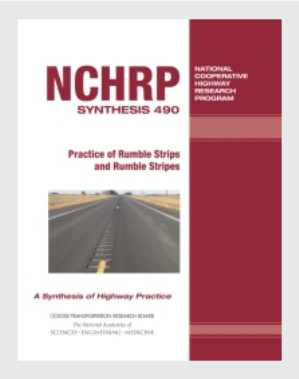


# Practice of Rumble Strips and Rumble Stripes

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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

# NCHRP SYNTHESIS 490

# Practice of Rumble Strips and Rumble Stripes

## *A Synthesis of Highway Practice*

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**SUBSCRIBER CATEGORIES**
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**NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM**

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**Cover figure:** A two-lane, two-way highway segment with a centerline rumble stripe on State Highway 109 just east of Winnebago, Minnesota. *Credit:* Smadi and Hawkins.

## FOREWORD

Highway administrators, engineers, and researchers often face problems for which information already exists, either in documented form or as undocumented experience and practice. This information may be fragmented, scattered, and unevaluated. As a consequence, full knowledge of what has been learned about a problem may not be brought to bear on its solution. Costly research findings may go unused, valuable experience may be overlooked, and due consideration may not be given to recommended practices for solving or alleviating the problem.

There is information on nearly every subject of concern to highway administrators and engineers. Much of it derives from research or from the work of practitioners faced with problems in their day-to-day work. To provide a systematic means for assembling and evaluating such useful information and to make it available to the entire highway community, the American Association of State Highway and Transportation Officials—through the mechanism of the National Cooperative Highway Research Program—authorized the Transportation Research Board to undertake a continuing study. This study, NCHRP Project 20-5, "Synthesis of Information Related to Highway Problems," searches out and synthesizes useful knowledge from all available sources and prepares concise, documented reports on specific topics. Reports from this endeavor constitute an NCHRP report series, *Synthesis of Highway Practice.*

This synthesis series reports on current knowledge and practice, in a compact format, without the detailed directions usually found in handbooks or design manuals. Each report in the series provides a compendium of the best knowledge available on those measures found to be the most successful in resolving specific problems.

## PREFACE

*By Donna L. Vlasak*
*Senior Program Officer*
*Transportation Research Board*

This synthesis documents current practices used by states installing rumble strips and explores variations in practice in terms of design, criteria, and locations for installation, maintenance, perceived benefits, communication of benefits, and what is considered as important issues.

Information was acquired through a literature review, survey on current practice, and case examples. The survey also included questions specific to the state of practice for rumble stripes, which is the term used when the pavement marking lines are painted on the rumble strip in an effort to increase visibility during inclement weather conditions.

Omar Smadi and Neal Hawkins, Iowa State University, Ames, Iowa, collected and synthesized the information and wrote the report. The members of the topic panel are acknowledged on the preceding page. This synthesis is an immediately useful document that records the practices that were acceptable within the limitations of the knowledge available at the time of its preparation. As progress in research and practice continues, new knowledge will be added to that now at hand.

# CONTENTS

Note: Photographs, figures, and tables in this report may have been converted from color to grayscale for printing. The electronic version of the report (posted on the web at www.trb.org) retains the color versions.

# PRACTICE OF RUMBLE STRIPS AND RUMBLE STRIPES


## SUMMARY

Rumble strips create audible and tactile warnings that alert a vehicle's driver as it crosses the center or edge line of a roadway. (When a pavement marking is applied over the rumble pattern, it is known as a rumble stripe.) Often these alerts are strong enough to get the attention of a distracted or drowsy driver, who can quickly make a corrective steering action to return to the roadway safely. Rumble strips can also alert drivers that they are on the edge of a lane in cases of low visibility conditions such as rain, fog, snow, or dust.

Research has shown that installing rumble strips can reduce severe crashes. Adding center line rumble strips resulted in a 45% reduction in crashes on rural two-lane roads and a 64% reduction on urban two-lane roads. Installing shoulder rumble strips reduced crashes by 36% on rural two-lane roads and by 17% on rural freeways.

Given the proven safety benefits from using rumble strips, many agencies are including them as part of their low-cost safety countermeasures. A survey of state DOTs showed that all of the 41 responding agencies install shoulder rumble strips and that 88% of those agencies also install center line rumble strips.

In contrast to other standardized safety countermeasures, such as signs or pavement markings, there are no national standards of practice for rumble strips, so their lengths, widths, gaps, applicable locations, and general maintenance can vary widely among agencies. In addition, how each agency chooses to address the common issues arising from the use of rumble strips, such as noise, bicycle and alternate use safety, and pavement deterioration—identified by the state agencies as the most problematic issues—adds further variation to the state of practice.

Given the wide use of rumble strips, the objective of this synthesis was to capture current practices used by states installing rumble strips and stripes and to explore variations in practice in terms of design, criteria and locations for installation, maintenance, perceived benefits, communication of benefits, and what are considered important issues.

A literature search on rumble strips and stripes from national and international sources was conducted before an online survey was sent to all of the state departments of transportation (DOTs) and Canadian provinces identified in the AASHTO Highway Subcommittee on Traffic Engineering. Forty-one (41) states, 82%, responded to the survey, as well as two Canadian provinces, Nova Scotia and Saskatchewan. The analysis of survey data was based only on the state DOT responses, although the two surveys from Canada indicated those agencies had similar practices. That was followed by an in-depth analysis of how the state DOTs have addressed issues related to noise, bicycle concerns, pavement deterioration, and explaining the benefits of rumbles.

The survey results document how varied state DOT practices are when it comes to designing, installing, and maintaining rumble strips and stripes. These include how agencies decide where rumbles are installed (urban vs. rural roadways, four- vs. two-lane roads, and undivided vs. divided roads); the dimensions of rumbles (length, width, spacing, and depth); whether to seal surfaces or not; and how to re-apply pavement marking in the case of a rumble stripe application.

The findings from the survey, indicated here, are addressed in detail in chapter five: Conclusions and Suggestions for Further Research.

To address the noise issue, two-thirds of the state agencies rely on traditional methods: skipping rumbles in residential areas, adjusting their depth, or not installing rumbles at all. The overwhelming majority of responding states, 83%, have developed policies or guidance to modify their rumble design practices to be sensitive to cyclists. Fewer than half the respondents have developed policies/guidance to address pavement deterioration; several agencies indicated that pavement condition is a factor on whether to install a rumble or not.

The survey also showed that very few state DOTs have created public campaigns to explain that the use of rumbles improves safety so that complaints regarding noise, bicycle issues, and other are minimized.

Based on the results from the literature search and the survey, several indicated gaps in current knowledge that could be addressed by further research are listed in chapter five.

CHAPTER ONE

# INTRODUCTION

Rumble strips and stripes are a low cost safety countermeasure used to reduce roadway and lane departure crashes; however, their use and installation in various states are not uniform and there may not be one ideal design for all applications to deliver the auditory and tactile cues required to warn the drivers to correct their path.

To address the problem of single vehicle run-off-road crashes, many transportation agencies use shoulder rumble strips or stripes to alert inattentive drivers that their vehicles have drifted out of the travel lane. Because of the documented safety benefits of shoulder rumble strips and their relatively low installation cost, transportation agencies are applying shoulder rumble strips on a widespread basis. Originally, rumble strips were installed primarily on rural freeways, but now transportation agencies are installing shoulder rumble strips along divided and undivided highways in both rural and urban areas.

Transportation agencies have also expanded their application of rumble strips and stripes to include installations along the center lines of undivided highways. The primary purpose of center line rumble strips and stripes is to reduce head-on crashes, opposite-direction sideswipe crashes, and, to some degree, single vehicle run-off-the-road to the left crashes; however, installing rumble strips and stripes either along the shoulder or on center lines, without considering the impacts on other highway users, may lead to unintended consequences.

## SYNTHESIS OBJECTIVES

The purpose of this synthesis is to identify current practices used by states installing rumble strips and stripes in the expectation that it may assist transportation agencies, researchers, and the road-building industry in identifying successful approaches. The scope of this synthesis study focuses primarily on the following aspects:

- Rumble designs–patterns, locations, pavement types and widths, etc.
- Expected safety benefits or crash mediation in poor visibility conditions
- Tolerances for installation
- Roadside noise
- Impacts on bicycle community
- Public outreach and education
- Maintenance and durability issues
- Other concerns identified through the survey.

This list was categorized into six categories:

- State departments of transportation (DOTs) general rumble practices
- Roadway selection criteria
- Design and installation
- Maintenance practices
- Benefits
- Issues.

With the cooperation and feedback of the NCHRP synthesis panel, an online survey was developed for distribution to the state DOTs and Canadian provinces. The survey was sent to the members of the AASHTO Highway Subcommittee on Traffic Engineering. After several months and follow-ups, the survey was closed, with 41 state DOT (82% response rate) respondents and two Canadian provinces responding.

## KEY DEFINITIONS

The following definitions, used in the questionnaire, were adapted from the FHWA guidance document on rumble strips and stripes (FHWA 2015):

- A **shoulder rumble strip** (example below) is a longitudinal safety feature installed on a paved roadway shoulder near the outside edge of the travel lane. It is made of a series of milled or raised elements intended to alert inattentive drivers (through vibration and sound) that their vehicles have left the travel lane. (FHWA definition).

- A **shoulder rumble stripe** (example below) is a special type of shoulder rumble strip placed directly at the edge of the travel lane with the edge line pavement marking placed through the line of rumble strips.

- A **center line rumble strip** (example below) is a longitudinal safety feature installed at or near the center line of a paved roadway. It is made of a series of milled or raised elements intended to alert inattentive drivers (through vibration and sound) that their vehicles have left the travel lane. (FHWA definition).

- A **center line rumble stripe** (example below) is a longitudinal safety feature at or near the center line and created when the center line pavement marking is placed over the center line rumble strip.

- A **bicycle gap pattern** describes a roadway stretch clear of rumbles (typically between 10 and 12 feet) followed by a series of rumbles (typically from 40 to 60 feet).
- An **intermittent gap** is a gap created between continuous application of the rumble line for pre-determined situations such as intersections, major driveways, bridge decks, etc.
- **Dimensions of rumble strips and stripes** (illustrated in Figure 5 in chapter three):
  *Length:* Dimension of the rumble strip measured lateral to the travel way. This dimension is sometimes referred to as the transverse width.
  *Width:* Dimension of the rumble strip measured parallel to the travel lane.
  *Spacing:* Distance measured between rumble strips patterns. Typically this dimension is measured from the center of one rumble strip to the center of the adjacent rumble strip, or it could be measured from the beginning of one rumble strip to the beginning of the adjacent rumble strip. Typical terms used to describe this dimension are on-center spacing, spacing on-center, center-to-center spacing, or simply "spacing."
  *Depth:* Dimension is the vertical distance measured from the top of the pavement surface to the bottom of a rumble strip pattern. This distance refers to the maximum depth of the cut or groove.

## REPORT ORGANIZATION

The synthesis is organized into five chapters and three appendices.

Chapter one contains introductory information, including background, objectives and scope, and key definitions.

Chapter two summarizes a literature review, which was conducted to explore different rumble strip and stripe practices included in the synthesis; and lists references (included in the bibliography) that may aid future researchers and practitioners interested in this topic.

Chapter three documents the survey results from the 41 responding state DOTs. The two Canadian provinces had very similar practices to the state DOTs, however, they are not included in the survey results and analysis.

Chapter four provides an in-depth analysis of key issues—noise, bicycle concerns, safety benefits, and pavement deterioration—identified from the synthesis results and case examples, and how some state DOTs are addressing those issues.

Chapter five summarizes the synthesis findings and conclusions, and offers suggestions on future research that may advance the rumble strip and stripe state of the practice within state DOTs.

Appendix A replicates the survey; Appendix B lists the survey participants; and Appendix C offers selected agency survey responses.

CHAPTER TWO

# LITERATURE REVIEW

A rumble strip is a raised or grooved pattern placed on the pavement surface of a travel lane or shoulder, intended to warn drivers that their vehicles have partially or completely left their intended travel lane or that a critical maneuver may be needed (Torbic et al. 2009). Noise generated as the vehicle tires traverse the rumble strip provides an audible warning, while vibrations induced by the rumble strips provide a tactile warning.

Rumble strip applications fall into the following general categories: shoulder, center line, and transverse. (This synthesis does not address transverse rumble strips.) There are generally four types of rumble strips: milled, rolled, formed, and raised, which differ by the installation method, shape, and size (Torbic et al. 2009).

Milled rumble strips, the most common, are easily installed on new or existing asphalt and Portland cement concrete surfaces, and they produce a great amount of noise and vibration. This type is made by a milling machine, which cuts a groove in the pavement surface.

Rolled rumble strips must be installed when the constructed or reconstructed pavement surface is compacted. Grooves are pressed into the hot asphalt surface by a roller with steel pipes welded to the drums. Depressions are created as the roller passes over the hot asphalt surface.

Formed, or corrugated, rumble strips are installed along concrete surfaces. Grooves or indentations are formed into the concrete surface during the finishing process.

