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ALASKA DEPARTMENT OF TRANSPORTATION

Qualitative Evaluation of Safety and Effectiveness of Rumble Strips in Alaska

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QUALITATIVE EVALUATION OF SAFETY AND EFFECTIVENESS OF RUMBLE STRIPS IN ALASKA

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Alaska Department of Transportation & Public Facilities

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Research & Technology Transfer
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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

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ABSTRACT

The Alaska Department of Transportation & Public Facilities (AKDOT&PF) conducted qualitative performance monitoring of various milled rumble strip configurations in hot mix asphalt paved roads in South-central Alaska. Researchers qualitatively characterized performance and identified positive and negative effects of various rumble strip configurations on the traveling public, the environment, and the AKDOT&PF. The researchers found that the milled shoulder rumble strips generally provide positive driver warning with minimal adverse effects. Centerline rumble strips promise to provide positive lane delineation throughout the winter when pavement markings are not visible.

SUMMARY OF FINDINGS

Effectiveness and Benefits

- Reduction of "run off road" accidents: Milled rumble strips present an effective method to reduce the number of "run-off-the-road" (ROR) accidents or near accidents. Compared to rolled-in rumble strips, milled rumble strips are much more audible inside large trucks and small automobiles. Nationwide, milled rumble strips prevent about 1/3 of all ROR accidents caused by inattentiveness or drowsiness. (4) Inattentive drivers are the second highest cause of accidents and the third highest cause of fatalities in Alaska. (1) Milled rumble strips appear to offer an effective deterrent for this type of driver.
- Reduction of "cross-over" accidents: Centerline rumble strips separating lanes of opposing traffic may reduce the number of cross-over accidents on Alaskan highways. Sufficient accident data is not yet available in Alaska to determine effectiveness in reducing cross-over accidents.
- Improved Lane delineation:
- Enhanced travel lane delineation: Centerline rumble strips separating lanes of single direction traffic may increase lane delineation when pavement markings are not visible. Rumble strips may offer the added benefit of protecting pavement markings located adjacent to or within the rumble strip. Further study of this phenomenon is recommended.
- Cost Effectiveness: Rumble strips are widely recognized a cost effective safety improvement. Their widespread usage in the United States is resulting in decreases in cost and more vendors available to install them. At the time of this writing nine contractors install milled rumble strips nationally. (4)

Adverse Effects

- External noise: Milled rumble strips may generate complaints about road noise near residential areas. FHWA has issued policy and guidance on noise analysis and abatement. (3)
- Bicyclists: Bicyclists may complain of discomfort or loss of control when crossing rumble strips. State departments of transportation are installing gaps in the rumble strips, providing an exit for bicyclists so that they do not have ride over the rumble strips to cross them.

- Debris buildup: Debris such as loose gravel and soil may accumulate in rumbles and on the paved road shoulder especially during the first year after ruble strip installation and on roads with travel speeds lower than or equal to 45 mph. For high speed roads, debris buildup in rumbles and on paved shoulders was not significantly greater than on roads without rumble strips.
- Snow/ice buildup: Snow /ice and/or debris may accumulate in rumble strips in low speed areas (<45 miles per hour) and in areas that frequently experience heavy/wet snow. Snow and ice buildup may result in inoperative rumbles until the snow/ice melts or dissipates with passing traffic. We have not observed snow/ice buildup to persist longer than 7-10 days in high-speed traffic areas.
- Pavement degradation: Pavement distress may develop when rumble strips are installed in degraded pavements or pavements of insufficient structural integrity. Rumble strips should not be installed in asphalt pavements less than two inches thick.

Conclusions and Recommendations

Generally, the safety benefits of milled shoulder rumble strips justify their continued use in Alaska. Adverse effects can be mitigated by good design practices to include development of proactive guidelines incorporating appropriate site selection, conformation to FHWA's Traffic Noise Policy and Guidance and use of non-continuous rumble strips. Chapter 3 of this document presents suggested guidelines for the use of rumble strips. However, accommodations to alternative users such as bicyclists and to dwellers may significantly reduce the effectiveness of rumble strips. Consideration of accommodations against safety must be carefully weighed.

Do not install rumble strips in residential areas.
AKDOT&PF should install breaks in rumble strips sufficient to accommodate bicyclists.

CHAPTER 1 - INTRODUCTION AND RESEARCH APPROACH

Problem Statement and Research Objective

During the 1990's the Federal Highway Administration (FHWA) advocated a handful of state departments of transportation (DOTs) began installing milled-in rumble strips as an effective "run-off-the-road" (ROR) accident reduction measure. However, national engineering standards do not exist for design and installation of milled-in rumble strips. During the summer of 2000, and based largely on precedent set by early adopting state DOTs, AKDOT&PF installed milled-in shoulder rumble strips and experimental milled centerline rumble strips on major asphalt pavement roadways in South-central Alaska. These were the first milled-in rumble strips in Alaska and AKDOT&PF had no documentation of their costs, benefits, and adverse affects.

The purpose of this research is to qualitatively document the effectiveness, benefits, and adverse effects of the rumble strips on the AKDOT&PF and the traveling public. AKDOT&PF intended to use this documentation in developing design criteria for a statewide rumble strip installation policy.

Scope of Study

Researchers focused their efforts on gathering qualitative observations of this study was on milled rumble strips installed on asphalt in Alaska and the United States. Rumble strips in Alaska must facilitate a multi-modal transportation system while providing sufficient stimulation to reduce ROR accidents. The effects of rumble strips on the traveling public, the DOT&PF, and the environment are considered.

Research Approach

Alaska DOT&PF Research and Technology Transfer visually inspected rumble strips in Alaska to determine the repercussions of installation. A survey of practices by other states and current research on shoulder rumble strips was conducted to examine the efficacy of shoulder rumble strips.

CHAPTER 2 - FINDINGS

State-of-the-Art Summary

Available literature suggests that milled rumble strips present a more effective deterrent to ROR accidents than rolled rumble strips. Rolled rumble strips result in less noise and vibration than the milled rumble strips. Many sources attribute milled rumble strips for a significant (1/3) reduction of ROR accidents after highway agencies began using them or switched over from rolled rumble strips.

Current research examines issues including: bicycle friendliness, cost benefit studies, accident reduction, centerline rumble strips, and advance warning. Bicycle friendliness of rumble strips is of ongoing concern to facilitate serving this group of users. Colorado tried square grooved rumble strips with 2" widths and ½" depths but found that while bicyclists found them more comfortable than standard circular bottomed strips, motor vehicles did not experience enough sound to make them desirable as a warning device. (8)

Many other states are trying combinations of skip patterns, different placements of rumble strips in relation to the edge line and changes of rumble strip dimensions. Michigan is in the process of developing a study on placing pavement marking in rumble strips for protection of markings from snowplows and vehicles.

Cost benefit studies are being performed by Georgia DOT, while accident reduction effectiveness is being studied in Michigan and Virginia.

Centerline rumble strips are currently being examined in Colorado, Connecticut and Maryland.

