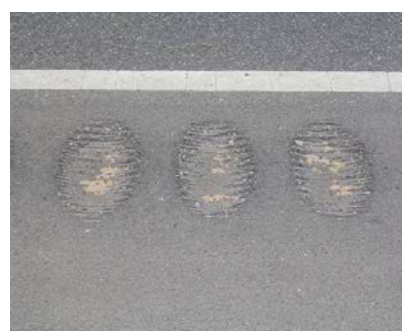
- "Only the milled rumble strip applications 12 inches or wider provided enough sound increase to alert drivers of commercial vehicles."

Kragh, J., B. Andersen, and S. Thomsen. Low Noise Rumble Strips on Roads—A Pilot Study. Proceeding of the Internoise 2007 Conference, Istanbul, Turkey, Aug. 28–31, 2007.

"Rectangular indentations gave rise ti su=ignificantly higher noise levels (3-7 dB higher) than the rumble strips with a sinusoidal profile as well as significantly higher noise levels (2-5 dB higher) than the "cylinder segment" strip."

KansasDOT & Kansas State University, Comparison of Football Shaped Rumble Strips versus Rectangular Rumble Strips, September 2007:

http://www.ksdot.org/PublicLib/doccontent.dll?LibraryName=PublicDocs^dt00mx38&SystemType=2&LogonId=78e1040688da53bb2c0865c434a8ead0&DocId=003759829



"2.3.3 Concerns Stemming from Centerline Rumble Strips
One of the concerns with the use of CRS (and inside SRS on divided highways) is a driver's expectancies derived from previous experiences with SRS (Noyce et al., 2003, 2004). Because of this expectancy, driver's subconscious reaction to an unexpected encounter with SRS is to correct the trajectory of the vehicle by turning left, away from the SRS. Drivers who encounter a CRS, and are unaware of their lane position, may assume that they are encountering a SRS and reactively turn left (Noyce et al., 2003, 2004).

In Noyce and Elango's study (2003, 2004), a driving simulator was used to determine the safety of drivers when crossing the centerline rumble strips and the possibility of correcting steering in the wrong direction, i.e., further into the oncoming traffic lane. The results of the analysis found that drivers took more time to return to the travel lane when CRS were present as compared to when CRS were not present. Also, drivers reacted to and corrected the

vehicle trajectory more quickly with CRS than SRS. However, 27% of the drivers made an initial leftward correction of the vehicle when
encountering CRS (Noyce et al., 2003, Noyce et al., 2004). No improper or rightward corrections were made with the SRS. As with SRS, there is the concern of noise and the impact on the environment. Always consider potential noise impacts when contemplating an installation of centerline rumble strips in residential and urban areas, and do not install them on bridges (Hood, 2002). Along with the noise concern, DelDOT (2002) states that the use of CRS potentially transfers a head-on collision problem further down the roadway to locations without CRS."

Michigan: *Rumble strips removed after the Amish say they're dangerous,* August 20, 2009
http://www.wwmt.com/articles/rumble-1366086-joseph-0in.html

Links to State Policies

Colorado: (Report on Bicycle friendly rumble strips)
http://www.dot.state.co.us/publications/Bicycle%20Friendly/Rumble%20Strip%20PDF.htm

Missouri DOT: http://epg.modot.org/index.php?title=Category:626_Rumble_Strips

Delaware DOT: http://www.deldot.gov/information/pubs_forms/manuals/dgm/pdf/memo_1-18_rumble_strips.pdf

Washington DOT: http://www.wsdot.wa.gov/Design/Policy/RumbleStrips.htm

Guidance on when to use rumble strips, section 1600.07 of chapter 1600 of the Design Manual:
http://www.wsdot.wa.gov/Publications/Manuals/M22-01.htm#Individualchapters

Dimensional details, on rumble strip patterns, Standard Plans M-60 & M-65:
http://www.wsdot.wa.gov/publications/fulltext/Standards/4_09StdPlanmanual.pdf

Minnesota DOT:
http://www.dot.state.mn.us/trafficeng/safety/rumble/Centerline%20Rumble%20Strip%20Guidelines.doc

Michigan DOT: http://www.michigan.gov/mdot/0,1607,7-151--191394--,00.html

Oklahoma DOT: http://www.okladot.state.ok.us/oshsp/pdfs/ld-shouldertreatments.pdf

Alaska DOT:
http://www.dot.state.ak.us/stwddes/dcspubs/assets/pdf/directives/053001att_rumblepolicy.pdf

Illinois DOT: http://www.dot.state.il.us/safetyEng/Appendix%20E.pdf

"Centerline rumble strips are considered experimental."

DC DOT:
http://ddot.dc.gov/ddot/frames.asp?doc=/ddot/lib/ddot/information/studies/awi/standards/AWI_Ch4-02_E_PedTraffSafety_S.pdf

"Restrictions: Rumble strips should not be implemented in neighborhoods because of the noise created. Nor should they be used in bike lanes."

Ohio DOT:

http://www.dot.state.oh.us/Divisions/HighwayOps/Traffic/publications2/TEM/Documents/Part_14/Part_14_complete_072007.pdf

Appendix A

Seattle Times Article Sept. 18, 2009

Originally published Friday, September 18, 2009 at 1:29 PM

State report: "Rumble strips" on state highways cut accidents by nearly 60 percent

An analysis of state highways has found that centerline rumble strips, the grooves cut into pavement on 2,000 miles of the state's two-lane highways, has reduced serious injury and fatal crossover collisions by 57 percent.

By Susan Gilmore
Seattle Times staff reporter

An analysis of state highways has found that centerline rumble strips, the grooves cut into pavement on 2,000 miles of the state's two-lane highways, has reduced serious injury and fatal crossover collisions by 57 percent.

The reported is included in the latest Gray Notebook, a quarterly update provided by the state Department of Transportation.

It found that the rumble strips, which have been in place since 1995, is most effective when the driver is tired or distracted and his car drifts over the center line.

Today the state has strips on 38 percent Washington's 5,250 miles of two-lane highways, said Jason Nye, with the DOT. They aren't on any freeways.

The state is installing another 650 miles of them.

According to the state study, the rumble strips show a 24 percent reduction in serious and fatal injury collisions on curves and a 52 percent reduction of accidents on straight roadways.

The state analyzed more than 6,800 police collision reports from 2002 through 2008 where rumble strips have been installed. It showed a 58 percent reduction in accidents where the driver was tired, a 59 percent reduction where the driver was distracted, a 45 percent reduction where the driver was speeding and a 43 percent reduction where the driver was intoxicated.

In other findings:

• The number of median collisions grew between 1995 and 2008, but serious injuries dropped by 59 percent and fatal collisions by 25 percent.

• The 522 traffic fatalities last year were the fewest since 1955, when there were 461.