Raised rumble strips are installations of material, such as asphalt bars or raised pavement markers, that adhere to new or existing pavement surfaces. There are some restrictions on using raised rumble strips in regions with winter maintenance operations.

## RUMBLES AND SAFETY

According to FHWA, more than half (57%) of U.S. traffic fatalities occur after a driver crosses the edge or center line of a roadway. Two-thirds (65%) of these fatal crashes occur in rural areas. Many factors contribute to drivers leaving the roadway or straying from their lane. These include driver fatigue and drowsiness; distracted driving; poor traction between vehicles and road surfaces (friction issues); and poor visibility in adverse weather conditions such as rain, fog, snow, or dust storms. Driver fatigue can occur when long, monotonous stretches of highway reduce the driver's concentration. These factors are sometimes compounded by driving too fast. Alcohol and drugs can contribute to both fatigue and speed.

There have been multiple studies assessing the safety effectiveness of both shoulder and center line rumble strips carried out by state DOTs and some at the national level. The FHWA website on rumble strips provides valuable information on those safety benefits and summarizes the findings of those studies (FHWA 2015a). The results from these studies led to the inclusion of rumble strips in the crash modification factors clearing house (CMF website), which is funded by FHWA and maintained by the University of North Carolina Highway Safety Research Center (CMF 2015). Data from the CMF website shows that in general, shoulder rumble strips reduce run-off-the-road crashes between 30% and 40% while center line rumble strips reduce cross-over crashes by 40% to 60%. Research has shown that installing center line rumble strips can reduce severe crashes by almost half (45%) on rural two-lane roads and by nearly two-thirds (64%) on urban two-lane roads; and that installing shoulder rumble strips can reduce crashes on rural two-lane roads by more than a third (36%) and by 17% on rural freeways (Torbic et al. 2009).

## RUMBLES AND NOISE

In addition to the noise that the rumble strip creates inside the vehicle to warn the driver, noise is created outside the vehicle that can be a nuisance to residents and businesses near the highway. The challenge for transportation agencies is to design and install rumble strips that provide enough warning noise inside the vehicle while at the same time trying to minimize outside noise. FHWA has developed a fact sheet that includes information on rumble strip placement issues and design flexibility to reduce noise (FHWA 2015b), but more studies examine the impact of pavement type, vehicle speed, and rumble strip characteristics on the in-vehicle noise than address the exterior noise issue.

Multiple studies have attempted to quantify the additional noise resulting from the installation of shoulder and/or center line rumbles strips, but none provided definitive noise values. Mostly, state DOTs try to mitigate the noise issue by installing the rumble strip farther away from the pavement edge (which might lessen its effectiveness because the driver

will have less time to react), not installing rumbles in residential areas; or by cutting off the rumble before driveways.

The Minnesota DOT recently completed a study on "Rumble Strip Noise Evaluation" (Terhaar and Braslau 2015) that looked at different rumble strip designs and their impact on noise. The research compared three different rumble strip designs based on designs used by the California DOT (Caltrans), Pennsylvania DOT (PennDOT), and Minnesota DOT (MnDOT). The three designs differed in rumble strip length, depth, and width (see chapter four: Case Examples). The results concluded that the Caltrans sinusoidal design provides similar in-vehicle noise levels to Minnesota's design, but with reduced exterior noise levels dependent on vehicle type and speed.

### RUMBLES AND PAVEMENTS

The impact of the rumble strip installation on the pavement condition (or accelerated deterioration) is not very clear from the literature review, as not many articles were found that addressed this issue. FHWA states on its rumble strip website (FHWA 2015a) that

> Maintenance crews were initially concerned that heavy traffic would cause shoulder pavements with rumble strips to crumble faster, or that the freeze-thaw cycle of water collecting in the grooves would crack the pavement. These worries have proved to be unfounded where rumble strips were installed in pavements in fair to good condition. Rumble strips have little if any effect on the rate of deterioration of new pavements.

The FHWA statement is specific to pavements in fair to good condition, which is why some state DOTs have made this as a criterion to installing rumble strips.

Some state DOTs try to address the uncertainty of the impact of the rumble strip on pavement condition by applying a sealant over the rumble to prevent water damage.

In a 2005 NCHRP synthesis on center line rumble strips (Russell and Rys 2005), a survey question asked about problems with water accumulating in the rumble strips, either for drivers or for pavement deterioration. Fifteen (15) of 24 respondents answered that there is no effect on pavement deterioration or problems for drivers because of water accumulation in the rumble strips, seven replied "can't say," and two—Alaska and Oregon—answered that they had experienced some problems. Alaska reported that it has noted pavement deterioration only when rumbles were installed in chip seals or otherwise compromised pavements. It also commented that sometimes snow or ice will compact into rumbles and persist for a short time after a storm, but that traffic eventually clears them. Oregon responded that water accumulation can lead to premature pavement deterioration. This again shows conflicting or insufficient information exists to answer this question.

For a study by MnDOT on the maintenance effects of rumble strips on hot mix asphalt pavements and what effect they might have on the service life of the pavement, a survey was sent to all 87 counties and the eight DOT districts. Most respondents either noted the presence of distresses in rumble strips, or were concerned that the rumble strips were the direct cause of distresses (Watson et al. 2008).

Another issue with rumble strip installation concerns concrete pavements where the longitudinal joint (either edge or center line) could be impacted by the rumble strip. Some state DOTs do not install rumble strips in concrete pavements because of the potential negative impact on the joint and the eventual impact on the pavement life. Again, not many research studies were found to address this issue, and those that exist offer conflicting conclusions. Two state DOTs, Michigan and Kentucky, have done some research that will be discussed in chapter four: Case Examples.

CHAPTER THREE

# SURVEY RESULTS

This chapter presents the results from the survey to which 41 state DOTs responded. The survey consisted of six main sections:

1. Rumble strip practices (three questions)
2. Selection criteria (three questions)
3. Design and installation practices
   a. General (nine questions)
   b. Shoulder rumble strips (seven questions)
   c. Center line rumble strips (six questions)
   d. Rumble stripes (seven questions).
4. Maintenance practices (10 questions)
5. Benefits (eight questions)
6. Issues (11 questions).

The survey questions are included in Appendix A.

## RUMBLE STRIP PRACTICE

Rumble strips are a low cost safety countermeasure used to reduce roadway/lane departure crashes. Table 1 shows that all of the 41 responding agencies reported that they use rumble strips. Table 2 shows that 37 (90%) of these agencies have a policy or guidance specific to the application of rumble strips.

Unlike most traffic control devices, where shape, size, and installation criteria are established, rumble strip installations can vary by the types of roads, the shapes and patterns used to install them, and the maintenance practices which keep them effective.

## RUMBLE STRIP SELECTION CRITERIA

The variation in rumble strip practice is often a result of influencing factors including roadway features, user groups, traffic volume, speed limit, pavement condition, available lane and shoulder widths, and other impact factors including sensitivity to noise generated within residential areas. State feedback on these influencing factors for rumble strip installations is explored here.

### Rumble Strip Practice by Roadway Type

Table 3 provides a summary of DOT practices for installing rumble strips by the type of roadway and rumble strip position on the roadway. Overall, results show that rumble strips are mostly applied in rural settings and that installation varies by the type of rumble strip considered.

#### *Urban Versus Rural*

Rumble strips are much more prevalent in rural settings, which typically have less dense housing and roadways with a higher frequency of single-vehicle run-off-road and cross-center line crashes. As shown in the "None" column in Table 3, all but one of responding agencies use some type of rumble strip on rural roadways. In contrast, 59% report not installing rumble strips on urban multilane divided highways, 73% do not use them on urban multilane undivided roadways, and 76% do not use rumble strips on urban two-lane roadways.

#### *Common Practice by Rumble Strip Type*

Agency practices show that a right shoulder rumble is the most common in rural settings, followed by left shoulder rumbles on rural multilane divided roadways and then center line rumble on two-lane rural roads. Additional discussion from Table 3 shows that:

- The right shoulder/passenger side rumble on rural multilane divided highways has the highest use of any rumble strip type, by 95% of responding agencies. Use of this rumble type is consistent with efforts to address single vehicle run-off-the-road crashes, particularly in rural settings. This is followed by 85% usage on both rural multilane undivided and rural two-lane roadways.
- Left shoulder/driver side rumble strips are most often installed by agencies on multilane roadways, especially on rural multilane divided highways (88% usage). In addition, 37% reported using left shoulder rumbles on urban multilane divided highways, which is within settings that allow for the balance between crash prevention and noise. Last, 39% reported installing left shoulder rumbles on rural multilane undivided roadways and rural two-lane roads, responses that may reflect some confusion concerning the question or special roadway conditions.
- Center line rumble strips were applied on rural two-lane roads by 71% of respondents, which is consistent with efforts to reduce cross-center line crashes.

TABLE 1
AGENCY USE OF RUMBLE STRIPS (survey question 1)

| Does Your Agency Use Rumble Strips? | Number of Agencies | Percent |
|---|---|---|
| Yes | 41 | 100 |
| No | 0 | 0 |

41 responding agencies.

TABLE 2
APPLICATION GUIDELINES AND POLICIES (survey question 2)

| Does Your Agency Have a Written Policy/Guidelines Concerning the Application of Rumble Strips? | Number of Agencies | Percent |
|---|---|---|
| Yes | 37 | 90 |
| No | 4 | 10 |

41 responding agencies.

### Conditions Influencing Rumble Strip Installation

Given that all 41 responding state DOTs use rumble strips, it is important to understand the factors that influence installation guidelines, and policies that contribute to variation in practice. The survey listed some common influencing factors, including shoulder width, pavement condition, and speed limit; and requested that states report their minimum required values for each applicable factor. Table 4 shows those results by shoulder and center line.

#### *Shoulder Rumble Strip Installation*

Table 4 indicates that having sufficient shoulder width is the most frequent criterion considered, with 37 agencies reporting a range in width of between two and eight feet. Speed limit was the second most frequently listed factor; 25 agencies reported installing shoulder rumbles on roadways having a posted speed higher than 40 mph and as high as 55 mph. Other common factors were reported by 19 agencies, including consideration of lane width, bicycle use, adjacent home locations, and roadway type. Agencies are also considering the quality of the pavement surface before installing rumble strips, as reflected by the 18 agencies noting that the pavement must be in "good" condition and typically asphalt rather than concrete or treated surfaces. Only 11 agencies, just over a quarter, use crash frequency or rate as a criterion for installation.

#### *Center Line Rumble Strip Installation*

Table 5 shows that having sufficient lane width is the most common criterion considered in center lane installations, with 22 agencies reporting a range in width of between 10 and 12 feet. Twenty (20) agencies identified the presence of homes, noise, functional classification, and urban versus rural setting as other factors. Speed limit is considered by 18 agencies, with the majority listing a minimum of a posted speed of 45 mph and the range being from 35 to 55 mph. As with shoulder rumble strips, agencies are looking to install on pavement in "good" condition. However, in contrast to shoulder rumbles, 13 agencies noted considering crash frequency for locations which either have a crash history or more than average head-on collisions.

TABLE 3
RUMBLE STRIP INSTALLATIONS BY ROADWAY TYPE AND RUMBLE STRIP LOCATION (survey question 4)

| Type of Roadway | None | Left Shoulder (median) | Center Line | Right Shoulder (outside) | Responses |
|---|---|---|---|---|---|
| Urban Multilane Divided Highways | 59% | 37% | 5% | 41% | 41 |
| Urban Multilane Undivided Highways | 73% | 7% | 12% | 27% | 41 |
| Urban Two-Lane Roads | 76% | 5% | 15% | 22% | 41 |
| Rural Multilane Divided Highways | 5% | 88% | 5% | 95% | 41 |
| Rural Multilane Undivided Highways | 5% | 39% | 59% | 85% | 41 |
| Rural Two-Lane Roads | 5% | 39% | 71% | 85% | 41 |

41 responding agencies.

TABLE 4
INFLUENCING FACTORS FOR SHOULDER RUMBLE STRIP INSTALLATION (survey question 5)

| Influencing Factor | Number of Agencies | Percent | Minimum Required Values/Explanation |
|---|---|---|---|
| Shoulder Width | 37 | 93 | Between 2 and 8 ft |
| Speed Limit | 25 | 63 | Between 40 and 55 mph with the most common answer at 45 mph |
| Other (please specify) | 19 | 48 | Factors include lane width, bicycle presence, home locations, roadway type |
| Pavement Condition | 18 | 45 | Good condition |
| Crash Frequency/Rate | 11 | 28 | |
| Pavement Type | 10 | 25 | Mostly asphalt and no treated surfaces (microsurface, seal coat, and chip seal) |
| ADT | 3 | 8 | |
| Alignment: | 1 | 3 | |

40 responding agencies.
ADT = average daily traffic.

## DESIGN AND INSTALLATION PRACTICES

These questions focused on understanding the state of practice for rumble strips and stripes in terms of how, when, and under what conditions they are used. The questions were asked, and are reported here, by category (general, shoulder rumble strips, center line rumble strips, and rumble stripes).

### General

Agencies were surveyed regarding general rumble strip and stripe installation practices including the use of a sealant over the rumble, whether they measure in-place rumble dimensions, and if they have performance targets for rumble performance.