New means of placing rumble strips are also developing, with Wirtgen adding a new attachment to its line of products for use with their cold milling machines which produces rumble strips and Bobcat adding a planer capable of producing rumble strips as an attachment available to its skid steer loaders.

Current Practices

Based on internet searches and contact with various state DOTs, the Research group compiled national practices regarding rumble strip installation policies, specifications and design. While many states have adopted a rumble strip design incorporating a 7" width, 16" length, ½" depth and 12" repeat pattern, placement of rumble strips varies widely from state to state. Most, but not all, states have specifications and most, but not all, states have abandoned use of rolled rumble strips. Roughly half of the states have a written installation policy, many of which incorporate guidelines limiting use of rumble strips to interstate or rural highways. Few states base their decisions on ROR accident data, opting to simply place rumble strips the full length of their interstate and/or rural highways.

Cost

The decline of installation costs of milled rumble strips corresponds with the emergence of new technology and increased popularity. In 1997, installation of milled in rumble strips approached

$7,638.00 per kilometer in Wyoming as reported in their weighted bid average prices (4). In the most recent bid letting in Alaska, milled rumble strips were installed at a cost of $273.00 (2001 dollars) per kilometer, showing a decline of 96% during those years. Of course, costs will vary with each contract according to size and conditions. But, the forecast for a continuing decline in installation costs looks positive, with more contractors entering the bidding field and new technology continuing to surface.

Effects

Safety

Nationally, rumble strips are credited with reduction of ROR accidents in many states. California, New York, Pennsylvania and Wyoming have published accident reduction data in areas with shoulder rumble strips varying from 20 to 78 percent (5). To date, no research addresses comparison of effectiveness of different configurations of milled rumble strips, with differing gap patterns, placement in relation to the edge of pavement/edgeline, or different lengths.

Motorists

ADOT has received complaints from the public that rumbles in gore areas and near driveways/mailboxes are causing undue irritation to those who drive in those areas during common maneuvers such as merging, entering off ramps, and turning. Other adverse effects include inattentive drivers over-correcting when stimulated and the possibility that rumble strips may actually only shift the location of accidents caused by inattentive drivers. No research was found which addressed these possibilities.

Bicyclists

Several studies indicate that rumble strips comfortable to bicyclists can only decrease effectiveness of rumble strips to motorized vehicles. The most recently available study, by Darren Torbic, Lily Elefteriadou, and Moustafa El-Gindy found that rumble strips best tolerated by bicyclists had the least effect on an automobile. Various depths, widths and intervals were considered as shown in the table below:

Table 1 Test pattern dimensions (2)

Test Pattern	Groove Width (mm)	Flat portion between cuts (mm)	Groove Depth (mm)
1	178	127	13
2	127	178	10
3	127	178	10
4	127	152	13
5	127	152	10
6	127	178	6.3

Data collection on bicyclist vertical acceleration, pitch angular acceleration and comfort resulted in pattern numbers 6 and 3 arising as the most acceptable rumble strip dimensions for bicyclists. However, based on sound levels within an automobile, patterns 1 and 4, the worst choices for bicyclist accommodations, ranked best for automobiles. (2)

Table 2 Overall ranking of test configurations based on bicyclist related measures (2)

	Test Pattern
Best	6
	3
	2
	5
	4
Worst	1

Table 3 Ranking of test configurations based on noise level testing for motor vehicles (2)

	Test Pattern	**Speed** (Km/hr)	**Avg. Max Sound Level dB(A)**
Best	4	72	83.6
	1	72	80.0
	5	72	79.3
	2	72	78.4
	3	72	75.2
Worst	6	72	74.7
	Smooth	72	68.4
Best	1	88	88.9
	2	88	83.7
	3	88	81.3
	4	88	81.2
	5	88	79.1
Worst	6	88	78.2
	Smooth	88	65.2

Based on this data, different configurations of rumble strips should perform adequately for vehicles on different speed zoned roadways with some accommodation to bicyclist comfort.

Alternatively, Colorado determined that placing gaps in rumble strips might be an effective strategy to accommodate bicyclists. Outcalt recommended a gap pattern of 12’ gaps interspersed with 48’ continuous sections of rumble strip. The most effective rumble strip dimensions tested in Colorado again presented the most discomfort to bicyclists. (8) However, while this gap pattern accommodates bicyclists traveling at high speeds, it does allow the possibility of an automobile exiting the traveled lane without the rumble strips alerting the driver.

Motorcyclists

Several studies conclude that rumble strips do not adversely impact motorcyclists. In 1992, Massachusetts performed a study using police motorcycle patrol officers to evaluate rumble strips. More recently, an in depth study of motorcycle performance on a variety of rumble strip configurations in Canada determined that motorcyclists experience no discomfort or adverse effects unless traveling at slow speeds (<20km/h). (7) Research on the effects of rumble strips on inattentive motorcyclists does not exist, nor has there been any quantification on the prevalence of inattentive motorcyclists. In addition, research has focused on motorcyclists traveling over rumble strips at high speeds without addressing the risks to motorcyclists who may be in distress and need to travel over rumble strips at slow speeds.

Environment

No research on the effect of rumble strips on the environment has been conducted. All information regarding potential impacts has been incidental. Two aspects that may be of concern include debris and noise. Although no quantitative information is offered, debris and noise are dealt with in a limited context in the following paragraphs.

Debris

The ADOT Research group qualitatively evaluated roadside shoulders for rumble strips installed one and two years ago. Rumble strips did not seem to affect the pattern of debris sweepage on highways. The problem presented is that the rumble strips block a large portion of the shoulder from use on small shoulders where the bicyclist may need to maneuver around large debris.

In those places where rumble strips had recently been installed, much more debris existed on the roadside, probably residual loose asphalt from the rumbling process. Debris apparently did not to increase when compared to non-rumbled shoulders except during the first year after installation when the rumbled asphalt had not yet healed.

Debris patterns were remarkably similar in both rumbled and non-rumbled areas. Debris patterns were marked by an edge on 55-mph roads about 4 feet from the edgeline. On 45-mph roads, debris accumulated at a 1.5/2-foot distance from the edgeline. On roads where the average traffic speed was between 60-65 mph, debris was both scarce and widely scattered, with no distinct edge.

Debris on the shoulder seems to accrue the most on those areas where anomalies such as pot holes, patches, cracks, ice buildup, turning traffic/exits/entrances, or curves exist. In general, at curves with 55 mph + speed limits, where drivers “straighten out” the road, debris tends to be about 2 feet away from the edgeline.

These patterns are most apparent in areas where heavy sanding occurs.

Large or massive debris tends not to be swept from its initial position on both rumbled and non-rumbled areas.

Additional concerns include the build up of snow and ice in rumble strips. Snow seems to behave in much the same way as particulate debris. However, when snow is not cleared from rumble strips as is the case at low travel velocity areas, snow and ice may completely obscure rumble strips. This renders them completely useless. Since maintenance operations were observed to clear the travel lanes and not the shoulders, snow and ice may remain in the rumble indentations until the next thaw.