For 2008, the miles traveled on state highways decreased about 3.8 percent from 2007, which may have contributed to the lower fatality rate, said the DOT. Over the past 18 years, the fatality rate on all Washington roads — state, city and county — has decreased 49 percent.

Washington is third highest in the nation in seat belt use.

The state's fatality rate is nine fatalities per 100,000 people, far below the national average of 14.

• During the first half of 2009, travel times during peak periods improved on 13 of 18 commuter routs in the Seattle area. The DOT attributes this to unemployment due to the economic recession.

Susan Gilmore: 206-464-2054 or sgilmore@seattletimes.com

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These things saved my life many times 14 years ago in NJ coming home late at night after work and they continue to be an invaluable addition to... Posted on September 18, 2009 at 2:23 PM by Hyperbole Much?. Jump to comment

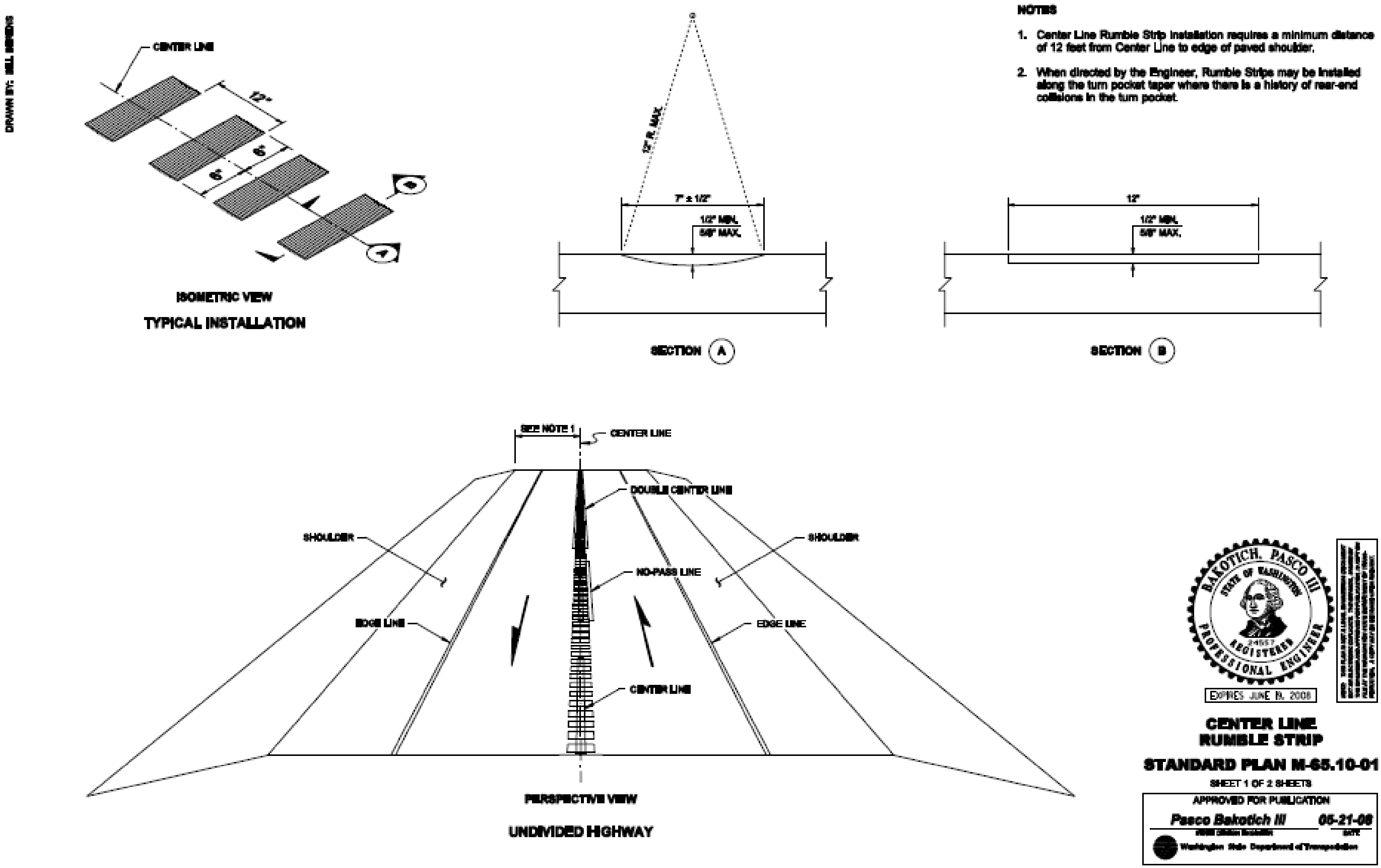
i love these things, i have fallen asleep twice and those things saved my life Posted on September 18, 2009 at 1:52 PM by Johnny Wang. Jump to comment

i cannot tell a lie. those things probably saved my life one night, but in that vein, wgaf about me at that point? the life it probably saved... Posted on September 18, 2009 at 3:24 PM by davidfelder. Jump to comment

Read all comments / Share your thoughts

Centerline Rumble Strips

Washington DOT Details



Centerline Rumble Strips

Washington DOT Policy

(c) **Centerline Rumble Strips**

Centerline rumble strips are placed on the centerline of undivided highways to alert drivers that they are entering the opposing lane. They are applied as a countermeasure for crossover collisions. Centerline rumble strips are installed with no differentiation between passing permitted and no passing areas. Refresh pavement markings when removed by centerline rumble strips.

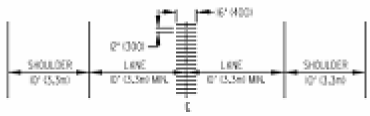
Drivers tend to move to the right to avoid driving on centerline rumble strips. Narrow lane and shoulder widths may lead to dropping a tire off the pavement when drivers have shifted their travel path. Centerline rumble strips are inappropriate when the combined lane and shoulder widths in each direction are less than twelve feet. (See Chapters 1130 and 1140 for guidance on lane and shoulder width.) Consider short sections of roadway that are below this width when they are added for route continuity.

Apply the following criteria when evaluating the appropriateness of centerline rumble strips:

- An engineering analysis indicates a crossover collision history with collisions considered correctable by centerline rumble strips. Review the collision history to determine the frequency of collisions with contributing circumstances such as inattention, apparently fatigued, apparently asleep, over the centerline, or on the wrong side of the road.
- Centerline rumble strips are most appropriate on rural roads, but with special consideration may also be appropriate for urban roads. Some concerns specific to urban areas are noise in densely populated areas, the frequent need to interrupt the rumble strip pattern to accommodate left-turning vehicles, and a reduced effectiveness at lower speeds (35 mph and below).
- Ensure the roadway pavement is structurally adequate to support milled rumble strips. Consult the Region Materials Engineer to verify pavement adequacies.
- Centerline rumble strips are not appropriate where two-way left-turn lanes exist.