#### *Use of a Sealant over Rumble Strips*

Rumble strips can allow water to pool and increase the exposed pavement surface area. Some agencies address this through the application of a sealant over the rumble. Figure 1 shows the current state of practice, with 44% of agencies reporting using a sealant; however, of these, 15% note that this is not standard practice. More than half, 56%, do not use any sealant. Of the agencies that use a sealant, the common reasons were to slow pavement deterioration and protect against moisture.

#### *Field Measurement of Installed Rumble Strip Dimensions*

Establishing rumble strip dimensions is critical in producing the audible and tactile ranges necessary for their effectiveness. Given that construction practices include tolerances and that installation techniques and contractor quality processes can vary, agencies were asked if they measure post-construction rumble strip dimensions. Figure 2 shows that more than two-thirds of agencies, 28 or 68%, do measure these field dimensions; however, only eight of that 28, or 20% or respondents, reported having a fully defined method to check these dimensions. Figure 3 shows that the most common field measurements are spacing, depth, and width, at 96%, 96%, and 93% respectively.

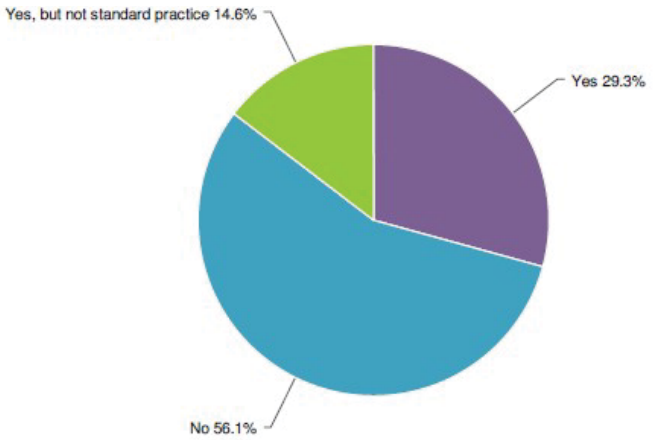
#### *Electronic Database of Rumble Strip Locations*

Having an accurate record of rumble strip locations, patterns, and dimensions is critical towards evaluating the impact these

TABLE 5
INFLUENCING FACTORS FOR CENTER LINE RUMBLE STRIP INSTALLATION (survey question 6)

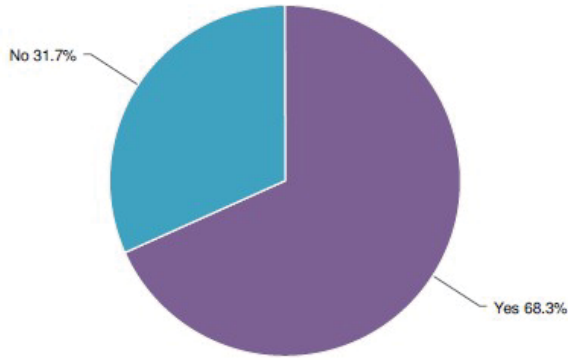
| Influencing Factor | Number of Agencies | Percent | Minimum Required Values/Explanation |
|---|---|---|---|
| Lane Width | 22 | 58 | Between 10 and 12 ft |
| Other (please specify) | 20 | 53 | Factors include homes, noise, functional class, and rural |
| Speed Limit | 18 | 47 | Between 35 and 55 mph with the majority at 45 mph |
| Pavement Condition | 17 | 45 | Good condition |
| Crash Frequency/Rate | 13 | 34 | Locations with a crash history or above average head-on crashes |
| Pavement Type | 9 | 24 | Mostly asphalt |
| ADT | 4 | 11 | |
| Alignment | 1 | 3 | |

38 responding agencies.
ADT = average daily traffic.



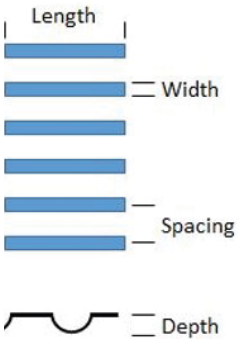

| | | | |
|---|---|---|---|
| Yes | 29.3% | | 12 |
| No | 56.1% | | 23 |
| Yes, but not standard practice | 14.6% | | 6 |
| | | Total | 41 |

FIGURE 1 Use of a sealant over rumble strips (survey question 7).




| | | | |
|---|---|---|---|
| Yes | 68.3% | | 28 |
| No | 31.7% | | 13 |
| | | Total | 41 |

FIGURE 2 Field measurement of rumble strip dimensions (survey question 8).




| | | | |
|---|---|---|---|
| Length | 88.9% | | 24 |
| Width | 92.6% | | 25 |
| Depth | 96.3% | | 26 |
| Spacing | 96.3% | | 26 |
| Pattern | 77.8% | | 21 |
| | | Total | 27 |

FIGURE 3 Measuring rumble strip dimensions in the field (survey question 11).

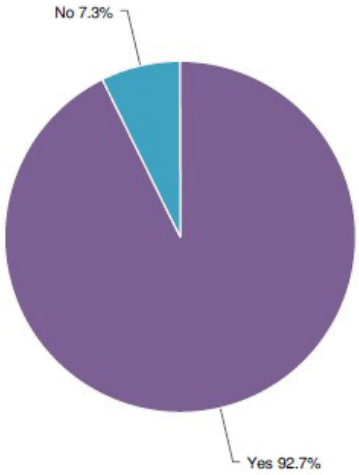
countermeasures are having on safety. When this information is tied to an agency's location referencing system, it allows for integration with other data sets such as crash experience. The survey found that 17 agencies (42%) have an electronic database of their installed rumble strip locations, but that 24 agencies do not. Of the 17 agencies responding affirmatively, 13 have tied the information to their location referencing system. This could provide the basis for conducting a national study on the effectiveness of rumble strips and stripes on safety.

### *Specifications for Desired Audible and Tactile Ranges*

Agencies were asked if they use audible and tactile specifications that an installed rumble strip should produce. Thirty-nine (39) agencies reported having no specific ranges; one reported using a specification for interior sound warnings (Arkansas, which uses a ½-inch rumble depth to produce 6 db at 65 mph); and one agency reported a standard for exterior sound (Delaware, which measures noise outside the vehicle at a distance of 275 to 350 feet).

### *Specifications for Rumble Strip Pattern*

Agencies were asked if they have a specification regarding the pattern to be used when installing rumble strips (Figure 4). Thirty-eight (38) agencies, 93%, reported using a specification for rumble strip patterns. The patterns (locations where rumbles are omitted) are applied to bicycle-friendly areas as well as intersections, bridge decks, and residential areas.




| | | | |
|---|---|---|---|
| Yes | 92.7% | | 38 |
| No | 7.3% | | 3 |
| | | Total | 41 |

FIGURE 4 Specification for rumble strip pattern (survey question 16).

TABLE 6
SHOULDER RUMBLE STRIP LOCATION FROM EDGE LINE (survey question 17)

| Inches from Edge Line | Number of Agencies | Percent |
|---|---|---|
| 0 | 7 | 17 |
| 4 | 7 | 17 |
| 6 | 12 | 29 |
| 12 | 3 | 7 |
| 16 | 2 | 5 |
| 18 | 1 | 2 |
| Varies | 9 | 22 |

41 responding agencies.

TABLE 7
REASONS AGENCIES CREATE INTERMITTENT GAPS WITHIN SHOULDER RUMBLE STRIPS (survey question 21)

| Gaps Created For: | Number of Agencies | Percent |
|---|---|---|
| Bridge Decks | 30 | 79 |
| Other | 29 | 76 |
| Noise | 22 | 58 |
| Bicycles | 17 | 45 |
| Special Users | 6 | 16 |

38 responding agencies.

### Shoulder Rumble Strips

*Shoulder Rumble Strip Placement Location*

Agencies were asked how close to the pavement edge line they install shoulder rumble stripes. Table 6 shows that the reported results range from 0 (i.e., directly on the edge) to 18 inches, with the most common answer being 6 inches (12 responses, or 29%).

*Types of Rumble Strip Patterns Installed*

Rumble strip pattern affect the sound levels produced; for example closely-spaced rumble strip patterns are expected to have a higher sound level difference than patterns spaced further apart. Agencies were asked what types of rumble strip patterns they install, between the choices of continuous, pattern (gap/cycle), or bicycle gap pattern. The findings show that 34 agencies, 83%, use the continuous pattern (mostly on divided highways), 14 agencies use the gap/cycle pattern, and 24 agencies use the bicycle gap pattern. Specific to the bike pattern, half of the states use a 12-foot gap with 48 feet of rumble. The smallest bike gap was 10 feet and the widest was 16 feet.

*Intermittent Gaps Installed for Rumble Strips*

Agencies routinely create intermittent gaps between continuous applications of the rumble line for pre-determined situations such as intersections, major driveways, bridge decks, and noise sensitive areas. Agencies were asked to identify if they used intermittent gaps, and if so, what factors determined where used. Table 7 shows the reasons gaps are created, the most common responses being bridges, "other," and noise, at 30, 29, and 22 agencies, respectively. For the gaps categorized as "other," the most common answers included urban areas (high driveway densities), poor pavement, horse and buggy areas, railroad crossings, and pedestrian crossing areas.

*Typical Dimensions for Shoulder Rumble Strips*

Rumble strip dimensions vary by agency, as shown in the survey of practice results in Table 8, which is based on the dimensions defined by Figure 5. The survey found the following most common values (bolded and shaded in a darker color):

- Length of 16 inches (15 agencies) followed closely by 12 inches (14 agencies)
- Width of 7 inches (29 agencies)
- Spacing of 12 inches (27 agencies)
- Depth of 0.5 inches (15 agencies).

*Typical Dimension Variation by Roadway Type*

Given the range of dimensions used, agencies were asked if any of these shoulder rumble strip dimensions varied by roadway type (Figure 6). As shown, all dimensions do vary by roadway type, and length appears to vary more than width, spacing, or depth. Agencies noted that these changes are influenced most often by roadway type, functional class, and pavement type (concrete versus asphalt).

### Center Line Rumble Strips

*Center Line Placement Location*

Agencies were asked where they install the center line rumble strip relative to the roadway center line and the pavement marking. The possible answer choices were rumble stripes, rumble strips, both, or other (with a required answer).

Table 9 shows that 32 of the states (78%) are using rumble stripes (strips with the pavement marking on the rumble); five agencies are not using any center line rumbles.

*Types of Center Line Rumble Strips Installed*

Agencies were asked what types of center line rumble strip patterns they install; the choices were continuous, pattern (gap/cycle), or bicycle gap pattern. Thirty (30) agencies use the continuous pattern where there is no need to provide gaps for intersections; nine agencies use the gap/cycle pattern, mostly for passing on two-lane roads; and two agencies use the bicycle gap pattern.

TABLE 8
SHOULDER RUMBLE STRIP DIMENSIONS (survey question 22)

| Length in Inches | Inches | | | | | | | | | | | No. of Agencies |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | |
| 6 to 16 | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | 1 |
| 7 | | ■ | | | | | | | | | | 3 |
| 8 to 12 | | | ■ | ■ | ■ | ■ | ■ | | | | | 1 |
| 8 to 16 | | | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | 2 |
| 12 to 16 | | | | | | | ■ | ■ | ■ | ■ | ■ | 2 |
| 12 | | | | | | | ■ | | | | | 14 |
| 16 | | | | | | | | | | | ■ | **15** |
| 18 | | | | | | | | | | | | 1 |
| 30 | | | | | | | | | | | | 1 |

40 responding agencies.

| Width in Inches | Inches | | | | | | No. of Agencies |
|---|---|---|---|---|---|---|---|
| | | 4 | 5 | 6 | 7 | 8 | |
| 4 | | ■ | | | | | 1 |
| 5 | | | ■ | | | | 5 |
| 6 | | | | ■ | | | 1 |
| 7 | | | | | ■ | | **29** |

36 responding agencies.

| Spacing in Inches | Inches | | | | | | | | | | | No. of Agencies |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | |
| 5 | ■ | | | | | | | | | | | 7 |
| 7 | | | ■ | | | | | | | | | 2 |
| 9 | | | | | ■ | | | | | | | 1 |
| 10 | | | | | | ■ | | | | | | 1 |
| 12 | | | | | | | | ■ | | | | **27** |
| 14 | | | | | | | | | | ■ | | 1 |

39 responding agencies.

| Depth in Inches | Inches | | | | | | | | | | | No. of Agencies |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0.25 | 0.30 | 0.35 | 0.40 | 0.45 | 0.50 | 0.55 | 0.60 | 0.65 | 0.70 | 0.75 | |
| 0.25 to 0.5 | ■ | ■ | ■ | ■ | ■ | ■ | | | | | | 1 |
| 0.375 | | | ■ | ■ | | | | | | | | 9 |
| 0.375 to 0.625 | | | ■ | ■ | ■ | ■ | ■ | ■ | ■ | | | 5 |
| 0.5 | | | | | | ■ | | | | | | **15** |
| 0.5 to 0.75 | | | | | | ■ | ■ | ■ | ■ | ■ | ■ | 2 |
| 0.75 | | | | | | | ■ | | | | ■ | 1 |

33 responding agencies.