External Noise

Currently few regulations exist regarding highway noise. The Environmental Protection Agency attempted to regulate ambient noise in various settings in the 1970s, but these ordinances were emasculated in the 1980s. This resulted in a narrow scope of federal enforcement impacting only airport, motor carrier, and railroad noise. Congruently, most states only minimally regulate noise, with regulations primarily dealing with occupational noise. The FHWA "Traffic Noise Policy and Guidance" regulates highway noise, but rumbles aren't dealt with in the guidelines. It does impact future rumbles because planning construction or alteration (i.e. altering the elevation or increasing the number of lanes) of type 1 highways near existing residential areas fall under the scope these regulations. If it becomes necessary to locate highways or alterations of highways near residential or quiet areas where rumble strip exist in the scope of work, noise mitigation will certainly become an important planning aspect.

Limited information exists about the impacts of rumble strips on ambient/outside noise. New York performed a study on rumble strip noise and found that the A-weighted decibel levels increased in small amounts compared to the perception of the noise generated. (6)

This may be due to the frequency generated by traffic passing over rumble strips. Higher frequencies have the effect of reducing the perceived loudness of sounds and rumble strips generally operate beneath that band (100 – 800 Hz) This effect is explicit at 10^3.5 Hz. (9)

It is generally accepted that 3 dB is perceptible noise, while 5 dB is definitely perceptible and 10 dB is perceived as twice as loud. In addition, nighttime noise seems twice as loud/annoying as it actually is. This perception equals a 10db adder to any measured values at night.(10)

When the sound generated by traffic driving on rumble strips is compared to ambient sound levels during nighttime, they found that rumble strip noise ranged from 9 to 17 dB higher than the 90th percentile sound level. (6) This is likely to be typical of communities although there will be some differences due to community composition and differing traffic patterns.

Pavement Degradation

Concerns about whether or not installation of rumble strips may lead to degradation of pavements have been raised. Conjecture of premature degradation of pavement due to installation of rumble strips does not appear to be supported. In all Alaskan installations on sound pavement, premature degradation has not occurred. Degradation has only occurred in those areas where rumble strips were installed on marginal pavements. There has also been conjecture that snow and ice buildups in conjunction with freeze thaw cycles would lead to premature degradation of pavements. No evidence of this was found in subjective observations of rumble strips that have been in service for two years.

Central Region AKDOT&PF has experienced problems with potholes where rumbles were installed on marginal pavements.

Effects on Maintenance and Operations

The largest effects of rumble strips are felt by the Maintenance and Operations Section (M&O) of ADOT. M&O, by far, has the most contact with rumble strips because of painting, plowing, sanding, guardrail maintenance, and other support operations. The most noticeable effects of rumble strips include driver discomfort and increased equipment wear. Increased damage and subsequent repair is most noticeable on snowplow blades that suffer from vibration incurred by plowing over the rumble strips.

There was speculation that maintenance crews may use rumbles as guidelines when plowing, which would result in lessened guardrail impact. However, this proved to be fallacious.

Additionally, speculation existed that motorists would avoid driving right next to rumble strips resulting in protection of the edgeline adjacent to rumble strips. This appears to be a valid hypothesis. ADOT measured retroreflective values for low VOC paint on various random straight and curved sections of the Parks Highway near the Old Nenana Highway in the Fairbanks area and found supportive evidence for this theory. This effect is degraded on curves, as drivers still tend to "straighten" the curves out. Generally, pavement markings applied on curves tend to completely disappear after a season due to abrasion by tires and snow plows. However, pavement marking visual presence is preserved on these areas, although measurements of retroreflective values are very low.

Figure 1 Pavement marking adjacent to rumble strip on curve

ADOT construction engineers have noted that pavement striping can "wander" over time. Errors in rumble strip placement have resulted when using striping for reference.

Internal Noise

New York measured internal ambient noise both with and without rumble strips and determined that a perceptible difference existed.

Table 4 Maximum A-weighted sound levels with and without rumble strips (6)

Vehicle Type	Without Rumble Strip[dBA]	With Rumble Strip[dBA]
Automobile	74	81
Medium Truck	80	89
Heavy Truck	84	94

However, while studies have been performed measuring inside noise no research exists which defines the amount of noise or vibration required to attract the attention of inattentive or drowsy drivers.

Lane Delineation

ADOT attempted to use rumble strips for lane delineation in several areas in the Anchorage, Alaska region. Four sections of road received rumble treatment. All sections rumble dimensions include ½" depth, 7" width, and 12" repeat pattern.

Table 5 Lane Delineation Sections

Section	Location	Length	Gap Pattern	Comments
B	Minnesota Blvd – from C St to Old Seward Hwy	12"	30' rumbles, 10' gaps	Removed.
C	SB Glenn Hwy near Weigh Station	8"	2' rumbles, 20' gaps (beginning and end of each skip stripe)	Very noisy.
D	SB Glenn Hwy near National Guard	6"	10' rumbles, 30' breaks	Most popular.
E	SB Glenn Hwy near Fort Richardson	4"	10' rumbles, 30' breaks	Not as visible as section D. Least noisy.

Section B, located on a major arterial near several subdivisions, caused a considerable number of complaints from nearby residential areas and required removal immediately after placement. Other attempts were well received from motorists. An informal survey of State of Alaska personnel reflected positive feedback regarding use of rumble strips for lane delineation on the Glenn Highway. Positive aspects reported included the improved ability to remain in the delineated lane during inclement weather. Of all lane line sections, section D received the most positive feed back.

Figure 2 Section D Lane Delineation

Centerline Rumble Strips

ADOT installed some centerline rumble strips on the Seward Highway south of Anchorage, Alaska. Some of these rumble strips were installed on marginal pavements and caused deterioration and potholing. In addition, complaints were received by local residents because of noise.

Other states have experimented with centerline rumble strips with good results. However, little research is available on this subject. Colorado published data showing a decrease in accidents on a two lane highway despite rising traffic counts.

Other states, such as Delaware, show similar experiences. Delaware installed centerline rumble strips on a 2.9 mile stretch of US301. When analyzing accident data before and after installation of rumble strips, fatalities and head on collisions decreased, however property damage and injuries increased. No analysis of whether accidents had merely migrated downstream of where they would have originally occurred was performed. Nor did they state if shoulder rumble strips were in place. (11)

CHAPTER 3 - INTERPRETATION, APPRAISAL, AND APPLICATIONS

General Recommendations

Installing a vibration-dampening device on the plow may decrease snowplow damage. Black Cat Blades manufactures the JOMA6000 Plow blade that incorporates carbide inserts in a rubber housing that attaches to a steel blade. The rubber insulates both the plow and the attached tractor from vibration resulting in reduced fatigue and stress on the machinery. This reportedly has the added benefit of being more pavement marking friendly as well. Iowa DOT tested this plow with good results. Urethane and rubber tipped blades are also reported to decrease vibration, however accelerated wear may occur.

Strategies for accommodation of bicyclists may include changing the length of the rumble strips so that more of the shoulder is usable by this class of users. However, accessibility for this group of users should be weighed against decreasing the rumble strips effectiveness in alerting non-attentive drivers. Decreasing the length of rumble strips correspondingly decreases the amount of time spent on the rumble strip and diminishes its warning.