Appendix B- AASHTO RAC Responses

MO	In Missouri we have been using the centerline and edgeline rumble stripes on our major roads for several years now. We have not had significant noise issues in residential areas. This is due to our guidelines where we do not install the rumblestripes, either centerline or edgeline, on roads where the posted speed limit is less than 50 mph. Typically where the speed limits are less than 50 are the cities and small communities where most of the residential is located. We decided on these guidelines early in the process to try and avoid excessive noise complaints where there could be residential areas. http://epg.modot.org/index.php?title=Category:626_Rumble_Strips	Jim.Brocksmith@modot.mo.gov
SK	In the Province of Saskatchewan the Ministry of Highways and Infrastructure does not place rumble strips or centreline rumble strips in close proximity to rural areas because of previous noise complaints from occupants from adjacent urban dwellings. Centreline and shoulderline rumble strips are placed on section of highway in rural areas for enhanced safety reasons	Ron.Gerbrandt@gov.sk.ca
IA	We have only installed center line rumble strips on one section of rural roadway which had a very high number of cross center line crashes. As such , even though some local residents do not like them they understand why we installed them and have accepted them. We will only be installing future center line rumble strips on about the 250 miles of roadways with the highest density of cross center line head on crashes. We will stop the installation on a particular road as we approach a community or large residential development . Michigan, Washington and Missouri have 1,000 's of miles of center line rumble strips . They could best answer you question . Could you please send me a summary of your findings so I can share with the DOT safety engineers in other states .	Tom.Welch@dot.iowa.gov
GA	We have had a limited number of complaints on the centerline rumble strips that we have installed. The majority of citizens accepted our explanation that they were safety and the only reason anyone would be on them is if they were outside their lane. We have had a few citizens that have been persistent and even had OEL do a noise evaluation in one area. The numbers did not turn out to be significant. We are sensitive to residential areas in the selection and installation.	Geary, Georgene ggeary@dot.ga.gov
DEL	We have had centerline rumble strips on a several mile stretch of US 301 since the late 90's and noise/complaints have not been an issue as there is little density of residential housing right along the corridor. The section for these is below.	Weber Donald (DelDOT) [Don.Weber@state.de.us]

<table>
<tr><td></td><td>


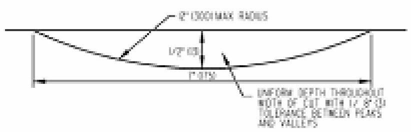
PLAN
FIGURE 2
CENTERLINE RUMBLE STRIP DETAILS
N.T.S


FIGURE 3
RUMBLE STRIP SECTION
We have had some issues/complaints with transverse rumble strips that have been used in several locations in our state where there are houses nearby. These typically are a double layer of thermoplastic. We have not yet come up with a better alternative or design for these and have kept them in place. Tom Meyer could provide a little more detail on that.

Working with our biking community we have installed several miles of edge line rumble strips along SR 1 in our beach/resort areas. During the peak season there is heavy bicycle use of the shoulders and there are sections where these are located adjacent to homes. We have not had complaints raised about noise and I can't say if that is because of the population being more transient than permanent or that the profile has mitigated for some of the noise. I know they do not feel as severe when you drive onto them (as what is along our US 301 section). A detail for these is at the following link.

http://deldot.gov/information/media_gallery/2008/rumblestrips/SR1_RumbleStrips_Details1.pdf
</td><td></td></tr>
<tr><td>ID</td><td>Idaho has installed several miles of centerline rumble strips, but none in an urban environment so the noise has not been an issue for us.</td><td>Brent.Jennings@itd.idaho.gov</td></tr>
<tr><td>MA</td><td>A number of years back, we had installed centerline rumble strips on three roads. Unfortunately, we have no conclusive data and, due to miscommunication and maintenance issues, two of the installations were removed.</td><td>Bonnie.Polin@state.ma.us</td></tr>
<tr><td>NH</td><td>We've experienced the same issue on some of our highways. A research project was suggested and funded about a year and a half ago to look at alternative design details but the project has not moved forward, partly because we're uneasy about the whole safety vs. noise complaint debate. We've decided to take a wait-and-see approach, trying to gauge how big of an issue this is for our front office (have complaints died down?) while also monitoring any work being done by others.</td><td>Glenn Roberts [GRoberts@dot.state.nh.us]</td></tr>
</table>

	In case you wanted a little more background about how centerline rumble strips (CLRS) became an issue in NH, I figure I would add to what Glenn said. We have had a section or two of CLRS along NH Route 16 in the Milton area for about 5 years or more. This roadway had a high crossover crash rate, which prompted the CLRS installation. When they were first put in we received a few noise complaints, but these complaints quickly died down. About 3 years ago we installed another section along NH Route 9 in Henniker and Hopkinton. The difference here was the CLRS were installed through designated passing zones. This prompted a substantial number of complains from people living in the areas of the passing zones. Their concerns were mainly that the rumble strip noise caused by passing cars is not constant, and therefore more annoying. They also indicated that passing was more frequent at night when traffic volumes are lower. These complaints have slowly started to die down, particularly given the obvious safety benefits. If I remember correctly, this summer we actually repaved this section of road and before the rumble strips could be reinstalled, we had our first crossover fatality (or serious injury?) on NH Route 9 in a long time. I think this solidified our safety arguments in the public's eyes and as a result we haven't heard much from them lately. My research proposal a few years ago was to study some alternative designs (rumble strip patterns, shapes, etc.) which might still alert drivers just as effectively but would not produce as much unwanted noise to the surrounding properties. My thought is that the noise problem has as much to do with frequency as actual noise levels. If you break up the "pattern" of the strips by skipping a strip here and there or varying the distance between each strip, the frequency might not emanate from the road as well, but would still alert the driver as effectively as the existing design. This would hopefully give us an alternative CLRS design which could be used in residential areas to help placate public concerns. Unfortunately we haven't had much upper management support for this research (particularly since complaints have died down for now). As a result, as Glenn indicated, we are in a "wait and see" holding pattern. I did discuss the proposal with Mark Ferroni from the FHWA Resource Center a few years ago and he indicated that this issue is something that had come up in several other states (I believe maybe Minnesota, Iowa and New York). He indicated that several years ago they had tried to produce an NCHRP research proposal similar to ours but that it never came to fruition due to lack of support. He felt it might mean more coming from a state agency rather than FHWA. I may attempt to submit an NCHRP proposal sometime in the future, but I will first need to get some more support in our Department. My only suggestion to you is that you be very careful in maintaining passing zones through areas with rumble strips and nearby residences. As Glenn said, we are definitely interested to see the results of your inquiry. Hopefully this helps. Please let me know if you have any questions. -Jon	Jonathan Evans [JEvans@dot.state.nh.us]
	We have installed centerline rumble strips (CRS) recently in areas where there were a number of head on fatals. There was an outcry from residents	Craig Green [CGreen@dot.state.nh.