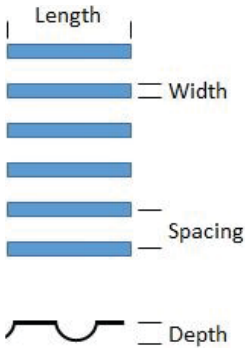



FIGURE 5 Shoulder rumble strip dimensions referenced.

*Intermittent Gaps Installed for Rumble Strips*

Agencies were asked whether if they used intermittent gaps on center line rumble strips, and if so, what factors determined where (Table 10). Bridges, "other," and noise were the most common responses, at 27, 23, and 20, respectively. Among "other" factors, the most common were intersections, urban areas (high driveway densities), pavement condition, and passing lanes.

*Typical Dimensions for Center Line Rumble Strips*

Rumble strip dimensions vary by agency, as shown in the survey of practice results in Table 11 based on the dimensions defined by Figure 6. The survey found the following most common values (bolded and shaded in a darker color):

- Length of 12 inches (18 agencies)
- Width of 7 inches (22 agencies)
- Spacing of 12 inches (19 agencies)
- Depth of 0.375 inches (18 agencies).

TABLE 9
CENTER LINE RUMBLE LOCATION (survey question 24)

| Center Line Rumble Type | Number of Agencies | Percent |
|---|---|---|
| Rumble Stripe | 32 | 78.0 |
| Rumble Strip | 2 | 4.9 |
| Both | 2 | 4.9 |
| None | 5 | 12.2 |

41 responding agencies.

*Typical Dimension Variation by Roadway Type*

Agencies were asked if any of these center line rumble strip dimensions varied by roadway type. The answers are summarized in Figure 7. In contrast to shoulder rumble strips, the center line dimensions have little variation by roadway type, with at least 30 agencies reporting no variation in each category. Agencies noted that these changes are influenced most often by pavement type (open graded thin asphalt), narrow roadways, and by higher functional class of roadway.

**Rumble Stripes**

*Rumble Stripe Usage*

Agencies were asked if they use edge and/or center line rumble stripes. Figure 8 shows that 29 agencies (70%) install edge line rumble stripes and that 35 (85%) install center line rumble stripes.

*Measuring Retroreflectivity*

Agencies were asked if they measure the pavement marking retroreflectivity of their rumble stripes. The results show that the majority, 29, do not; however, 15 agencies are measuring retroreflectivity. Of these 15, 12 agencies measure under

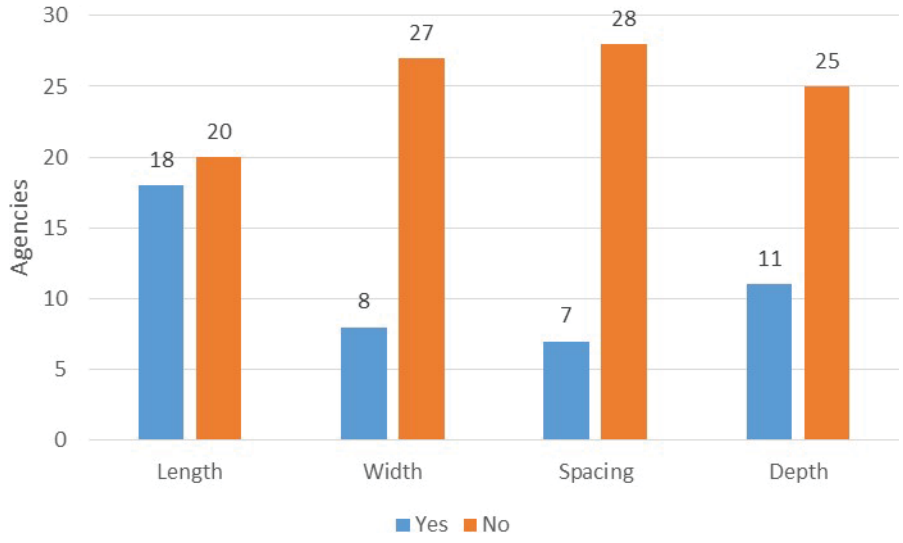



FIGURE 6 Do shoulder rumble strip dimensions vary by roadway type (survey question 23)?

TABLE 10
REASONS AGENCIES CREATE INTERMITTENT GAPS WITHIN CENTER LINE RUMBLE STRIPS
(survey question 27)

| Gaps Created For: | Number of Agencies | Percent |
|---|---|---|
| Bridge Decks | 27 | 79.4 |
| Other | 23 | 67.6 |
| Noise | 20 | 58.8 |
| Special Users | 6 | 17.6 |
| Bicycles | 3 | 8.8 |

34 responding agencies.

dry conditions, three include wet recovery, and two agencies include continuous wetting measurements.

*Pavement Marking Materials*

Agencies were asked to identify the pavement marking products being used for rumble stripes. Table 12 shows that the most common is standard acrylic waterborne paint (17 agencies, or 42%) followed by epoxy at 16 agencies (39%). In addition, 11 agencies reported using wet reflective media to enhance wet night visibility of the rumble stripes. Another nine DOTs reported using some wet reflective media but that

TABLE 11
CENTER LINE RUMBLE STRIP DIMENSIONS (survey question 28)

| Length in Inches | Inches | | | | | | | | | | | No. of Agencies |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | |
| 4 | | | | | | | | | | | | 1 |
| 7 | ■ | | | | | | | | | | | 2 |
| 8 | | ■ | | | | | | | | | | 2 |
| 10 | | | | ■ | | | | | | | | 1 |
| 12 | | | | | | ■ | | | | | | **18** |
| 14 | | | | | | | | ■ | | | | 1 |
| 16 | | | | | | | | | | ■ | | 11 |

36 responding agencies.

| Width in Inches | Inches | | | | | | No. of Agencies |
|---|---|---|---|---|---|---|---|
| | 4 | 5 | 6 | 7 | 8 | | |
| 4 | ■ | | | | | | 1 |
| 5 | | ■ | | | | | 6 |
| 6 | | | ■ | | | | 2 |
| 7 | | | | ■ | | | **22** |
| 7.5 | | | | | ■ | | **2** |

33 responding agencies.

| Spacing in Inches | Inches | | | | | | | | | | | No. of Agencies |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 4 | 6 | 8 | 10 | 12 | 14 | 16 | 18 | 20 | 22 | 24 | |
| 4 | ■ | | | | | | | | | | | 1 |
| 5 | ■ | ■ | | | | | | | | | | 6 |
| 12 | | | | | ■ | | | | | | | **19** |
| 14 | | | | | | ■ | | | | | | 2 |
| 24 | | | | | | | | | | | ■ | **6** |

34 responding agencies.

| Depth in Inches | Inches | | | | | | | | | | | No. of Agencies |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0.25 | 0.275 | 0.300 | 0.325 | 0.350 | 0.375 | 0.400 | 0.425 | 0.450 | 0.475 | 0.500 | |
| 0.25 | ■ | | | | | | | | | | | 1 |
| 0.375 | | | | | | ■ | | | | | | **18** |
| 0.25 to 0.5 | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | 2 |
| 0.5 | | | | | | | | | | | ■ | 13 |
| 0.5 to 0.75 | | | | | | | | | | | ■ | 1 |

35 responding agencies.

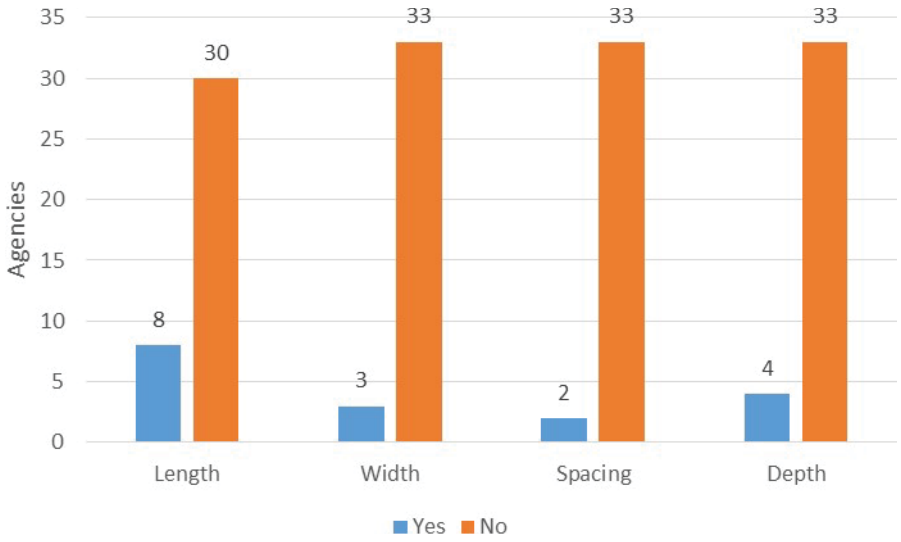



FIGURE 7 Do center line rumble strip dimensions vary by roadway type (survey question 29)?

this was not a standard practice; and 21 agencies reported using no wet media.

## MAINTENANCE

These questions focused on DOT maintenance practices when rumble strips and stripes are present. The questions were asked, and are reported here, by category: sealant, life expectancy, winter maintenance, and maintaining the pavement marking within the rumble.

- *Sealant*—Agencies were asked whether over time they re-apply sealant over the rumble strip. Only five agencies re-apply, and this is based on a pavement condition assessment with no standard frequency for re-application.
- *Life expectancy*—Agencies were asked if they have determined a life expectancy for rumble strips (in terms of tactile and audible effectiveness) or whether their replacement is based on pavement surface rehabilitation. The results show that 30 agencies (73%) replace rumble strips based on pavement surface rehabilitation as opposed to tactile/audible effectiveness.
- *Winter maintenance*—Agencies were asked if winter maintenance operations vary based on the presence of rumble strips (snow removal, sanding, salt and brine applications). Thirty-nine (39), 95%, do not alter winter maintenance practice as a result of the presence of rumble strips. One agency noted that districts typically place some amount of melting material near the center line joint with the expectation that the material will work its way down the cross slope. Some districts use more material with the expectation that the center line rumble will "catch" some of the material. Another agency reported that salting practices are adjusted when center line rumble strips are present to avoid the salt collecting in the rumble strip rather than being distributed.
- *Maintaining the pavement marking within the rumble*—Agencies were asked how they maintain the pavement marking within the rumble stripe. The results show that 85% paint over the existing marking, while the rest remove the existing marking prior to reapplication. When asked about experiencing differences in retroreflectivity by direction of travel for center line rumble stripes, only 20% (eight agencies) noticed any difference. One agency commented that this has been addressed through establishing minimum retroreflectivity in both directions and another reported painting center line stripes in both directions.

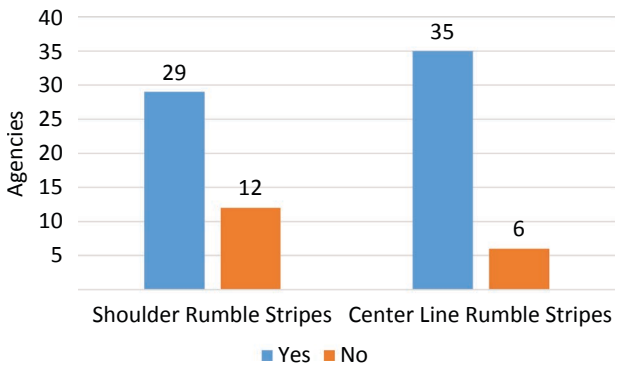



FIGURE 8 Rumble stripe use by line type (survey questions 30 and 32).

## BENEFITS

This section focused on the benefits of using rumble strips and stripes as experienced by state DOTs. The questions focus on crash modification factors (CMFs), pavement marking performance, and other benefits.

TABLE 12
PAVEMENT MARKING MATERIALS USED FOR RUMBLE STRIPES
(survey question #5)

| Pavement Marking Material Used | Number of Agencies | Percent |
|---|---|---|
| Standard Acrylic Waterborne Paint | 17 | 46 |
| Epoxy | 16 | 43 |
| Other (required) | 15 | 41 |
| High Build Acrylic Waterborne Paint | 11 | 30 |
| Sprayed Thermoplastic | 11 | 30 |
| Polyurea | 6 | 16 |
| Urethane | 1 | 3 |

37 responding agencies.

*Crash modification factors*—A CMF is a multiplicative factor used to compute the expected number of crashes after implementing a given countermeasure at a specific site (CMF 2015). Agencies were asked whether they have established crash modification factors for installing rumble strips. Ten (10) of 41 agencies, 25%, reported crash reduction values, which are shown in Table 13. For those agencies using CMFs from the CMF Clearing House, it is advisable that they use the studies that are rated 4 or 5 stars, as these studies have had a more rigorous evaluation.

*Cost-effectiveness*—Agencies were asked whether they have established a cost-effectiveness value for installing rumble strips based on safety benefits. The results show that 11 agencies (27%) have established values ranging from 7:1 to 75:1, with multiple states currently conducting research projects to determine these values.