Recommendations for Rumble Strips in Alaska

Based on available information and research conducted to date, the AKDOT&PF Research Section presents the following recommendations for the design and installation of rumble strips.

1. **Rolled vs. Milled** - Install milled rumble strips instead of rolled rumble strips.

2. **General Configuration**: The following configurations are recommended:

Table 6 Recommended rumble strip configuration

Location	Width Inches (mm)	Length Inches (mm)	Repeat Pattern Inches (mm)	Depth Inches (mm)
All speeds, with dedicated bike path or no bike traffic allowed	7” 178mm	16” 400mm	12” 305mm	0.5” 13mm
All speeds, with bike traffic	5” 127mm	16” 400mm	12” 305mm	0.5” 13mm

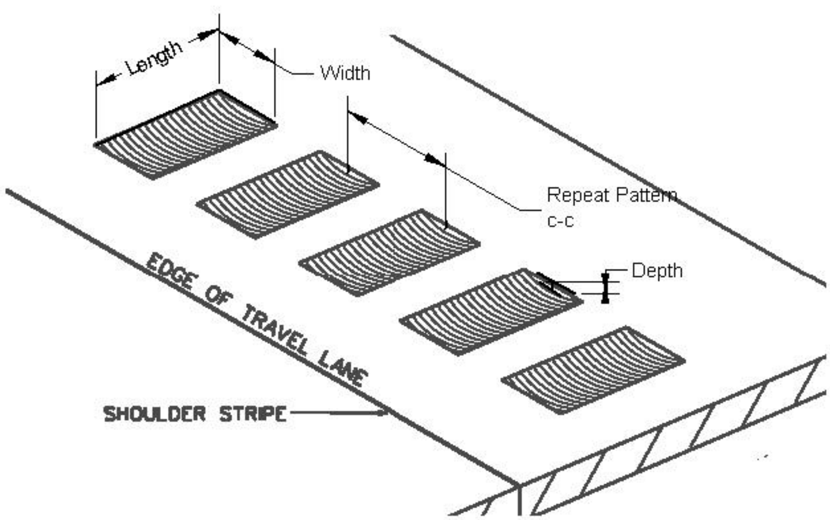

Figure 3 Rumble Strip Dimensions

3. **Centerline rumbles** - Do not install centerline rumble strips until additional information becomes available.

4. **Snow/Ice** - Installing rumbles only in areas where posted speeds are sufficient to keep the rumbles clear (45 mph [75 km/h] or greater).

5. **Bicycle friendliness** - To accommodate bicycle traffic:
    a. Install breaks (skips) in the rumble strip patterns. We suggest a conservative gap of 6-foot (1.8 m) breaks every 34 feet (10.2 m).
    b. Provide a minimum of 4 feet (1.2 m) of usable shoulder for bicycle traffic. Where guardrail is present, provide a minimum of 5 feet (1.5 m) between the outside edge of the rumble strip and the face of the guardrail.

6. **Placement –**
    a. Do not place rumbles in front of driveways and consider avoiding placing rumble strips in front of mailboxes.
    b. Do not place rumbles in freeway exit gores.
    c. On freeway entrance gores, place rumbles far enough to discourage early entrance without unnecessarily channeling merging traffic.
    d. Offset rumbles a minimum of 2 inches (50 mm) from the edge of the travel lane on both sides of the roadway.
    e. To ensure accurate placement of the rumble strips, consider establishing field control before installing rumble strips.

7. **Maintenance Concerns –**
    a. Assess pavement condition before installing the rumble strips.
    b. Do not install rumbles on any pavement exhibiting greater than 20% distress such as alligator and/or fatigue cracking.
    c. Do not install rumbles on bridge decks.
    d. Do not install rumbles on any pavement less than 2 inches (51 mm) thick.

8. **Configuration –**
    a. Due to the paucity of data on the effectiveness of various rumble widths (transverse to path of travel) in alerting errant drivers, we recommend installing rumbles not less than 12 inches (305 mm) in width until further information becomes available. Available information suggests that rumble strips should be effective between 12 and 16 inches (305 – 400 mm) in width.

Lane Delineation

Where lane delineation by rumble strips is used, it may be desirable to use rolled in rumble strips. Since rolled in rumble strips offer significantly less noisy formations, they may offer the best of visual interruption combined with less annoying aural presence. Further research on different configuration of rumble delineation should be pursued.

Removal of Rumble Strips

Removal of rumble strips may be accomplished by using the rumble machine to cut a continuous groove slightly wider and deeper than the originally placed rumble for the length of the section where removal is required. Patching the resulting trench renders the pavement whole once more. This strategy was successfully used on Minnesota Boulevard for removal of lane delineation rumble strips.

CHAPTER 4 - CONCLUSIONS AND SUGGESTED RESEARCH

Conclusions

A complete body of knowledge regarding all of the effects of utilizing rumble strips does not yet exist. However, given the effects defined in this report, we can still conclude that the benefits of installing rumble strips considerably outstrip the disadvantages. Many of the disadvantages concern three distinct groups of users, bicyclists, occupants of housing in proximity to rumble strips, and maintenance users. The undesirability of rumble strips to these users may be minimized with accommodations to specific discomforts either with better planning/design practices or by other means.

Suggested Research

Center of traveled lane rumble strips should work by targeting the driver side tire vs. the passenger tire, allowing a wider configuration to be installed and maximization of warning time, as well as accommodation to bicyclists.

Installing and monitoring experimental centerline rumble configurations may be useful until additional information becomes available. If centerline rumble strips are installed on an experimental basis, we recommend against installing them between lanes of opposing traffic where passing in either direction is legal.

Examination of the effect of rumble strips on equipment repair costs may offer important information for determining the true cost of rumble strips. Determining whether vibration dampening devices are effective in preventing rumble strip related damage to maintenance or snow removal equipment may also be of use.

Locating pavement markings adjacent to rumble strips seems to enhance preservation of the markings. It may be worthwhile to evaluate this effect in more detail, perhaps with durable pavement markings at varying distances or placed over the rumble strip.

Improved lane delineation configurations of rumble strips merits further research. Combining this with preservation of pavement markings by locating the markings on or very close to rumble strips may also be a profitable avenue for research.

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APPENDIX

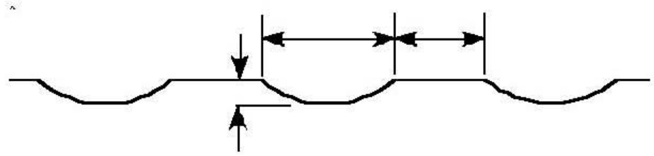
A1 Current Alaska Policy

Alaska DOT/PF Policy on Rumble Strip Installation

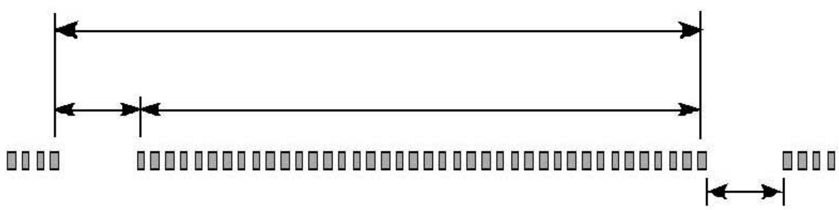
1. Installation Method: Milled rumble strips are more effective safety enhancements than rolled-in rumble strips. They should be used wherever their installation is feasible. In other cases, rolled-in rumble strips may be used as an interim treatment.