	that could hear traffic crossing the rumble strips, however the law enforcement officers strongly supported the CRS and there hasn't been a lot of opposition since.	us]
IN	We have not used centerline rumble strips on any state highways, so I think we have nothing to offer in the way of comments.	Nantung, Tommy [TNANTUNG@indot.IN.gov]
NV	Nevada has not installed rumble strips in residential areas or deployed any noise mitigation measures.	Moore, Tom [tmoore@dot.state.nv.us]
MT	To date the Montana Department of Transportation (MDT) has installed centerline rumble strips at only two locations, neither of which is near residential areas. We have installed shoulder rumble strips on the majority of our Interstate system and on all applicable projects on the other state systems. In general, MDT's policy is to install rumble strips on any roadway having shoulder widths 4 feet or greater. We do make some exceptions for roadways that have shoulder widths of 4 feet and some documentation of significant bicycle usage - the documentation and the quantification of "significant" are fairly subjective at this point. We have limited the installation of rumble strips near residential areas on a project-by-project basis. However, we have not established any guidelines such as distance from residences, density of development or traffic volumes. We haven't done any noise mitigation for rumble strips either. If I can provide any additional information please contact me at 406-444-6244 or email - pferry@mt.gov	Ferry, Paul [pferry@mt.gov]
MN	Here is a final report on CLR we completed with the U of MN this summer. There is some discussion on noise. The Draft NCHRP Project 17-32 report does proposes CLRS designs that produce a smaller sound level differences. The draft report also provides models that will predict the sound level differences that result from various rumble strip designs. The factors that are needed to use the models include the rumble strip dimensions, vehicle speed, angle of departure, pavement type, pavement condition (i.e., wet or dry), rumble strip type, and location. Brad Estochen from my office is conducting a noise study of rumble strips. It should be completed sometime this fall. I'll ask him to send you a copy of that report too.	Susan Groth [Sue.Groth@dot.state.mn.us]
AK	I have cc'd Alaska's central region traffic engineer, Scott Thomas, because he is responsible for the majority of Alaska's rumble strips. I have attached Scott's recent presentation on rumble strips, which was well-received by the AK Motorcycle Safety Advisory Committee (AMSAC). AMSAC does not have a problem with these rumble strips, partially because the strips are not imbedded too deeply into the pavement.	Cashen, Cindy L (DOT) [cindy.cashen@alaska.gov]
MD	Typically, the Maryland State Highway Administration will not place rumble strips within residential areas because of the noise issues. We have on occasion placed them near some houses in rural areas, but the residents are usually understanding regarding the safety benefits to a point where noise is	Eric Tabacek [ETabacek@sha.state.md.us]

	not an issue for them.	
FI	Florida does not use centerline rumble strips but do use rumble strips on the shoulder next to the edge of pavement on freeways. They are designed to create an 80 dB(A) level in the cabin of a truck. We have not done research on them	Dockstader, Darryll [Darryll.Dockstader@dot.state.fl.us]
CN	On behalf of the Connecticut Department of Transportation, in response to your question regarding rumble strips. We only install rumble strips in the shoulder pavement on the limited access highways. The actual rumble strip is offset from the edge of travel (location of line stripe) by 6 inches for the left shoulder and 12 inches in the right shoulder respectively. Back in 1999 the Department did install centerline rumble strip for a short section of Route 6 in the Town of Bolton (see attached picture) at the request of a state legislator. The rumble strip was modeled after those used in the State of Maryland at the time. These centerline rumble strips were removed after a year due to numerous noise complaints from residents within a two mile radius of them.  	Kilpatrick, David J [David.Kilpatrick@ct.gov]
BC	The BC Ministry of Transportation uses centreline rumble strips in no passing zones in rural areas. Shoulder rumble strips are also typically installed on rural highways. Rumble strips are typically installed on new highway sections or when a re-paving or rehabilitating an existing section of highway. Section 650 of the 2007 BC Supplement to TAC Geometric Design Guide contains further details on installation considerations and rumble strip design/layout. http://www.th.gov.bc.ca/publications/eng_publications/geomet/TAC/TAC.htm#first	Hardy, Jennifer L TRAN:EX [Jennifer.L.Hardy@gov.bc.ca]

	There have not been issues regarding noise complaints. However, the strips are only installed in rural areas and breaks are provided in the strips across any private driveway accesses.	
OH	Ohio does not use centerline rumble strips. Let me know if you need anything else.	Michael.Bline@dot.state.oh.us
NY	New York installed centerline rumble strips at three locations as an exploratory effort about four years ago. We have not received much positive or negative feedback or accident information from those installations. Basically, we have no experience to offer on your question. Note that we are nearing the end of a process of preparing and issuing design guidance that will make centerline rumbles strips the recommended practice on rural two-lanes where double yellow pavement markings are present.	Terry Hale [thale@dot.state.ny.us]
MI	By the end of 2010 MI DOT will have retro-fitted approximately 5700 miles of two-lane trunkline with centerline rumble strips. The Department does receive noise complaints, but we also receive a lot of positive feedback. MI DOT's rumble strip design and usage guidelines take noise concerns into account. We use a 3/8" cut rather than the 1/2" cut used freeway shoulders and all intersections are gapped. The guidelines call for the centerline rumbles to be installed on all rural two-lane and four-lane roadways with a speed limit of 55 mph in an effort to avoid more residential areas. We do mill rumbles in passing zones which means rumbles will be hit during a passing maneuver.	Mark Bott [BOTTM@michigan.gov]
MO	In Missouri, we are just beginning to install a large amount of miles of the centerline rumble stripes on our major roads (most traveled routes). With the completion of our construction program in 2011, we should have over 1,000 centerline miles of installed centerline rumble stripes. We have made it policy that these most traveled roads (about 5,600 miles) will have specific safety enhancements installed like edgeline and centerline rumble stripes. For the miles we have installed, we are fielding a few complaints but overall this has not been a real issue. There has been some discussion on proximity of our edgeline rumble stripe since we move it closer to the driving lane when compared to other states, but we do this to get the wet-night visibility gain (we are currently down about 25 percent on lane departure crashes from 2005 to 2008). I have provided a link to our Engineering Policy Guide on rumble stripes for you to review. Also, please feel free to call me if you need to further discuss our program. Good luck. http://epg.modot.mo.gov/index.php?title=Category:626_Rumble_Strips	John.P.Miller@modot.mo.gov
TX	Our guidance is to install centerline rumble strips in areas where there is a high percentage of head-on collisions or side swipe type crashes. We do not have any type of blanket policy of installing these on all 2-lane roads or undivided roadways. We have the occasional complaint sometimes when the rumble strips are first installed but I don't think that it is that bad. We have the option to lessen	Brian Stanford [mailto:BSTANFO@dot.state.tx.us]