*Rumble stripe longevity*—It was noted in the survey that anecdotal evidence suggests installing a pavement marking over the rumble strip extends the life of the marking. Agencies were asked for their expectations of the results of this procure given the following choices: providing similar strip performance, extending a strip's life by less than one year, or extending it by more than a year. Fifteen (15) agencies reported expecting similar performance, two agencies expect that the life would be extended by less than 1 year, and six agencies anticipate that pavement marking life would be extended by more than one year (the average was 3–4 years) when installed within a rumble (see Figure 9). However, comments indicated that agencies do not have enough experience monitoring pavement markings within the rumble to have a good idea on what impact this has on life expectancy.

*Visibility*—The survey asked if rumble stripes were being used as a wet night visibility solution, and 11 agencies (27%) confirmed that they are.

*Additional benefits*—Agencies were asked if there are other benefits not touched on in the survey that they consider from using rumble stripes. Some of the comments are summarized here in three general categories.

Winter weather conditions:

- Rumbles help snow plow operators maintain their position in the lane during winter weather events.

TABLE 13
CMF AND CRASH REDUCTION FINDINGS BY AGENCY (survey question 47)

| State | CMF for Rumble Strips | | Note |
|---|---|---|---|
| | Shoulder | Center Line | |
| AK | | | CRF: −20% on rural two-lane hwy > 50 mph −10% on four-lane rural hwy > 50 mph |
| CO | | | 0.70 CMF |
| GA | | | Refer to the *Highway Safety Manual* and CMF Clearinghouse. |
| MI | | 0.53 to 0.45 | |
| MO | | | 0.75 CMF |
| NC | | | https://connect.ncdot.gov/resources/safety/Pages/Safety-Evaluation.aspx |
| OR | | | CRF: −12% for centerline, all crashes; −22% for shoulder RS |
| PA | 0.96 to 0.57 | 0.94 to 0.55 | |
| TX | | 0.65 | Centerline: milled 0.50, profile 0.40 |
| VA | 0.71 | 0.56 | |

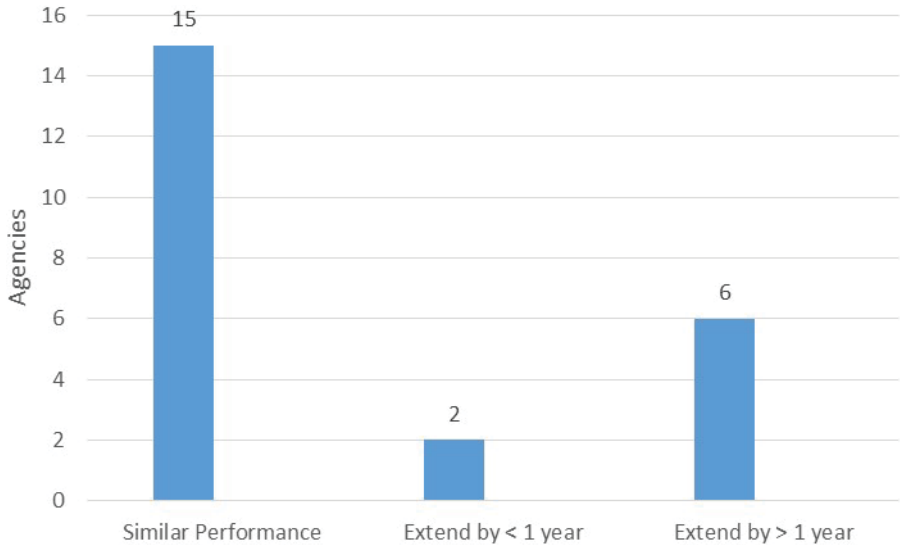



FIGURE 9 Pavement marking longevity (survey question 51).

- Rumbles help snow plow operators to locate the center line of the roadway during snow storms.
- Vibrations from rumbles help plow drivers detect the edge of the lane when snow covers the pavement markings.

Safety:

- Rumble strips potentially reduce speeds in some areas.
- Rumbles help with road navigation in bad weather and low-light conditions, especially as a result of vibrations from center line rumbles.
- Even in non-storm conditions, the vertical face of the rumble indentation makes the stripe more visible to the driver at night. Vibrations from the rumble strip can also aid in navigation under extremely low visibility conditions.
- Rumble strips provide a more clear shoulder distance for cyclists, especially where roadside barriers or other obstructions exist.
- Beyond the improved road departure safety performance involving distracted, fatigued, impaired and drifting motorists, there have been some instances where highway workers and emergency responders on the road shoulder were alerted to an errant vehicle by the audible warning created when encroaching vehicles tires engaged the rumble strip.

Service Life:

- Rumbles protect some pavement markings from snow plow damage and reduce maintenance costs by eliminating plowable raised markers.

## ISSUES

The survey included a section asking agencies to identify the relative importance, on a scale of 1 to 5 (with 5 being the most important) of specific issues faced when using rumble strips or stripes. Table 14 shows the rated issues and scores.

Noise and bicycle complaints had the highest average score in terms of issue importance, with 24 agencies (58%) giving noise a score of 4 or 5; bicycle complaints were the most important, rating 4 or 5, to 21 agencies (51%). The next issue in terms of importance was related to pavement

TABLE 14
ISSUES FACED WHEN USING RUMBLE STRIPS AND STRIPES (survey question 55)

| Issue | 5 | 4 | 3 | 2 | 1 | Average |
|---|---|---|---|---|---|---|
| Bicycle Complaints | 12 | 9 | 10 | 9 | 1 | 3.5 |
| Noise Complaints | 9 | 15 | 4 | 10 | 3 | 3.4 |
| Pavement Deterioration (center line joint) | 10 | 7 | 6 | 8 | 10 | 3.0 |
| Rumbles on Challenging Surfaces | 4 | 10 | 8 | 10 | 9 | 2.8 |
| Pavement Deterioration (edge line) | 4 | 7 | 9 | 10 | 11 | 2.6 |
| Pavement Marking Performance | 4 | 2 | 12 | 8 | 15 | 2.3 |
| Motorcycle Complaints | 0 | 5 | 12 | 13 | 11 | 2.3 |
| Winter Maintenance Issues | 0 | 1 | 6 | 15 | 19 | 1.7 |

Ranking: 5 = Most Important Issue Faced.

deterioration owing to the rumble or the inability to place a rumble on challenging surfaces (microsurfaces, thin asphalt, seal coat, chip seal, etc.). When it comes to pavement deterioration, perspectives can be quite different. For example, center line joint pavement deterioration was ranked a 5 (most important) by 10 agencies, while the same number ranked it a 1 (least important). State DOTs did not view winter maintenance as an important issue, with 33 states (80%) rating this either a 1 or 2. Other issues reported include:

- Added wear and tear on snow plowing equipment
- How many chip seals can be applied before it is necessary to regrind the rumble strip
- Maintenance of pavement markings in rumble stripes
- Installation accuracy (particularly on edge line rumbles stripes) improving on the method of controlling lateral alignment
- Schedule of upcoming resurfacing
- Future use of the pavement as a travel lane [and] issues with future work zone phases and staging (may have to fill in the rumble and overlay to use)
- Need to consider impact to agency and vehicles on shoulder operations
- Ability to effectively restripe without having to blast/remove markings in the rumble stripe (most would be expected to survive until next resurfacing)
- What needs to be done when it is time to resurface to avoid reflection through thin overlays.

*Noise issues*—Agencies were asked if their rumble strip policy/guidance addresses noise concerns. Table 15 shows that 27 agencies (66%) are addressing noise concerns, as described in more detail in chapter four: Case Examples. Various agencies address noise by installing strips away from urban areas, eliminating roads with speeds less than 45 mph, and being sensitive to community needs.

*Bicycle issues*—Agencies were asked if their rumble strip policy/guidance addresses bicycle concerns. Table 16 shows that 34 agencies (83%) are addressing bicycle concerns, as detailed in chapter four. Of these, 15 agencies reported that this impacts installation practices by location selection. In addition, 10 agencies noted that this impacts rumble strip design in terms of bicycle gap selection.

*Pavement deterioration issues*—Agencies were asked if their rumble strip policy/guidance addresses pavement deterioration concerns. Table 17 shows that 18 agencies (44%) do address deterioration, as described in chapter four. Of those 18 agencies, 10 reported that this impacts installation practices by location; three said it affects rumble strip design.

*Public complaints*—Agencies were asked to rate the level of public complaints specific to issues commonly associated with rumble strips. Table 18 shows that DOTs are primarily receiving complaints regarding bicycles—

TABLE 15
ADDRESSING NOISE CONCERNS (survey question 57)

| Address Noise Concerns | Number of Agencies | Percent |
|---|---|---|
| Yes | 27 | 66 |
| No | 7 | 17 |
| Not Applicable | 7 | 17 |

41 responding agencies.

TABLE 16
ADDRESSING BICYCLE CONCERNS (survey question 59)

| Address Bicycle Concerns | Number of Agencies | Percent |
|---|---|---|
| Yes | 34 | 83 |
| No | 4 | 10 |
| Not Applicable | 3 | 7 |

41 responding agencies.

TABLE 17
ADDRESSING PAVEMENT DETERIORATION CONCERNS (survey question 63)

| Address Pavement Concerns | Number of Agencies | Percent |
|---|---|---|
| Yes | 18 | 44 |
| No | 19 | 46 |
| Not Applicable | 4 | 10 |

41 responding agencies.

TABLE 18
PUBLIC COMPLAINTS BY TOPIC (survey question 67)

| | Level Of Public Complaints | | |
|---|---|---|---|
| Complaints Regarding: | Low | Medium | High |
| Noise | 18 | 16 | 7 |
| Bicycle Related | 17 | 11 | 13 |
| Motorcycle Related | 33 | 6 | 1 |
| Pavement Deterioration (center line joint) | 36 | 3 | 2 |
| Pavement Deterioration (edge line) | 35 | 5 | 1 |
| Winter Maintenance Issues | 38 | 3 | 0 |
| Pavement Marking Performance | 35 | 6 | 0 |
| Rumbles on Challenging Surfaces | 34 | 5 | 2 |

13 agencies rating these as "high"—followed by noise. Both of these issues have the highest ratings in the medium complaint level category as well.

*Public outreach materials*—Agencies were asked if they had developed fact sheets/brochures regarding the benefits of rumble strips. There results show that only eight agencies have developed outreach materials while 29 agencies have not. Specific resources agencies reported using included FHWA materials, NCDOT documentation materials, and in Delaware, brochures given out during state DOT public events.

Five agencies also provided specific links:

- http://www.ct.gov/dot/cwp/view.asp?a=3199&q=526532
- http://www.dot.state.mn.us/trafficeng/safety/rumble/
- http://www.dot.state.wi.us/safety/motorist/roaddesign/rumblestrips/how-they-work.htm
- http://www.maine.gov/mdot/safety/docs/rumblestrip-brochure-general.pdf
- http://www.dot.state.ak.us/stwddes/dcstraffic/rumble/index.shtml.

*Public service announcements* (*PSAs*)—In addition to fact sheets, agencies were asked if they had developed PSAs (web, radio, television) to communicate the benefits of rumble strips; the answer options were yes, no, and other. Only two agencies, the Michigan and North Dakota DOTs, said they have developed PSAs using web and traditional media, in contrast to the 36 agencies that have not. For example, Michigan DOT developed a PSA in response to vehicles not wanting to cross the center line to pass a bicycle when rumble strips were present. In addition, three agencies reported "other" with explanations of using national campaign materials (North Carolina and New York DOTs) and having conducted a public education and information campaign when first starting to use rumble strips (South Carolina DOT in 2008). These links refer to existing web/media provided by Michigan DOT, MnDOT, and FHWA:

- Michigan Rumble Strips Save Lives https://www.youtube.com/watch?v=EEQXuu6ITjA
- Michigan DOT Share the Road. https://www.youtube.com/watch?v=MUL8l9_65Ic
- Minnesota DOT noise video (traditional rumble vs. sinusoidal rumble) https://www.youtube.com/watch?v=W3-uPGb1nmM
- FHWA Video "Sound Investment" https://www.youtube.com/watch?v=bug-KDhu2Ec

CHAPTER FOUR

# CASE EXAMPLES

This chapter provides an in-depth analysis of four key issues—noise, bicycle, safety benefits, and pavement deterioration—identified from the synthesis results; and discusses how some state DOTs are addressing those issues.

## NOISE ISSUES

The survey found noise to be one of the most important issues identified by the state DOTs when it comes to rumble strip and stripes. Twenty-four agencies (almost 60%) ranked noise issues as the highest importance or one level below (5 or 4). When asked if the agency had developed a policy to address noise issues, 27 agencies (66%) responded yes. The information that follows is a sample of how some state DOTs addressed the noise issues resulting from rumble strip and stripes starting with alternative designs (Caltrans and MnDOT) and also the more traditional ways.

In 2012, Caltrans conducted the most extensive background search by a state agency to date on noise issues by conducting a comprehensive literature review (at national and international levels), interviewing state DOTs, and conducted an evaluation of two alternative rumble designs to investigate their noise impacts. An excerpt from its report follows:

> 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-in. milled rumble strip with thermoplastic stripe (CTC 2012).