2. Lateral Width: 400 mm (16")

3. Longitudinal Milling Pattern: 175 mm (7") cut, 13 mm (_") deep, 125 mm (5") flat



4. Gaps for bicycles: Do not install gaps on roads where bicycles are prohibited. On other roads use a 1.8 m (6') gap and a 10.2 m (34') rumble on a 12.0 m (40') cycle). The gap and rumble dimensions given are measured from center to center of grooves. The gap width from edge to edge of groove is 1.6 m (5'5").



5. Offset between outside edge of shoulder stripe (and inside edge of rumble strip:
   - 1.8 m (6') Shoulders: 50 mm (2")
   - Wider Shoulders: 150 mm (6")

   Note that if lane-lines or centerlines are used as control for rumble strip alignment, the above offsets should be measured from where the shoulder stripe *should be*, rather than where it is.

6. Alignment: Consider using the centerline or lane-lines, rather than the shoulder stripe, as control for rumble strip alignment. This would require marking a new line, independent of the shoulder stripe, as a guide for rumble strip alignment. If this is done, re-stripe all locations where rumble strips overlap shoulder stripes or are inside of them. Existing striping should be removed at re-striped locations unless it has little effective life remaining. In no case should rumble strips be allowed to protrude on the inside of final striping.

5/23/01

7. Clear shoulder width outside of rumble strips:

   - Segments with guardrail: Provide at least 5' (1.5 m) between the edge of rumble strip and the face of rail (note that this precludes rumble strip installation on 1.8 m (6') shoulders with guardrail).
   - No guardrail: Provide at least 4' (1.2 m) between the edge of rumble and the edge of pavement.
   - Segments where bicycles are prohibited: No minimum.

   These width requirements apply to shoulders on climbing and passing lanes as well as other locations.

   A 150 mm (6") deviation from required clear widths is allowed for distances under 30 m (100'). If a width deficiency exceeds 150 mm or lasts longer than 30 m, the rumble strip shall be discontinued until the required clear width becomes available again.

   Care in maintaining clear width: As-built plans are often inaccurate. Shoulder width should be spot-checked during design and continuously checked during construction*.

8. Speed Limit: Do not install rumbles where the speed limit is 45 MPH or lower.

9. Centerline rumbles: Do not install centerline rumble strips unless you have written approval from me. Do not install centerline rumble strips, in any case, where it is legal to pass in either direction.

10. Lane-line delineating rumbles on multi-lane roads. Lane line rumble strips should not be wider than 150 mm (6") or have more than a 3.3 m (10') total length in any skip stripe cycle.

11. Break rumble strips for intersections, driveways and in front of multiple mailbox installations.

12. Do not install rumble strips on bridge decks, bridge approach slabs, or concrete weigh-in-motion slabs.

13. Do not place rumble strips in freeway exit gores. Terminate rumble strips 23 m (75') before exit ramp angle points.

14. Do not install rumbles on stripes separating through lanes from turning lanes.

15. Do not install rumbles on pavement with substantial alligator and/or fatigue cracking.

16. Do not install rumbles on shoulders that are to be overlaid or reconstructed in the near future.

17. Do not install rumbles on any pavement less than 51 mm (2") thick.

* During construction, width can be checked by fixing a 1.2 m (4') wide pointer bar (with an additional pointer at 1.05 m (3.5')) on the rumble strip milling machine.

5/23/01

Rumble Strip Policy
Background

The following discussion explains some of the decisions that went into the DOT&PF rumble strip policy.

Rumble Time – a Primary Consideration.

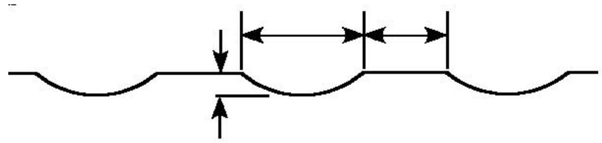
One important, but often overlooked, issue is the length of time errant drivers typically spend on rumble strips. Motorists who test-drive rumble strips, usually by driving on them for several seconds, often don't understand why the rumbles need to be so loud and aggressive. What they're missing is how brief rumble time is for drivers who are at risk of leaving the road – around 6/10 of a second of outside-tire rumble for drivers leaving at a 3 degree angle (less than 2/10 of a second if you only count the time the tire is in full-width contact with the rumble). Departures at greater angles result in even less rumble time. It takes a lot of noise and vibration to wake drivers in such a short time. For this reason, we need to be conservative with any modifications that reduce noise, vibration, or rumble time.

Milling Pattern

We have chosen the common 7" wide, _" deep cut pattern over the newer 5" cut patterns recommended by Pennsylvania DOT in their "Bicycle-Tolerable Shoulder Rumble Strips", 2000, for the following reasons:

1. 5" cut rumble strips are substantially quieter than 7" cut rumble strips.
2. 5" cut rumble strips are quieter yet for large-tired vehicles such as trucks and buses.
3. 5" cuts are slower to install and are consequently more expensive. According to Surface Preparation Technologies, the company that did the Central Region rumble strips last year, 5" / 3/8" cuts take more than four times as long to install as the 7" / _" cut installed in Central Region. This is because they have to slow much more for each 5" cut than they do for the more gradual 7" cut.
4. Surface imperfections result in a large depth variance in the 5" / 3/8" cuts (machine tolerance is a greater proportion of total cut depth).
5. There is little, or no, actual accident data on the effectiveness of 5" cuts. Pennsylvania has installed few of these on their roads as of May 2001.
6. Although a 5" / _" cut was list as one of the options in the PennDOT study (and was selected as the DOT&PF standard in the first draft of this policy), it is not possible to cut rumbles to those dimensions given the dimensions of the milling machine used (The 16" mill can't cut that deep with a 5" width).

Until additional testing and post-project crash analysis identifies patterns that are bicycle-friendly, effective, and economical, the department should stay with the pattern used in Central Region last year. This is the Sonic Nap Alert Pattern (SNAP) developed by the Pennsylvania Turnpike Authority in the mid 1990s. It is the pattern that most states with milled rumble strips use, according to the FHWA Rumble Strip Web Site, and the pattern that the outstanding safety record of milled rumble strips resulted from.



Sonic Nap Alert Pattern

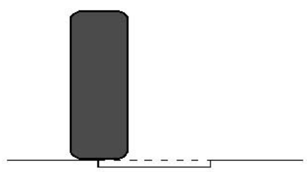
Rumble Strip Lateral Width.

The most common width of milled rumble strips in the U.S. is 16". This width has contributed to the outstanding crash-reduction record of rumble strips. We have been asked to change the standard width to 12" in Alaska.