	the depth of the cut to 3/8" in residential areas, churches, etc. Our standard sheet for centerline rumble strips can be viewed at the following web address: ftp://ftp.dot.state.tx.us/pub/txdot-info/cmd/cserve/standard/traffic/rs3-06.pdf Other than lessening the depth of the cut, we have not tried any other noise mitigation measures. Please contact me if you have any other questions. Thanks.	
AR	Arkansas is in the process of developing a policy for the use of shoulder and centerline rumble strips. The policy is currently under administrative review and has not been adopted and implemented to date, but in it we recommend the following: • Centerline Rumble Strips shall be installed on rural highways only where an engineering study reveals a cross-centerline accident history correctable by their use. • Centerline Rumble Strips shall only be considered in bi-directional no passing zones where the posted speed limit is 45 mph or greater. • The minimum lane width shall be 10 feet in tangent sections, 11 feet for curves with a minimum radius ≥ 800 feet, and 12 feet for curves with a minimum radius ≥ 500 feet. **Rationale** The out-to-out track width of a WB-67 (semi with a 53' trailer) design vehicle was used to determine the minimum radii criteria. At a radius of 800', the out-to-out track width is 10'. At a radius of 500', the out-to-out track width is 11'. The minimum lane widths are 1'greater to allow for ½ of the rumble strip (6") plus 6" clear (3" each side). Our current rumble strip is 16" wide and 1/2" deep. We are proposing to revise that to a 12" wide strip that is 3/8" deep for posted speeds of 45 - 55 mph based largely on a study done by Colorado DOT on Bicycle Friendly Rumble Strips (attached), which has some good discussion on minimum noise levels needed to provide adequate warning. As you see, our proposal allows for their use only in rural areas, and only after an engineering study recommends their use. These restrictions were included due to noise concerns in populated areas.	Mathis, John [John.Mathis@arkansashighways.com]
ND	I apologize for the delay in response; I wanted to contact the Engineers in the Department that work most closely with operations before I replied. North Dakota only recently began installing centerline rumble strips. The first project in our state was constructed two years ago on the Standing Rock Reservation. The location was chosen because of the disproportionate amount of head on crashes. The roadway is two lane, head to head and runs from the Bismarck/Mandan area through Fort Yates on the Reservation. The roadway is the main access to the Reservation and also to the Casino located there. There is moderately high traffic at times because of the tourist draw of the Casino. During the development of the rumble strip project, we initially intended to install the centerline rumble strips only in areas with highway speeds of 45mph or greater. The people of Fort Yates, however, requested we extend the centerline rumble	Smith, Jack L. [jasmith@nd.gov]

	strips through town. Fort Yates has a population of less than 300 and many of the homes are not very far from the highway. We agreed to the tribal members request and extended the centerline rumble strips into the town. We did not take any noise mitigation measures. Complaints that we received since the installation have typically come from the road users rather than people living near that stretch of roadway. Motorcyclists have complained that they have been caught off guard while trying to traverse the strips when making a passing maneuver. In other areas where we have installed centerline rumble strips since the first project, we at times get complaints from local roadway users who question the necessity of the strips. In both cases of motorcyclists and local roadway users, a simple explanation of the purpose of the strips and our intent in installing them usually defuses the complaint. I would expect the number of complaints to reduce as we work toward educating the public about this safety measure. If you have any further questions don't hesitate to contact me.	
OR	Check out pgs. 6-55 thru 6-59 of the ODOT Traffic Manual for our policy on use (contains info for shoulder, centerline, and transverse). For centerline rumble strips the ODOT Traffic Manual states that they should not be installed on urban highways unless an engineering study considers the noise impacts (among other things...see pg. 6-58). http://www.oregon.gov/ODOT/HWY/TRAFFIC-ROADWAY/docs/pdf/Traffic_Manual_09.pdf We do not have any rumble strip designs that are used to specifically mitigate noise. If noise is an issue, rumble strips typically don't get installed (or they get "removed"). Profiled striping could probably be used instead of rumble strips if noise is an issue as they are typically less audible but still provide good driver feedback when crossing over a line. However, profiled striping is much more expensive and as per the ODOT Traffic Manual, profiled striping effectiveness compared to milled-in rumble strips is not known. Below are the links to our current rumble strip designs: ftp://ftp.odot.state.or.us/techserv/roadway/web_drawings/details/traffic/pdf/det4550.pdf ftp://ftp.odot.state.or.us/techserv/roadway/web_drawings/details/traffic/pdf/det4551.pdf ftp://ftp.odot.state.or.us/techserv/roadway/web_drawings/details/traffic/pdf/det4552.pdf Below is a link to our profiled striping design:	LAZARUS Jon M [Jon.M.LAZARUS@odot.state.or.us]

	ftp://ftp.odot.state.or.us/techserv/roadway/web_drawings/traffic/rev_01/tm520.pdf You may want to contact the people on the CC list as I know some of them have dealt with rumble strip noise complaints (Angela and Sue). Kevin or Doug could also provide some good input as they are the keepers of the ODOT Traffic Manual. If you have any additional questions on the design itself, please contact me. If you have questions on the policy in the Traffic Manual, please contact Kevin.	

Traffic noise at rumble strips on roads – a pilot study

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Abstract

Rumble strips may be established in the middle of roads in order to improve traffic safety by assisting in preventing vehicle drivers from crossing the centre line without noticing it. The noise/vibration created by such strips warns drivers. However, the noise level outside increases, and may cause annoyance to road neighbours. A pilot study was conducted by the Danish Road Institute to test rumble strips generating low noise levels in the environment. Five types of rumble strips made by milling indentations in the pavement of two-lane roads were tested.

Sinusoidal indentations led to only 0.5 – 1 dB increase in maximum pass-by noise level while "cylinder-segment" indentations spaced by 0.6 m gave an increase of 2 – 3 dB in relation to the noise level from pass-bys on the old stone mastic asphalt. With a spacing of 0.33 m "cylinder-segment" indentations gave rise to 3 – 7 dB higher noise levels than sinusoidal indentations and 2 – 5 dB higher levels than "cylinder segment" indentations spaced 0.6 m. These results are valid for passenger cars, at distances exceeding 25 m from the road.

In the autumn of 2008 the Danish Road Directorate has 100 km of sinusoidal rumble strips milled with 0.6 m wavelength and ±5 mm amplitude.

1. Introduction

Rumble strips in the middle of roads are in some cases established to improve traffic safety by assisting to prevent vehicle drivers from crossing the road centre line without noticing it. They create noise/vibration in the vehicle to warn drivers, but at the same time the noise level outside increases and this may cause annoyance to road neighbours. The Danish Road Institute (DRI) conducted a pilot study to test rumble strips giving rise to low noise levels in the environment.