The study found that sinusoidal rumble strips provide sufficient audible and tactile warning to drivers and at the same time reduce noise outside the vehicle.

In 2014, MnDOT initiated a research study to evaluate its existing rumble design (⅜-inch to ½-inch depth, 16 inches wide with 12-inch spacing) in comparison to the Caltrans (1/32- to ⅝-inch depth, eight inches wide with 14-inch spacing) and the Pennsylvania contractor pilot project (⅛- to ½-inch deep, eight inches wide with 24-inch spacing) sinusoidal rumble designs (Figure 10). The study showed that the California's rumble strip design had the most efficient exterior-to-interior sound ratio: It produced as much noise inside the vehicle as the Minnesota design, but less sound outside of the vehicle. PennDOT's contractor design produced lower exterior and interior sound levels, and may not produce adequate feedback to alert inattentive drivers (Terhaar 2015).

Caltrans's design also had a better tonal quality than MnDOT's current design. Minnesota's design produces a single, strong tonal peak at 125 hertz, which stands out against ambient noise because few sounds in the natural environment produce similar tones. California's design produces two smaller peaks at 100 hertz and 200 hertz, so the sound is less abrupt.

The noise of a rumble strip is considered detectable if it produces a sound level at a listener's location greater than the ambient noise at any frequency. In passenger vehicles driving at 60 mph, the Caltrans design has been modeled as just detectable at 3,000 feet, whereas the Minnesota design would be detectable at well beyond 3,000 feet.

This research showed, however, that Caltrans design only produces its greatest volume when a tire is fully on the rumble strip. MnDOT's design provided feedback to the driver immediately after the tire made contact with the rumble strip.

The Ohio DOT deals with noise issues in residential areas by adjusting the distance from the edge of where the rumble will be installed. The policy reads:

> In residential areas, noise generated by rumble strips could be objectionable. Rumble strips installed in these areas may be placed further from the edge of the traveled lane to reduce the frequency of contact while still providing some degree of warning to drifting drivers.
>
> The distance from the edge of the traveled lane to the rumble strip pattern should not exceed 2.0 feet on the outside shoulder. Also, the use of either rolled or formed rumbles is preferable to the use of the milled rumble in these areas.

The Montana DOT deals with the noise issue by modifying the shoulder rumble strip dimensions. Its policy reads:

> The rumble strip dimensions shown in the MDT Detailed Drawings should be used for most installations. However, situations will occur when modifications to these dimensions must be evaluated. The following factors should be considered in the decision to modify the rumble strip dimensions:
>
> Depth of rumble strip—A ⅝ inch rumble strip depth is typically used. The depth of a rumble strip can be reduced to minimum of ⅜ inch to provide a "quieter" pattern near residential areas. The ⅜ inch depth will not provide adequate noise/vibration after a chip seal has been placed, so the rumble strip would have to be

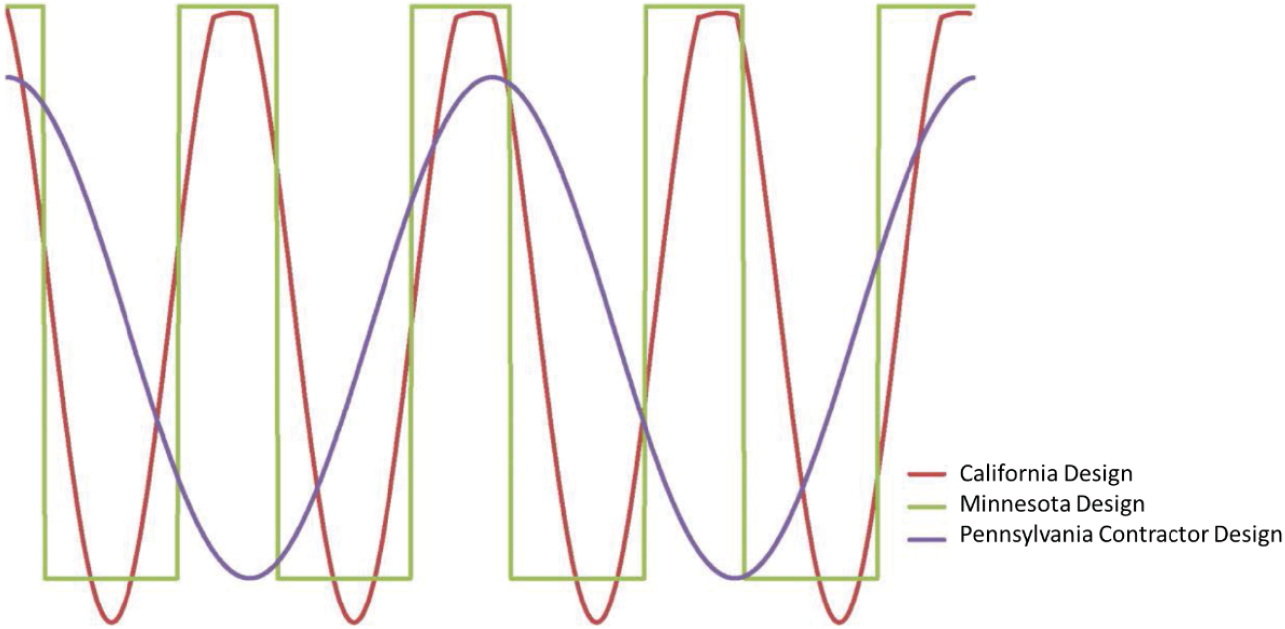



FIGURE 10 Comparison of rumble strip cross sections (Minnesota, California, and Pennsylvania) (Terhaar 2015).

re-milled after every chip seal. Depths shallower than ⅜ inches do not provide enough noise/vibration to alert the errant driver.

Rumble strips have often been terminated through residential areas due to the nuisance noise from incidental contact. MDT's position is that rumble strips should be placed on highways in residential areas where the distance to the residences is adequate to minimize the adverse effect of rumble strip noise. Two options are available to decrease rumble strip noise through these areas:

- The first option is to increase the offset from the edge of the travel lane. A greater offset can be beneficial where there is substantial truck traffic, because trucks tend to crowd the shoulder resulting in more "nuisance" contact. However, the greater offset will somewhat reduce the effectiveness of the rumble strip.
- The second option is to use a quieter (less aggressive) rumble strip. The depth of the rumble strip can be reduced to ⅜ inch to decrease noise. As noted above, the ⅜ inch rumble strip will not provide adequate noise after a chip seal has been placed over the strip, so they will have to be re-milled after every chip seal application.
- If the decision is made to eliminate rumble strips, research has indicated that terminating rumble strips 650 feet (200 m) from residences resulted in tolerable noise levels.

The policy of the Saskatchewan Ministry of Highways and Infrastructure in Canada states, "Installation of shoulder rumble strips through urban areas is not recommended because of the noise."

## BICYCLE ISSUES

The survey found bicycle issues is second only to noise among issues identified by the state DOTs when it comes to rumble strip and stripes. Twenty-one (21) agencies, just over half, ranked bicycle concerns at the highest importance or a level below (5 or 4). When asked if the DOT developed a policy to address noise issues, 34 agencies (83%) responded yes. Following is a sample of agency approaches:

The South Carolina DOT (SCDOT) addressed bicycle concerns by establishing a policy that adjusts their current rumble strip design standards. The rumble strip design details and location criteria were developed after receiving input from the South Carolina cycling community, FHWA and other state DOTs. The SCDOT has implemented the following accommodations to address the presence of cyclists:

- Reducing maximum depth of milled groove,
- Providing an option of various width rumble strips based on width of paved shoulder,
- Providing an option of a skip pattern for the milled-in rumble strips,
- Establishing minimum ADT threshold for rumble strip application,
- Establishing a minimum roadway width for rumble strips, and
- Where RS are placed on bike lanes, a minimum width of 3 feet and 6 inches will remain undisturbed.

To ensure that bicycle concerns are addressed, the Maryland State Highway Administration rumble strip and stripe guidelines regarding bicycles indicates that

All future revisions to rumble strip design document that may impact bicyclists shall require the notification to both the [State Highway Administration] Bicycle and Pedestrian Coordinator within the Office of Planning and Preliminary Engineering and the [Maryland] DOT Director of Bicycle and Pedestrian Access within the Office of Planning and Capital Programming to gain their input on proposed changes.

This basically ensures that bicycle concerns will always be considered as part of the design process.

The Arkansas DOT indicated that a common complaint of bicyclists is that a continuous shoulder rumble strip along a narrow shoulder sometimes requires bicyclists to move into the travel lane. To address this concern, it is important that shoulder rumple strips with a gap pattern be installed on highways that do not have full access control and have at least four feet of shoulder beyond the rumble strip. The typical longitudinal pattern will consist of 48 feet of rumble and 12 feet without rumble. When driveways or intersections are present, the use of a gap pattern will be adjusted at the discretion of the Engineer so that the driveway or intersection may be utilized as a gap. In addition, the ⅜-in. depth of grooves of rumble strips on rural, undivided highways is considered to be less disruptive to bicyclists traveling on these routes.

The Ohio DOT takes a different perspective on dealing with bicycle concerns. Its rumble policy indicates that rumble strips generally are not to be used on the shoulders of roadways designated as bicycle routes or having substantial volumes of bicycle traffic, unless the shoulder is wide enough to accommodate the rumble strips and still provide a minimum clear path of four feet from the rumble strip to the outside edge of the paved shoulder or five feet to adjacent guardrail, curb, or other obstacle.

In areas designated as bicycle routes or having substantial volumes of bicycle traffic, the rumble strip pattern would not be continuous but consist of an alternating pattern of gaps and strips, each 10 feet in length. Also, gaps are to be provided in the rumble strip pattern ahead of intersections, crosswalks, driveway openings, and at other locations where bicyclists are likely to cross the shoulder.

The Kansas DOT specifies that a minimum three-foot paved area outside of the shoulder rumble strip should be provided for bicyclists on highway routes on the American Discovery Trail Route, Trans America Route and other suggested cross-state bicycle routes per the latest edition of the Kansas Bicycle Guide. Also, a recent research study completed in 2007 (KSU-00-4: *Comparison of Football Shaped Rumble Strips Versus Rectangular Rumble Strips*), found that bicyclists prefer the "football" shape shoulder rumble strip when traveling on highway shoulders. The football shape, according to this study, is easier to traverse by a cyclist, but still provides the same noise levels for motorists.

Montana DOT also modifies its rumble strip design to address bicycle concerns. The policy states that where bicycle usage is a consideration, the following modifications to rumble strip installation should be evaluated:

- Where the shoulder width is between 1 and 4 ft (1 ft < shoulder width < 4 ft) reduced lateral width rumble strips should be installed adjacent to the outside edge of the pavement.
- Where shoulder widths are greater than 4 feet, the use of a 2-ft offset from the edge of travel lane should be evaluated. This offset will provide an area for bicyclists between the edge of travel lane and the rumble strip.
- Where center line rumble strips will be used on narrow roads, it should be noted that drivers tend to shy away from center line rumble strips which could adversely affect vehicle/bicycle interaction. The use of a modified lateral width rumble strip should be evaluated.

In all cases the benefits to bicyclists must be weighed against the potential for roadway departure incidents, because greater offsets reduce the effectiveness of rumble strips.

In Arizona, the DOT developed a shoulder width policy to address bicycle concerns. The policy states that:

> If appreciable bicycle traffic exists or is anticipated then a minimum effective clear shoulder width of three-feet and five-inches (3′-5″) should be provided from the outside edge of the rumble strip groove to the front face of the barrier or guardrail. If this clear area cannot be maintained then a change of configuration and/or deletion of the rumble strip should be considered.

## SAFETY BENEFITS OF RUMBLES

Over the years, multiple state DOTs have conducted studies to examine the safety benefits of installing rumbles on the edge line, center line, or both. *NCHRP Report 641* documented 11 state studies and conducted a national study to determine the safety benefits. Research has shown that installing center line rumble strips can reduce severe crashes as much as 45% on rural two-lane roads and by 64% on urban two-lane roads; and that shoulder rumbles can reduce crashes as much as 36% on rural two-lane roads and by 17% on rural freeways.

Of the 41 state DOTs responding to the survey, 10 indicated that CMFs effectiveness values have been determined for rumble strips and stripes; 11 discussed cost effectiveness based on crash reductions (fatal and injury crashes) compared with the cost of installing rumbles (six agencies responded to both options).

PennDOT developed effectiveness graphs to show the impact of installing rumbles (edge and center line) on crashes, and published them in its state highway safety report. Figure 11 shows the effectiveness of the edge line rumble strip in reducing run-off the road fatalities, and Figure 12 shows the effectiveness of the center line rumble in reducing head-on fatalities.