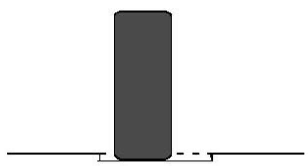
Going to a 12" width would allow us to provide more clear shoulder space for bicycles and/or greater offset from the shoulder stripe. On the other hand, it would reduce rumble time and, as a consequence, rumble strip effectiveness.

1. Effectiveness.

Sixteen inch rumbles sound significantly more substantial than twelve inch rumbles when crossed at an angle - more than you would expect from a 33% increase in width. To a large degree, this is due to the increased time tires are in full-width contact with the rumble.



Partial Tire-Width Rumble Contact



Full Tire-Width Rumble Contact

Full tire-width rumble contact allows the tire to fully drop into the rumbles. It is the loudest interval of a rumble strip crossing and is most effective at getting drivers' attention. Its duration *doubles* when rumble width increases from 12" to 16" (assuming an 8" tire contact patch).

Wider rumble strips also improve safety on intermittent rumble strips. Additional width reduces the probability of a car's outer tires driving through a gap without contacting the rumble.

2. Clear shoulder space.

The 12" width would give an additional 4" that could be used to widen the clear shoulder space. However, according to Central Region personnel, this rarely would have made the difference between having adequate and inadequate shoulder width on their rumble strip project. On roads with 8' or 10' shoulders, it never would have made that difference.

3. Offset

The additional 4" could also be used to increase the offset between the shoulder stripe and the rumble from 4" to 8". This would reduce inadvertent contact with rumble strips but would also limit the debris-free area available for bicyclists on the outside of the rumble. There is little agreement on how much of a benefit, or disadvantage, an increased offset would be.

In summary, going to 12" from 16" would trade an important safety advantage, half of the full-contact rumble time, for a less important consideration – 4" more space for shoulder or offset.

We should retain the 16" width that has proven effective throughout the nation.

Offset from Shoulder Stripe.

The Central Region shoulder rumble strips were installed at 4" from the edge of the shoulder stripe. Current recommendations by DOT&PF personnel range from 2" to 10".

Considerations:
1) Larger offsets would reduce the frequency of accidental rumble strip contact.
2) Larger offsets postpone the time when a dozing driver contacts the rumble, thus limiting the time and area available for recovery.
3) Larger offsets limit the clear width available for bicyclists.
4) Larger offsets move bicyclists further into the debris on the shoulder. Wind blast from cars keeps the inner part of the shoulder clear. This may result in bicyclists riding on the road side of the rumble strip.
5) Smaller offsets may improve striping longevity (due to drivers shying away from the rumbles)
6) Offsets larger than 6" would preclude the use of 16" rumbles on 6' shoulders. A 6" offset with a 16" rumble would allow no margin of error for varying pavement widths or stripe alignment.

To maintain room for larger rumbles and some margin of error for clear width for bicycles, the inner edge of rumble strips should be offset 2" from the outer edge of the shoulder stripe on 6' shoulders. On wider shoulders, which have more than the required clear width for bicyclists, an offset of 6" would reduce inadvertent rumble contact to some extent.

Gaps.

The ideal rumble strip gap pattern would allow all bicyclists at all speeds to cross without rumble contact but ensure that all departing automobiles at all departure angles would contact the rumbles for long enough to wake them. In practice, this is unattainable. The long, frequent gaps desired by bicyclists would result in some automobiles either missing the rumbles entirely or having too little rumble time to wake them.

Every gap pattern is a compromise between bicycle-friendliness and vehicle safety. Because we have to act with limited information (there is little data on the effectiveness of intermittent rumble strips), we should err on the side of vehicle safety.

The following facts are pertinent:

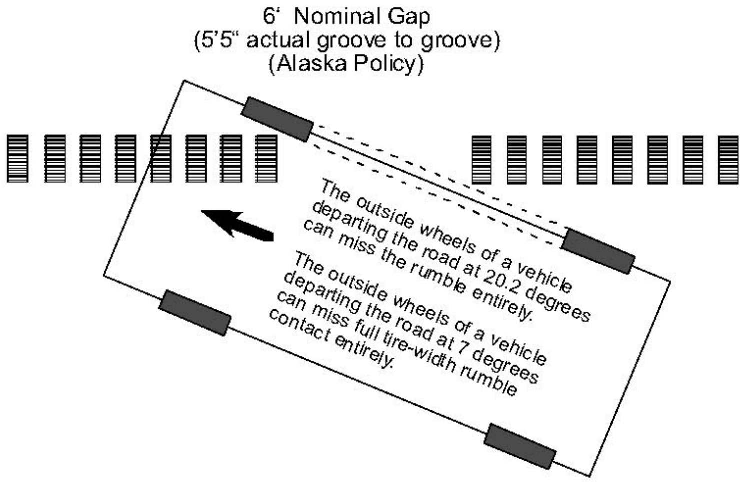
1. Florida is reportedly using a 7' rumble, 5' (4'5" edge to edge) gap pattern.
2. A recent Arizona study recommends either a 28' or a 48' rumble with a 12' gap.
3. The 12' gap recommended by the Arizona study was based on 100% of riders of varying abilities on different types of bikes being able to cross the gap without slowing from 25 MPH without touching a rumble on either side.
4. As shown on the roughly-to-scale drawings on the following page, gaps can significantly reduce the effectiveness of rumble strips, either by allowing drivers to miss them, or by reducing the duration and volume of rumble noise and vibration.
5. It is not difficult to drive off the road at an angle that would allow a car's outside tires to drive through a 12' gap without significant rumble contact. It is difficult to attain the angle necessary to clear a 5'5" gap. However, it is not difficult to attain the angle necessary to cross either with no full-tire-width rumble contact.
6. In addition to gap length, gap frequency plays an important part in the likelihood that rumble time will be reduced. Less frequent gaps reduce the probability that errant drivers will encounter them.

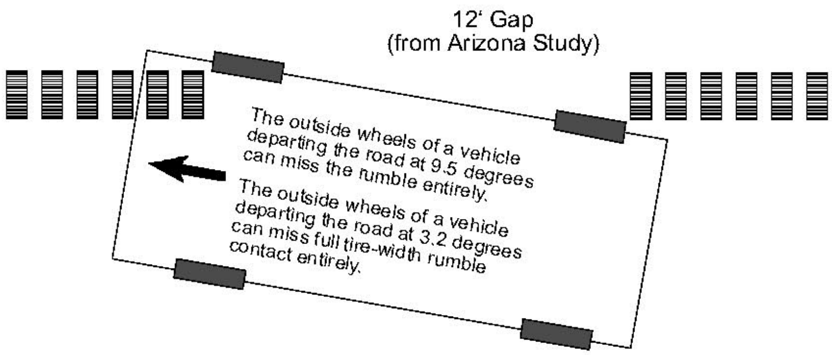
This information leads to no exact answer. However, because short gaps have the least negative impact on safety and still provide a significant benefit to bicyclists, they are the best choice.