2. Delimitation

Only noise levels from passenger cars at 80 km/h have been investigated. The effect of the rumble strips on heavy vehicle noise levels is not known.

The warning effect on drivers, including noise and vibration levels inside the car, has not been investigated by DRI but we know that vibration inside a car has been measured by DanCrash, a Danish consultant. Drivers involved in the pilot study agreed that noise/vibration in their vehicle when driving on the tested rumble strips would give sufficient warning.

3. The rumble strips

Table 1 shows some characteristics of the rumble strips tested in the study and Figure 1 - Figure 2 illustrate the profiles of rumble strips No. 1, 4 and 5 and No. 2 – 3, respectively.

In 2004 Danish road authorities had 30 cm wide rumble strips milled on both sides of the centre line of a two-lane rural road where the speed limit is 90 km/h. Cylinder segment indentations were milled, 4 mm and 8 mm deep, respectively, per 0.33 m. These rumble strips (named No. 4 - 5 in the following) gave rise to noise complaints.

Swedish road authorities have decided to mill rumble strips with maximum 10 mm deep cylinder segment shaped indentations per 0.6 m. Such a rumble strip was milled as a part of the Danish pilot study, called No. 1 in the following, on a rural road with speed limit 80 km/h.

In a British investigation three measurement series were carried out [1] on sinusoidal rumble fields with various wavelengths and amplitudes. The conclusion was that the best warning effect would be obtained by applying a waveform generating an excitation frequency of 37 Hz. The British experiments were made at 30 mph ≈ 48 km/h and the corresponding wavelength was 0.36 m. In the final measurement series rumble fields with 35 cm wavelength and amplitudes of 4.14 mm and 6.62 mm, respectively, were used [1].

At a speed v and with a wavelength λ the car is excited by a frequency f: $f = v/\lambda$ or $\lambda = v/f$. The optimum excitation frequency $f = 37$ Hz is obtained at $v = 80$ km/h = 22 m/s with a wavelength $\lambda = 22/37 = 0.6$ m. Sinusoidal rumble strips were milled with this wavelength and with amplitudes ±3.5 mm and ±2 mm, respectively.

Table 1. Summary of rumble strip characteristics

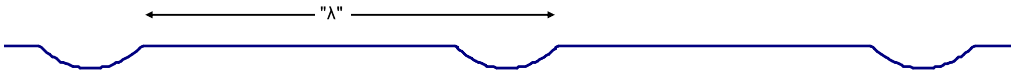
Rumble strip No. [-]	Indentation
1	Segment of cylinder per 0.6 m, max. 10 mm deep
2	Sinus 7 mm top to bottom, wavelength 0.6 m
3	Sinus 4 mm top to bottom, wavelength 0.6 m
4	Segment of cylinder per 0.33 m, max. 4 mm deep
5	Segment of cylinder per 0.33 m, max. 8 mm deep

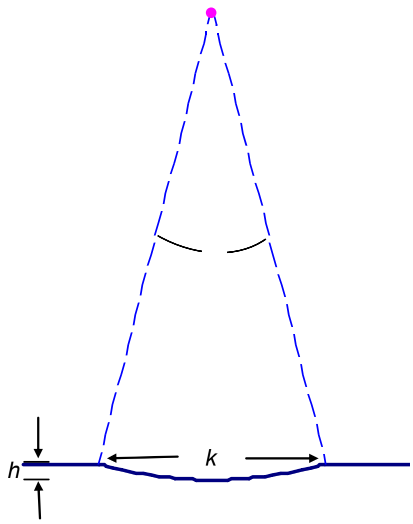
The actually measured surface profiles of rumble strips No. 1 – 3 are shown in Figure 3. Due to dense traffic, the surface profiles of rumble strips No. 4 – 5 could not be measured.

4. Method

The measurements were Controlled Pass-By measurements (CPB) made using a procedure similar to the statistical pass-by method in ISO 11819-1. Three passenger cars were selected based on advice from DanCrash. Information on the cars is summarised in Table 2.

A microphone was placed on one side of the two-lane road at a distance of 7.5 m from the road centre line and at a height of 1.2 m above the road surface, cf. Figure 4. The drivers attempted to pass the measurement position at a constant speed of 80 km/h while no vehicles were passing in the opposite lane. During each pass-by the maximum noise level was recorded and the vehicle speed was measured by means of a radar device.





Noise levels were recorded during 3 – 5 undisturbed pass-bys of each car in each direction with their left wheels on the rumble strips. When driving in the near lane the left wheels rolling on the rumble strip were screened from the micro-phone by the car body while these wheels were directly visible during pass-by in the opposite direction in the far lane.

For comparison, the same vehicles passed the microphone at rumble strip No. 3 driving on the pavement, a 22 years old stone mastic asphalt (SMA) without touching the rumble strip.

Figure 1. *Cylinder segment strip; No. 1: h ≈ 0.01 m; k ≈ 0.15 m; strip width ≈ 0.30 m; "λ" = 0.6 m; No. 4: h ≈ 0.004 m; k ≈ 0.15 m; strip width ≈ 0.30 m; "λ" = 0.33 m; No. 4: h ≈ 0.008 m; k ≈ 0.15 m; strip width ≈ 0.30 m; "λ" = 0.33 m*

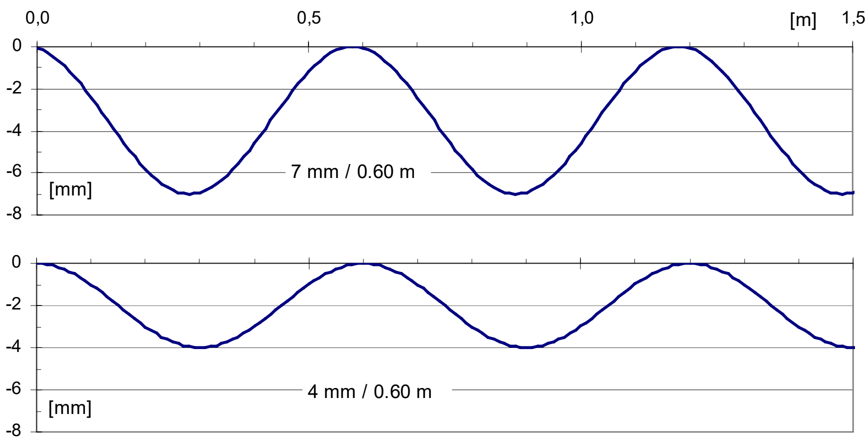


Figure 2. *Sinusoidal strips. Strip No. 2 (top) and No. 3 (bottom)*

4.1 Data analysis

Measured pass-by noise levels L_{pAFmax} were corrected from the actual speed v to 80 km/h by adding -37 $\log_{10}(v/80)$ which is the basic relation between maximum noise level and vehicle speed in Nord2000, the new Nordic prediction method for road traffic noise [2].