Figure 11 shows the relationship between the number of run-off-the-road fatalities (based on a five-year running average) and the total number of miles that have edge line rumbles

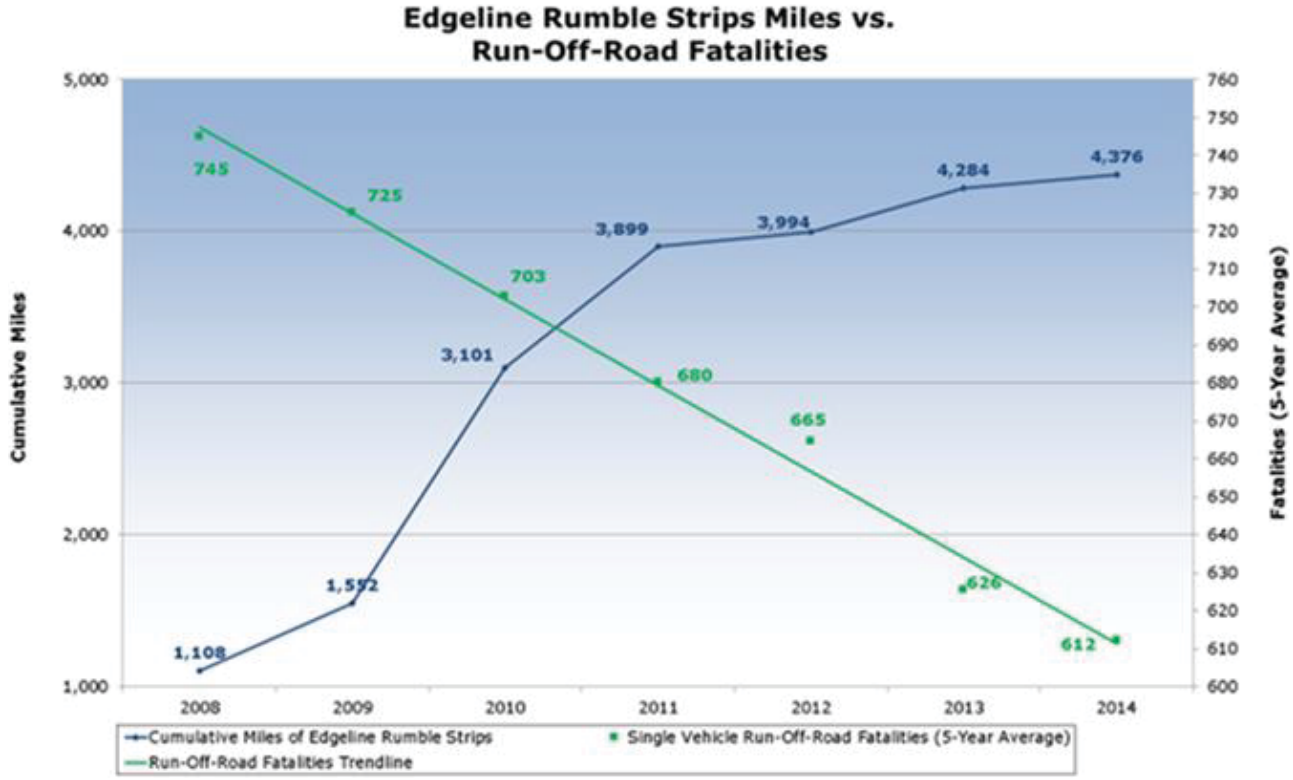



FIGURE 11 Pennsylvania DOT edge line rumble effectiveness.

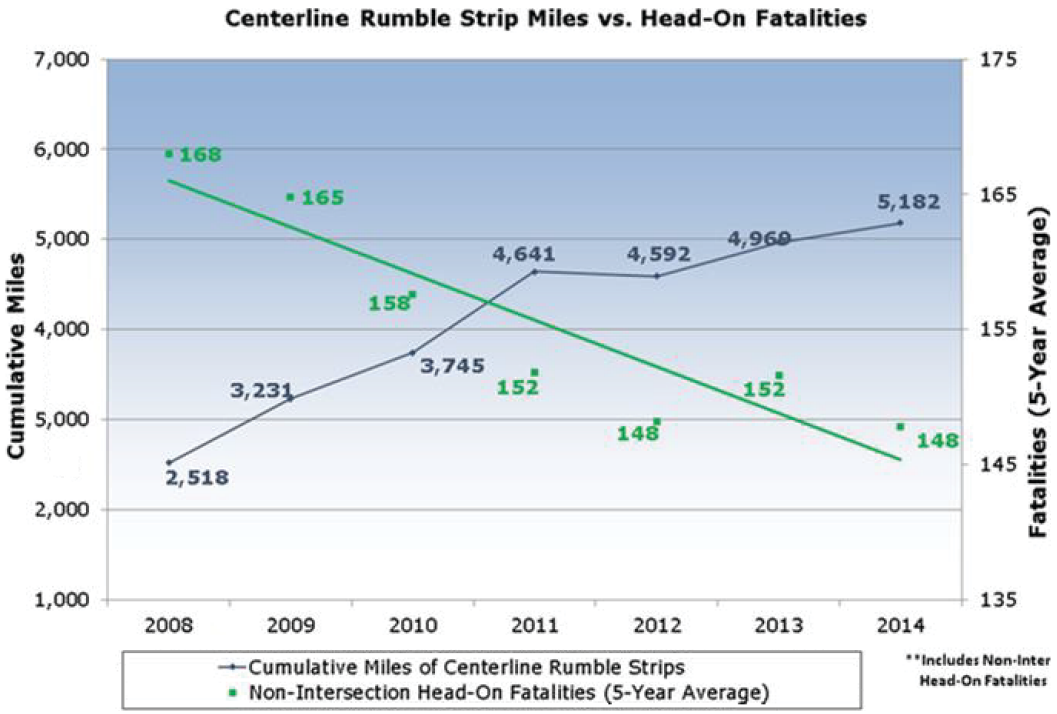



FIGURE 12 Pennsylvania DOT center line rumble effectiveness.

installed. The data shows that as the number of miles increased, the average number of run-off-the-road fatalities decreased from a high of 745 in 2008, with more than 1,100 miles of edge line rumbles, to a low of 612 in 2014 with more than 4,300 miles of edge line rumbles. That is a reduction of 133 run-of the road fatalities in 6 years, representing an approximately 18% reduction.

Figure 12 shows the relationship between the number of head-on fatalities (based on a 5-year running average) and the total number of miles with center line rumbles installed. The data show that as the number of miles with center line rumbles increased, the average number of head-on crashes decreased from a high of 168 in 2008, with more than 2,500 miles of center line rumbles, to a low of 148 with more than 5,100 miles of center line rumble. This is a reduction of 20 head-on fatalities over 6 years representing about a 14% reduction.

As part of the MnDOT "Towards Zero Deaths" initiative, the DOT developed a brochure to show the safety impact of rumble strips "Saving Lives by Keeping Drivers Focused: Noise from Centerline Rumble Strips" (MnDOT 2015). The brochure presents information from one two-lane rural highway from 1986 to 2011. The data show that 25 people were killed in head-on crashes (an average of one per year). The brochure then addresses how rumble strips reduce those types of crashes. Figure 13 shows a partial image of the brochure.

A study by the Michigan DOT (Datta 2015) addressed the impact of center line rumble strips on safety. The analysis revealed a total of 2,488 "before" and 1,306 "after" target crashes (incidents involving at least one vehicle crossing or encroaching on to the center line, resulting in a crash) with regard to the center line rumble strip installation period. The crash analysis indicated statistically significant reductions after rumble installations in all target crashes, including

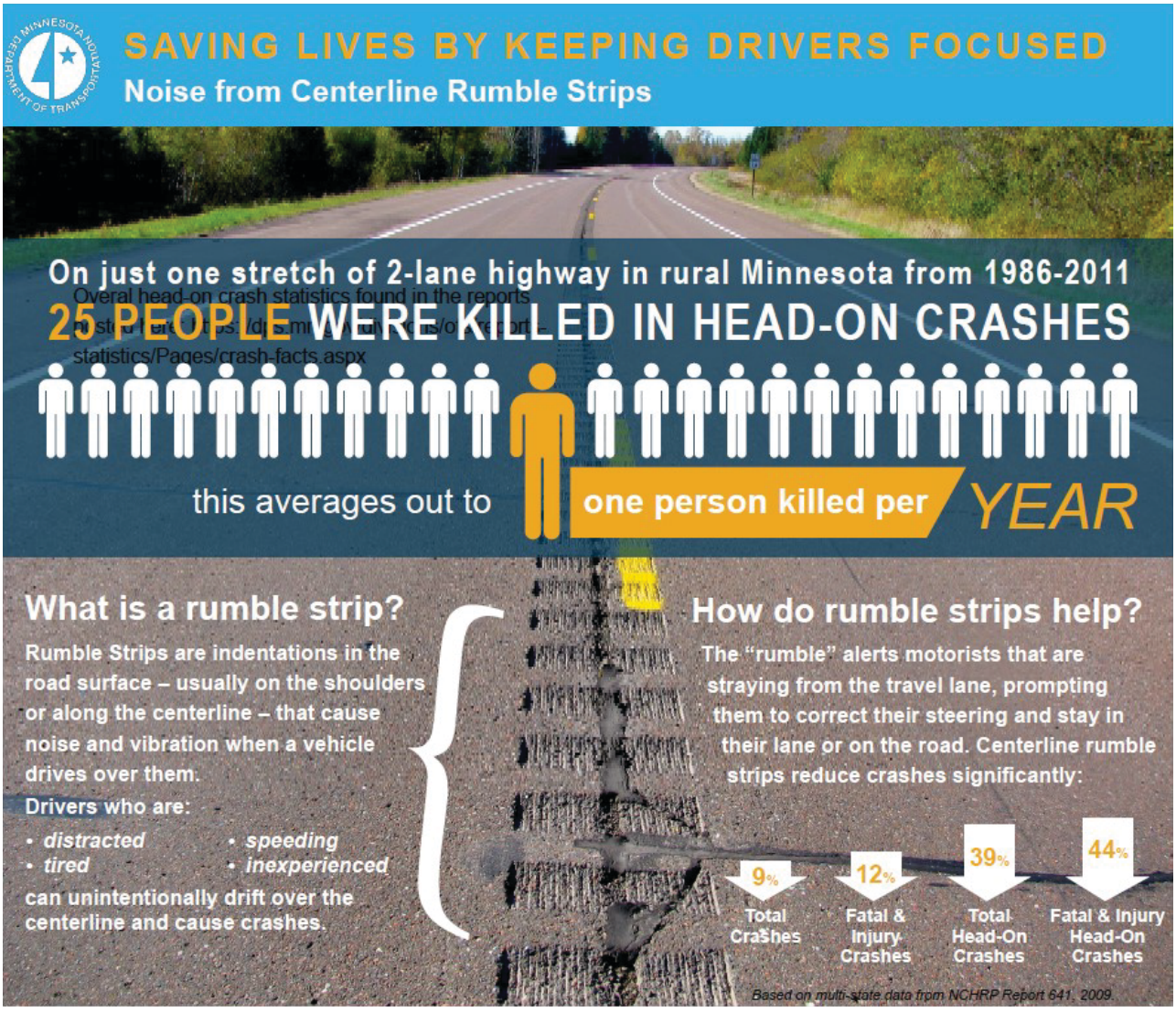



FIGURE 13 Minnesota DOT brochure on how rumble strips save lives (MnDOT 2015).

TABLE 19
"BEFORE AND AFTER" SAFETY PERFORMANCE

| CRASH TYPE OR SEVERITY | THREE-YEAR TARGET CRASH FREQUENCY | | PERCENT REDUCTION IN TARGET CRASHES |
|---|---|---|---|
| | "BEFORE" PERIOD | "AFTER" PERIOD | |
| Angle | 13 | 3 | 76.92% |
| Head-On | 240 | 118 | 50.83% |
| Sideswipe Opposite | 365 | 161 | 55.89% |
| Sideswipe Same | 121 | 68 | 43.80% |
| S.V. Run-Off-the-Road | 1,729 | 928 | 46.33% |
| Fatal | 83 | 40 | 51.81% |
| A | 237 | 139 | 41.35% |
| B | 353 | 177 | 49.86% |
| C | 381 | 206 | 45.93% |
| PDO | 1,434 | 744 | 48.12% |

*Source*: Datta (2015).

head-on, sideswipe opposite, and single vehicle run-off-the-road incidents. The study of crash severity resulted in the reduction in fatalities and all categories of injury crashes (Table 19).

These reductions were statistically significant and ranged from 43% to 55%. A study of the safety impact of various traffic volume (average annual daily traffic) groups and crash factors also indicated statistically significant crash reductions after center line rumble strip installation. Passing-related target crashes were reduced by 47%, those occurring on wet pavement by 54%, and others that involved impaired drivers as a result of alcohol or drug use were reduced by 35%.

## PAVEMENT DETERIORATION

There appears to be little consensus concerning the issue of pavement deterioration resulting from rumble installation. When the DOTs ranked the issues in terms of importance, pavement deterioration (focused more on center line joint deterioration) was third, after noise and bicycle issues. However, a closer look at the survey results reveals that while 17 DOTs rated the issue as important (5 or 4), 18 ranked it as not important (1 or 2). In addition, 10 ranked pavement deterioration at 5; the same number ranked it at 1, the lowest level. Of the 17 agencies who identified pavement deterioration as a high-level issue, 12 reported they apply sealants over the rumble to protect the pavement.