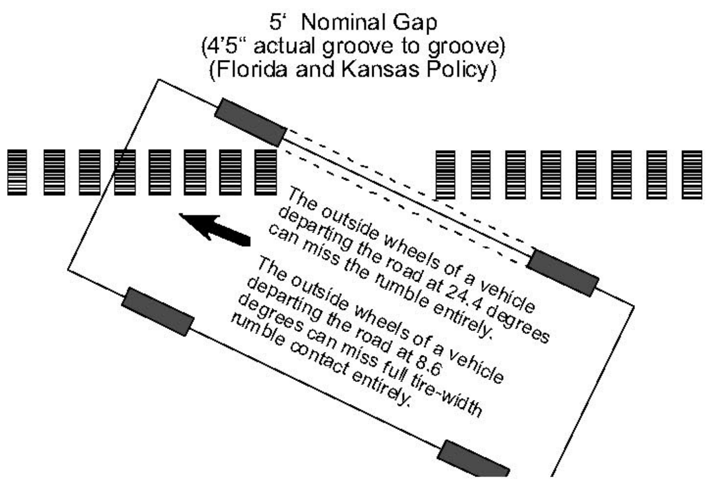
A one foot increase over the 4'5" gap used in Florida (and installed on Hiland Road) would make bicycle crossing a little easier. It would result in 14% gaps in the rumble strip, which reduces the probability of encountering them, and would require motorists to depart at an unusually high angle to entirely miss the rumbles. It requires high-speed bicyclists to either slow or clip a few rumbles as they cross the gap.

The 40' cycle recommended by the Arizona study provides crossing opportunities every 1.8 seconds for bicyclists traveling at their average speed of 15 MPH.

Consequently, go with 6' center to center (5'5" edge to edge) gaps every 40'.


6‘ Nominal Gap
(5’5“ actual groove to groove)
(Alaska Policy)
The outside wheels of a vehicle departing the road at 20.2 degrees can miss the rumble entirely.
The outside wheels of a vehicle departing the road at 7 degrees can miss full tire-width rumble contact entirely.


12‘ Gap
(from Arizona Study)
The outside wheels of a vehicle departing the road at 9.5 degrees can miss the rumble entirely.
The outside wheels of a vehicle departing the road at 3.2 degrees can miss full tire-width rumble contact entirely.


5‘ Nominal Gap
(4’5“ actual groove to groove)
(Florida and Kansas Policy)
The outside wheels of a vehicle departing the road at 24.4 degrees can miss the rumble entirely.
The outside wheels of a vehicle departing the road at 8.6 degrees can miss full tire-width rumble contact entirely.

A2 Current Alaska Rumble Strip Specifications

SECTION 406

RUMBLE STRIPS

406-1.01 DESCRIPTION. This work consists of forming a series of indentation bars into both shoulders of the pavement, where indicated on the Plans.

406-2.01 CONSTRUCTION REQUIREMENTS.

Form rumble strips in new pavement after breakdown rolling and before the surface temperature of the pavement falls below 80 °C, using one roller pass.

Begin the indentations 200 mm ± 50 mm beyond the edge of the traveled way and extend perpendicular to centerline.

The finished rumble strip shall conform to the following:

Length of indentation	450 mm ± 50 mm
Width of indentation	30 mm ± 10 mm (at pavement surface)
Depth	20 mm ± 5 mm
Spacing	225 mm ± 25 mm

The edges of the indentation shall be smooth and free of spalling.

Do not place rumble strips on side streets, where shoulder stripe is stopped, or where the shoulder is less than 1.2 m wide.

406-4.01 METHOD OF MEASUREMENT. Rumble strips will not be measured for payment.

406-5.01 BASIS OF PAYMENT. At the contract lump sum price, complete in place.

Payment will be made under:

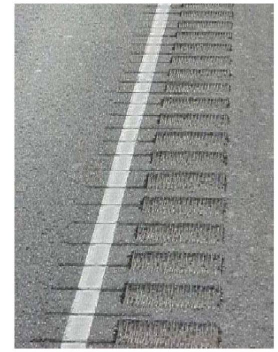
Pay Item	Pay Unit
406(1) Rumble Strips	Lump Sum

A3 AADOT Test Configurations

Notes:
Individual grooves of all milled rumble strips are 12" on center, 12" max radius, 7" long, with depth of a nominal 1/2" (stable asphalt) to a nominal 5/8" (where surface is chip seal)

Section	Description	Comments	GPS Latitude	GPS Longitude	Location of Noise meter reading	
Glenn Highway - Highland Road to Ft. Rich Interchange	**Lane line rumble strip configurations -**					
SECTION C - Southbound Glenn Highway between Highland Drive and the middle of the weigh station tangent.	8-inch wide lane line rumbles 2-feet long (3 grooves) on 20-foot spacing. This places the rumbles at the beginning and end of each existing skip stripe.	They give a less "tactile" feel than the Minnesota Drive delineation but are still fairly noisy. We are not sure about their "visual" effects. 2/2/00 -	61.17.280	149.35.779	On Curve	
SECTION D - southbound lanes of the Glenn Highway from the middle of the weigh station tangent to the middle of the National Guard Armory tangent	6-inch wide lane line rumbles 10-feet long with 30-foot breaks - our standard striping pattern	Even less "tactile" feel and noise than Section C, but better "visual" recognition. 2/2/00 - Delineatatiojn is positive. Noise is high when hit directly. Shoulder rumble on tangents are compeletely filled with debris. Photos 7-10	61.16.977	149.36.896	On Tangent	
SECTION E - southbound lanes of the Glenn Highway from the middle of the National Guard Armory tangent to the Fort Richardson Interchange	4-inch wide lane line rumbles 10-feet long with 30-foot breaks, centered between the existing 10-foot skip stripes (identical to Section D except 4 inches rather than 6-inches wide).	This section was intended to closely approximate the inverse of the raised ceramic "dot" pavement markers. They have almost no "tactile" feel, no noise, but seem to have less "visual" effect. These rumbles make the least noise, but there is still a sound that	61.15.970	149.38.248	On Curve	
Seward Highway - along Turnagain Arm						
SECTION A - Seward Highway along Turnagain Arm on curves greater that 2-degrees, most that are marked for no-passing zones. In several cases the rumbles overlap into the passing striping. On the new section between Girdwood and Bird Point (MP 90-97), the whole length of the centerline was grooved with rumbles.	Continuous 12-inch wide **centerline** rumble strip.	2/2/2001 - some ice buildup in rumbles. Much of traffic cuts across centerline rumble. Rumble noise is substantially higher than vehicle noise.	61.00.020	149.38.675	Rainbow Valley Residences - in driveway ~ 55 yds from centerline	
Minnesota Drive						
SECTION B - Minnesota Drive from "C" Street to the Old Seward Highway.	12-inch wide **lane line** rumbles 30-feet long with 10-foot breaks for the existing skip striping	This is the original Project design for Minnesota Drive and the Ingra-Gambell Street Couplet.				