These corrected noise levels were averaged and a statistical uncertainty u of the average was calculated as $u = s/n^{1/2}$ where s = the standard deviation of the mean; n = the number of pass-bys.

To explain apparent discrepancies between results from the two driving directions, trial-and-error modelling was carried out to obtain the best fit to the data, cf. Figure 4. The figure illustrates the positions of the wheels during pass-by. The wheels nearest to the road centre line are at a distance x from this line and each wheel is represented by a noise source at the road surface. The

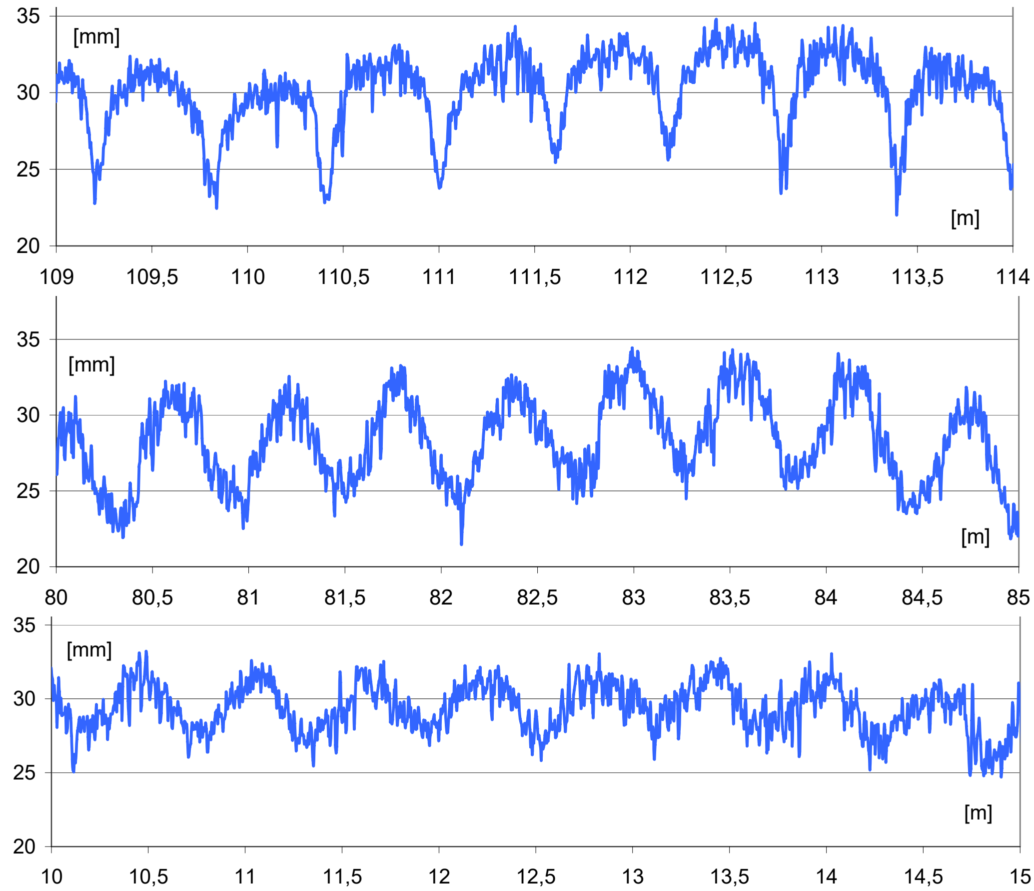


Figure 3. Extracts of surface profiles of rumble strip No. 1 (top), No. 2 (middle) and No. 3 (bottom) measured using DRI laser equipment.

Table 2. Data on the selected cars and their tyres

<table>
<tr><th>Car No.</th><th>1</th><th>2</th><th>3</th></tr>
<tr><td>Make</td><td>Volkswagen</td><td>Skoda</td><td>Toyota</td></tr>
<tr><td>Model</td><td>Golf 1,8</td><td>Octavia 1,9 TDI</td><td>Combivan (Corolla Verso)</td></tr>
<tr><td>Year</td><td>1995</td><td>2006</td><td>2003</td></tr>
<tr><td>km</td><td>200,000</td><td>5,000</td><td>15,000</td></tr>
<tr><td>Tyres Front</td><td>Gislaved Speed 516 185/60 R14 82T</td><td rowspan="2">Continental ContiEcoContact 3 195/65 R15 91H</td><td rowspan="2">Goodyear Ultragrip 6 (M+S) 195/65 R15</td></tr>
<tr><td>Tyres Rear</td><td>Michelin Energy 185/60 R14 XT2</td></tr>
</table>

wheels on the rumble strip are assumed to emit z dB more sound power than the wheels on the reference surface. The source at the wheels on the far side of the car as seen from the microphone is assumed to be y dB screened by the car body and by the nearest wheels.

This model was used to determine the values of x, y and z giving the best fit between measured and calculated differences between on one hand the pass-by level in the near and far lane and on the other hand the pass-by level on the rumble strip and the pass-by level on the reference section. This is explained in [3] - [4]. The values of *z* and *y* in turn were used to calculate the pass-by level at further distance from the road.

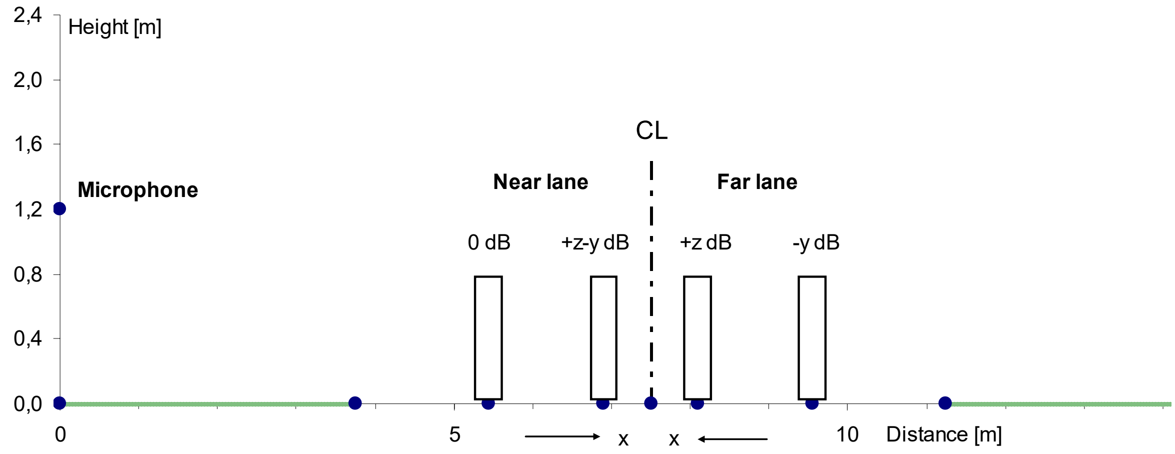


Figure 4. Vertical cross section sketching wheel positions when driving in the two directions

5. Results

The detailed results can be found in [3] while a summary is given in Figure 5. The main results of the measurements and subsequent analyses, including the corrections and calculations mentioned in Section 4.1 are given in Table 3. The numbers in the table are the increments [dB] of the overall A-weighted maximum noise level when driving with one set of wheels on the rumble strip as opposed to driving with both sets of wheels on the reference pavement. These increments are given in relation to the noise level at an old stone mastic asphalt surface and they are valid for passenger cars at 80 km/h, at distances exceeding 25 m or so from the road.