Central Region Highway Shoulders	Shoulder rumble strip configurations -				
SECTION F -- EXISTING Central Region Highways	Continuous shoulder rumble strip that is rolled in at the time of paving. They are 18-inches wide on 8-inch spacing.	The disadvantage is that they are not noticed by larger vehicles, and can only be installed on new pavements.			
SECTION G -- New milled rumbles on Central Region Highways	Continuous 16-inch wide milled shoulder rumbles on 12-inch centers offset from the edge line 4-inches.	This was the design in the current Project, and the advantage is that they are effective on larger vehicles, and they can be installed at any time if the equipment is available.			
SECTION H - about 1 mile along the southbound lanes of Eagle River Loop Road.	12-inch wide shoulder rumbles 8-foot long with 5-foot breaks	projects a different noise when crossed, and gives a visually different edge marking. 2/2/00 - inside of curve is full of snow and ice. Photos 1-3	61.17.581	149.34.480	
Section I - ¼-mile section imediately preceding Section H	12-inch wide continuous shoulder rumbles.	2/2/00 - only inside of curve effective. Seems to be clearing out well. Photos 4-6, Traffic Prefers Left Lane	61.17.705	149.32.905	Distance ~45 feet opposite side of road from rumble, Peak reading = 101db



GENERAL OBSERVATIONS:

Sections (A, B and C) are probably more appropriate for 2-lane roadway separation to help prevent unintentional cross-overs.

A4 States Practices

Standard State Asphalt Milled Rumble Strip Practices											
State	Policy Date	Dwg Date	Written Policy (Y/N)	Rumble dimensions dependant on location (Y/N)	Bicycles considered (Y/N)	Distance from EOP/ edgeline	Length	Width	Repeat Pattern (c-c)	Depth (tolerances usually 1/8")	Comments
Alabama	Oct-93	Jul-99	Y	N	N	18"	16"	7"	12"	.5"	policy doesn't address milled rumbles
Alaska	May-01	May-01	Y	N	Y	2-6	16"	7"	12"	.5"	
Arizona	Mar-02	Feb-02	Y	Y	Y	0-10"	6-12"	7"	12"	3/8"	
Arkansas		Aug-02	N	N	N	4"	16"	7"	12"	.5"	
California	Sep-02	Sep-02	Y	N	Y	6"	12"			.33"	
Colorado		Dec-02			Y	0"	12"	5"	12"	3/8"	pattern: 12' gap followed by 48' rumbles
Connecticut		Oct-99	N	N	N	6-12"	16"	7"	12"	.5"	only state with removal specs
Delaware		1997	N	N	N	12"	16"	8"	12"	.5"	
Florida	Jan-98	Nov-93	Y	N	Y	16"	16"	7"	12"	.5"	pattern 5' gap followed by 7' rumbles or continuous, considers both logitudinal and transverse cuts, minimum 16" of 1/2" depth cut on both, longitudinal may be upto 12" longer due to cut method to achieve full depth.
Georgia			N	N		8 - 18"	16"	7"	12"	.5"	
Hawaii		Mar-03	N	N	Y	2"	12"	6 - 9"	12"	.5"	pattern: 13' gap followed by 47' rumbles
Idaho		Sep-02	N	N	Y	12"	12"	7"	12"	.5"	6-12' gaps recommended
Illinois	Dec-02	Jan-03	Y	N	Y	12"	16"	7"	12"	.5"	
Indiana		Mar-03	N	N	Y	6"	16"	7"	12"	.5"	pattern: 20' gap followed by 80' rumbles
Iowa	draft	draft	Y	N	Y	12"	16"	7"	12"	.5"	Pattern 12' gaps followed by 48' rumbles or continuous depending on location
Kansas	Mar-01	Mar-02	Y	N	Y	6"	16"	7"	12"	.5"	Pattern: 2m gap followed by 10 depressions
Kentucky	Jun-95	Dec-02	Y	N	Y	12"	16"	7"	12"	.5"	
Louisiana	Nov-97	Feb-03	N	N	N	6"	16"	7"	12"	.5"	
Maine			N			4"	16"	7"	12"	.5"	
Maryland	May-97	Jun-03	Y	N	Y	4-12"	16"	7"	12"	.5"	Draft policy in the works.
Massachusetts	Oct-02	1996	Y	N	N	10"	16"	7"	12"	.5"	
Michigan						1-2'	16"	7"	12"	.5"	
Minnesota	May-00	May-00	Y	Y	Y	4-24"	12-16"	7"	12"	.5"	pattern: 12' gap followed by 48' rumbles
Mississippi			N	N	N	12"	16"	7"	12"	.5"	
Missouri											
Montana	Jun-00	Dec-02	Y	N	Y	6"	12"	7"	12"	.5"	
Nebraska			N	N	N	6"	16"	7"	12"	.5"	
Nevada		Jan-01				0-6"	16"	7"	12"	.5"	
New Hampshire		Jul-01				6-30"	16"	7"	12"	.5"	
New Jersey		Dec-97				4"	16"	7"	12"	.5"	
New Mexico		Aug-98				12"	16"	7"	12"	.5"	
New York	Nov-98		Y	N	Y	4-6"	16"	7"	12"	.5"	
North Carolina	Jul-02	Jan-02	Y	N	N	20 - 36"	16"	7"	12"	.5"	
North Dakota	May-02	May-02	Y	Y	Y	12 - 24"	12 - 16"	6.5"	12"	.5"	patterned 10' gap followed by 40' rumbles or continuous
Ohio	Dec-96	Jul-00	Y	N	Y	6" - 6'	16"	7"	12"	.5"	
Oklahoma	Jul-00	Nov-02	Y	N	Y	12-24"	16"	7"	12"	.5"	
Oregon	Jul-99	Jul-02	Y	N	Y	12"	16"	7"	12"	.5"	
Pennsylvania	Jul-02	Jul-02	Y	Y	Y	0-6"	6/16"	5"	12"	3/8"	centerline: 7" wide, 14 - 18" long, 1/2" deep, 2' c-c spacing, may have 4' c-c gaps. Edgeline rumbles on stripe, no gaps.
Rhode Island			N	N	Y	4-12"	16"	7"	12"	.5"	Pattern: 5' gap followed by 15' rumbles
South Carolina		Jul-00	N			12"	18"	7"	12"	.5"	Double 4" x 4" Raised Yellow Pavement Marker 40' c-c between edgeline and rumbles
South Dakota		Mar-01				6-12"	16"	7"	12"	.5"	
Tennessee		special provisions 12/98				16"	16"	6"	12"	3/8"	
Texas		Jan-94	Y	N	Y	4-8"	16"	7"	12"	.5"	
Utah		Jul-02		Y	Y	0-12"	6-12"	8"	12"	5/8"	
Vermont				N	Y	6" - 30"	16"	7"	12"	.5"	
Virginia	Dec-02	Dec-02	Y	N	Y	6"	16"	7"	12"	.5"	
Washington	2002	Mar-03	Y	N	Y	6"	16"	7"	12"	.5"	pattern: 12' gap followed by 28' rumbles or 12' gap followed by 12' rumbles or 16' gap followed by 16' rumbles
West Virginia											
Wisconsin	Feb-03		Y			6-24"	16"	7"	12"	.5"	
Wyoming	Aug-01		Y	Y	Y		16"	7"	12"	3/8 or .5"	