Table 3. Increment in passenger car pass-by noise level at 80 km/h in the far lane and near lane given relatively to the pass-by noise level on the reference pavement.

Rumble strip	Far lane [dB]	Near lane [dB]
1 Cylinder 0.6 m / 10 mm	3,0	1,8
2 Sinus 0.6 m / ±3.5 mm	0,8	0,4
3 Sinus 0.6 m / ±2 mm	0,9	0,5
4 Cylinder 0.33 m / 4 mm	5,6	3,7
5 Cylinder 0.33 m / 8 mm	7,5	5,2

6. Conclusions

The rumble strips with sinusoidal shape led to only 0.5 – 1 dB increase in maximum noise level while “cylinder-segment” indentations spaced by 0.6 m gave an increase of 2 – 3 dB in relation to. With 0.33 m spacing, “cylinder-segment” indentations gave rise to 3 – 7 dB higher noise levels than sinusoidal indentations and 2 – 5 dB higher levels than “cylinder segment” indentations spaced 0.6 m. These increments in pass-by noise level are given relatively to the noise level from pass-bys on the old stone mastic asphalt, and they are valid for passenger cars, at distances exceeding 25 m from the road.

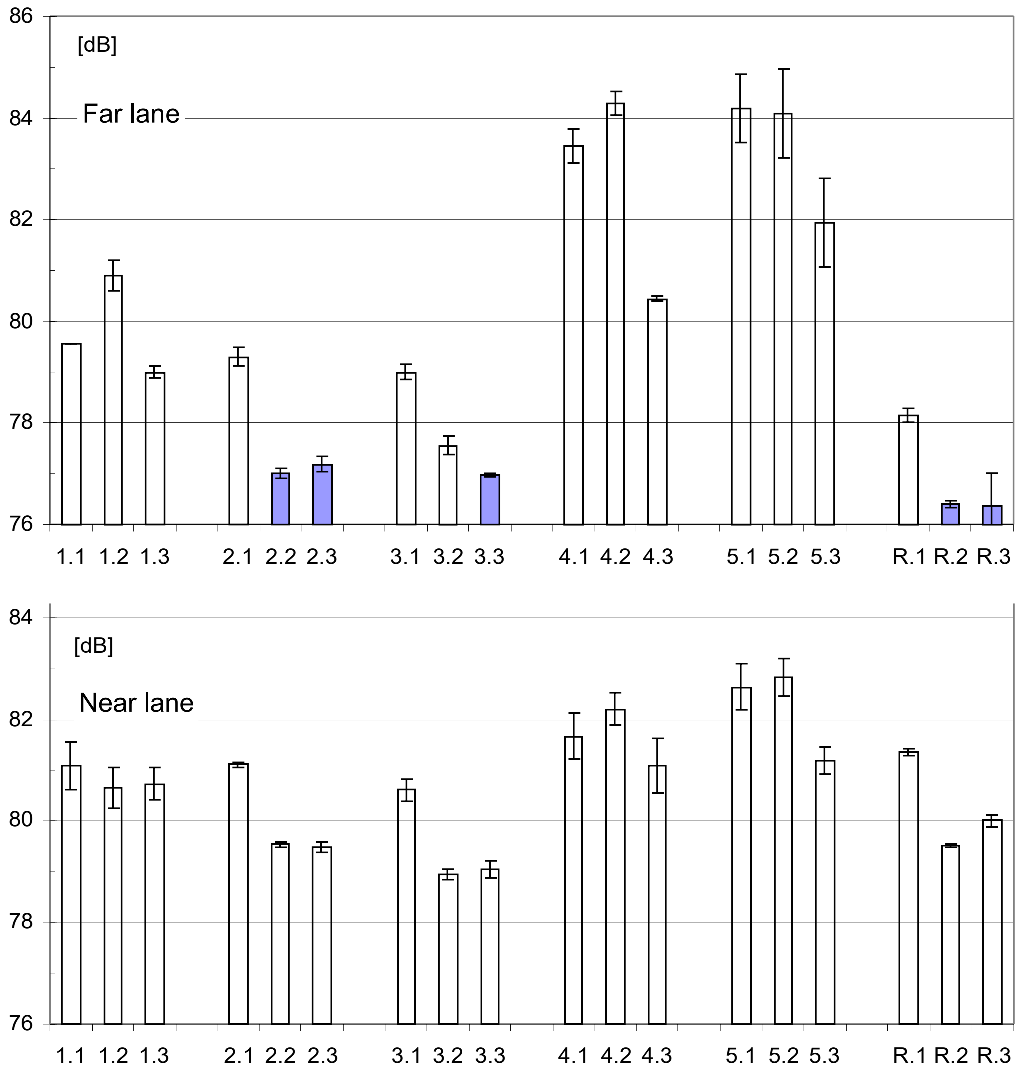


Figure 5. Mean pass-by noise levels ± uncertainty. X-axis label: a.b = rumble strip No. a and car No. b. R = reference (i.e. R.3 = Car No. 3 on the reference pavement)

7. References

1. Watts, G.R., Stait, R., Layfield, R.E., (2001), Optimisation of traffic calming surfaces, *Proceedings Inter•Noise 2001*.
2. Kragh, J., Jonasson, H.G., Plovsing, B., Sarinen, A., Storeheier, S.Å., Taraldsen, G., *Nord2000 Users Guide*, DELTA Technical Report AV 1171/06, Hørsholm, 2006.
3. Kragh, J., Andersen, B., *Traffic noise at rumble strips – a pilot study* (in Danish), Danish Road Institute / Road Directorate Note 51/2007 http://www.vejdirektoratet.dk/publikationer/VInot051/index.htm
4. Kragh, J., Andersen, B., Thomsen, Sigurd N., Low noise rumble strips – a pilot study, *Proceedings Inter•Noise 2007*