As was indicated in the literature review, FHWA states on its rumble strip website (FHWA 2015a) that "Maintenance crews were initially concerned that heavy traffic would cause shoulder pavements with rumble strips to crumble faster, or that the freeze-thaw cycle of water collecting in the grooves would crack the pavement. These worries have proved to be unfounded where rumble strips were installed in pavements in fair to good condition. Rumble strips have little if any effect on the rate of deterioration of new pavements." This provides anecdotal evidence that the pavement deterioration resulting from rumbles is not an issue, but does not provide specific information based on field research to back this statement.

Two states, Kentucky and Michigan, have investigated the topic. In a study on rumble trips conducted for the Kentucky Transportation Cabinet (Kirk 2008), the effect of the rumble on pavement deterioration was of special concern. To address these concerns, a special meeting was held with maintenance personnel from Districts 6, 9, and 11, where limited applications of center line rumble strips exist on the Daniel Boone Parkway, Mountain Parkway, and AA Highway. Pavement deterioration along the center line joint was noted on the Mountain Parkway and Daniel Boone Parkway; however, it was noted that this was a retrofit application and pavement performance was poor before the rumble strip placement. Other applications on new pavement were not reported to have suffered any significant problems of pavement deterioration.

Though the Kentucky study provided further anecdotal evidence that rumbles do not negatively impact pavement condition, the scope was very limited and not based on comparing field pavement performance data.

The Michigan DOT study (Datta et al. 2012) investigated the short-term pavement performance and the impact of the rumble on non-freeway segments. The effects of center line rumble strips were assessed by comparing the rate of crack propagation between road segments where rumble strips were installed, and similar control segments where rumble strips were not installed. The study considered other factors such as traffic, pavement age, and region in determining their samples to conduct the comparison. The study showed that in each case, the increase in cracks during the two-year analysis period was marginally higher in the control sections in comparison to rumble strip sections. The differences were not statistically significant, but these data

TABLE 20
COMPARISON OF INCREASE IN CRACKS BETWEEN RUMBLE STRIP AND CONTROL SECTIONS

| REGION | INCREASE IN CRACKS PER 0.1 MILE DURING A TWO-YEAR PERIOD | | | | T-TEST STATISTIC | P-VALUE | SIGNIFICANT DIFFERENCE? |
|---|---|---|---|---|---|---|---|
| | RUMBLE STRIP SECTIONS | | CONTROL SECTIONS | | | | |
| | MEAN | STANDARD DEVIATION | MEAN | STANDARD DEVIATION | | | |
| I | 3.04 | 4.32 | 3.26 | 5.77 | -0.82 | 0.41 | No |
| II | 3.30 | 5.07 | 3.51 | 5.40 | -0.78 | 0.44 | No |
| III | 4.57 | 5.14 | 4.70 | 4.92 | -0.44 | 0.66 | No |

*Source*: Datta (2012).

suggest that rumble strips did not create adverse impacts on pavement performance in the short-term. Table 20 shows the comparison results.

The Michigan DOT study on the impact of rumbles on pavement condition is the most comprehensive and field-data oriented. Even though it showed no impact, the study only considered short-term (2 years) effects, and pavement and material engineers may argue that it is the long-term performance of the pavement that is critical and that could be impacted by rumbles. This might be a topic for further research.

CHAPTER FIVE

# CONCLUSIONS AND SUGGESTIONS FOR FUTURE RESEARCH

Rumble strips and stripes are low-cost safety countermeasures that can be placed on highway shoulders or center line to reduce roadway/lane departure crashes. State rumble strip and stripe practices are not uniform, and there may not be one ideal design that can deliver the auditory and tactile clues required to warn drivers to correct their path.

The objective of this synthesis was to identify current practices used by states installing rumble strips and stripes. The scope of this synthesis study focuses primarily on the following aspects of rumble strips and stripes:

- Rumble designs–patterns, locations, pavement types and widths, etc.
- Expected safety benefits such as crash modification, white-out/packed snow/fog driving, wet night driving, etc.
- Tolerances for installation
- Roadside noise
- Impacts on bicycle community
- Public outreach, including education, public involvement, department of transportation (DOT)/agency responses, etc.
- Maintenance/durability issues–winter, pavement preservation, etc.
- Other concerns identified through the survey.

This list of issues was grouped into six categories, which were then used to develop a logical flow for the survey:

- State DOT general rumble practices
- Roadway selection criteria
- Design and installation
- Maintenance practices
- Benefits
- Issues.

There were 41 responding state DOT agencies for a response rate of 82%.

## OVERALL FINDINGS

There is overwhelming evidence that rumble strips and stripes have a positive impact on safety by reducing run-off-the-road and/or head-on crashes. The literature review showed examples of how state DOTs assessed those safety benefits and the survey results showed how state DOTs embraced their use as part of safety planning. All the survey participants indicated they install shoulder (edge line) rumbles, and 88% install center line rumbles.

The state of the practice survey showed the variation among state DOT practices when it comes to installing, designing, and maintaining rumble strips and stripes. The variability ranges from where to install them (urban vs, rural, four-lane vs. two-lane, and undivided vs. divided roadways); their dimensions (length, width, spacing and depth); whether or not to apply sealants; and how to re-apply pavement markings in the case of a rumble stripe application.

Even though rumbles have a huge safety benefit, there are issues that arise from installing them. The main issues identified by the state DOTs in the survey are noise, bicycle concerns, and pavement deterioration.

To address the noise issue, the majority of the states take traditional approaches—skipping rumbles in residential areas, adjusting their depth, or not installing rumbles at all. Very few agencies (California and Minnesota DOTs and a Pennsylvania contractor) have experimented with different pattern design (sinusoidal pattern) to reduce the noise issue. This promises to be a viable solution to the noise issue but additional research might be needed to ensure that with noise reductions, enough audible and tactile warnings are delivered to the driver to react.

Related to the bicycle concern issue, the state DOTs developed policies to modify their rumble design practices to be sensitive to cyclists. Most of the DOTs deal with bicycle issues by introducing a bicycle gap (most alternate 48 feet of rumble with a 12-foot rumble-free gap); adjusting the shape of the rumble strip; and ensuring there is sufficiently wide paved shoulder or enough clearance from barriers or guard rails. More could be done in this area by communicating more with cycling groups and also explaining the importance of using such a safety countermeasure to address safety.

Pavement deterioration (mostly center line joint deterioration) rounds off the major concerns identified by the state DOTs in the survey. Of the 18 agencies who identified pavement deterioration as an issue, 12 agencies (67%) also reported applying sealant over the rumble. The literature search did not produce many publications on the impact of rumbles on pavement performance, which is why it has been identified as

one of the suggestions for future research. Some agencies indicated that pavement condition is a factor in considering whether to install a rumble or not. Others also indicated that rumbles will not be installed on portland cement concrete pavements.

The survey showed that very few state DOTs have created public campaigns to explain their use of rumbles to improve safety, which might minimize complaints regarding noise, bicycle issues, and others. Examples from Michigan, Minnesota, and North Carolina could be used as templates by other DOTs to start addressing the communication issues.

## SUGGESTIONS FOR FURTHER RESEARCH

Work on this synthesis has identified several gaps in current knowledge that could be addressed by the following suggested research topics.

- Dealing with noise (new design standards)—State DOTs could further investigate alternative rumble designs to reduce noise. As the literature showed, the sinusoidal pattern is promising, but further research is needed. As shown in the Minnesota DOT study, the reduction of the rumble length from 16 inches to 8 inches resulted in reduced audible and tactile warnings when the whole tire was not in contact with the rumble.
- Specifications (audible and tactile)—Rumble strips and stripes provide feedback to the drivers by producing audible and palpable warnings. Survey responses show that only two agencies have developed specifications for these two items. Additional research could assess how powerful audible and tactile warnings need to be and how they can be measured.
- Rumble stripes—When the pavement marking and the rumble strip are combined, a rumble stripe is born. The survey showed the lack of information on the impact of the rumble on the performance of the pavement marking. Another aspect of rumble stripe is the wet/night visibility advantage; as yet, very few states have measured wet retroreflectivity of rumble stripes. Additional research could provide more guidance to the state DOTs on rumble stripes.
- Pavement deterioration—Additional research could assess the impact of the rumble on the pavement deterioration. A number of states said they have an electronic database with all locations of their rumbles that is tied to a location referencing system. This would allow for the integration of pavement condition data over time to determine if the rumbles have a negative impact on pavement performance, and if so, how much.
- Rumble strip design (impact on safety benefits)—Results from the survey showed how the state DOT practices vary, from size to design to installation; and also how the resulting crash modification factors vary. This suggested research topic would address the potential differences in safety benefits resulting from different rumble strip and stripe designs.

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# APPENDIX A

# Survey Questions

## NCHRP Synthesis on Rumble Strip Practices 46-13

**Dear State DOT Safety/Traffic Engineer**

The Transportation Research Board (TRB) is preparing a synthesis on **Practice of Rumble Strips and Rumble Stripes**. This is being done for NCHRP, under the sponsorship of the American Association of State Highway and Transportation Officials, in cooperation with the Federal Highway Administration.

Rumble strips are a low cost safety countermeasure used to reduce roadway/lane departure crashes. When a pavement marking is applied over the rumble pattern, it is known as a rumble stripe. The practices from state to state are not uniform and there may not be one ideal design for all applications. There are advantages and disadvantages to the different rumble designs.

This synthesis will identify current practices used by states installing rumble strips and rumble stripes. The scope of this synthesis study will focus on the safety benefits, rumble design, external noise considerations, durability/maintenance issues, impacts on bicyclists, and public affairs/outreach efforts. Results will benefit government agencies, researchers, and the road-building industry in providing guidance on successful practices.

This questionnaire is being sent to all state DOTs. Your cooperation in completing the questionnaire will ensure the success of this effort. *If you are not the appropriate person at your agency to complete this questionnaire, please forward it to the correct person.*

Please complete and submit this survey by *April 20, 2015.* We estimate that it should take approximately 12 minutes to complete. If you have any questions, please contact our principal investigator Omar Smadi. Any supporting materials can be sent directly to Omar Smadi by email at smadi@iastate.edu.

**Questionnaire Instructions**

To view and print the entire questionnaire click on the following link and print using "control p"

To save your partial answers and complete the questionnaire later click on the "Save and Continue Later" link on the top of your screen. A link to the incomplete questionnaire will be emailed to you from *SurveyGizmo.* To return to the questionnaire later, open the email from *SurveyGizmo* and click on the link. We suggest using the "Save and Continue Later" feature if there will be more than 15 minutes of inactivity while the survey is opened, as some firewalls may terminate due to inactivity.

To pass a partially completed questionnaire to a colleague click on the on the "Save and Continue Later" link in the upper right hand corner of your screen. A link to the incomplete questionnaire will be emailed to you from *SurveyGizmo.* Open the email from *SurveyGizmo* and forward it to a colleague.

To view and print your answers before submitting the survey click forward to the page following question 70. Print using "control p." To submit the survey click on "Submit" on the last page.

**Thank you very much for your time and expertise!**

**Definitions**

**Shoulder Rumble Strip is a longitudinal safety feature installed on a paved roadway shoulder near the outside edge of the travel lane. It is made of a series of milled or raised elements intended to alert inattentive drivers (through vibration and sound) that their vehicles have left the travel lane (FHWA definition).**

**Center Line Rumble Strip is a longitudinal safety feature installed at or near the center line of a paved roadway. It is made of a series of milled or raised elements intended to alert inattentive drivers (through vibration and sound) that their vehicles have left the travel lane (FHWA definition).**

**Bicycle Gap Pattern (gap plus cycle) consists of a gap clear of rumbles (typical between 10 to 12 feet) and then a cycle of rumbles (typical 40 to 60 feet).**

**Intermittent Gap is a gap created between continuous application of the rumble line, for pre-determined situations such as intersections, major driveways, bridge decks, etc.**

**Edge Line Rumble Stripe is a special type of shoulder rumble strip placed directly at the edge of the travel lane with the edge line pavement marking placed through the line of rumble strips.**

**Centerline Rumble Stripe is when the center line pavement marking is placed over the center line rumble strip.**

**Tactile is the vibration induced in the motor vehicle by the rumble strips which can be referred to as the "tactile warning."**

**Audible is the noise generated as the motor vehicle tires pass over the rumble strip thus providing an audible warning to the motorist.**

**Contact Information**

Please enter your contact information:

First Name:

Last Name:

Agency/Organization:

Street Address: Suite: City: State: Zip Code:

E-mail Address:

Phone Number:

**Rumble Strip Usage**

1) **Does your agency use rumble strips?**

   Yes

   No

2) **Does your agency have a written policy/guidelines concerning the application of rumble strips?**

   Yes

   No

3) **If Yes, please provide a copy by e-mail to smadi@iastate.edu or link to this policy/guidance**

**Rumble Strip Selection Criteria**

4) **On what types of roadways does your agency install shoulder and/or centerline rumble strips?**

   **Definitions:**

   **Shoulder Rumble Strip** is a longitudinal safety feature installed on a paved roadway shoulder near the outside edge of the travel lane. It is made of a series of milled or raised elements intended to alert inattentive drivers (through vibration and sound) that their vehicles have left the travel lane. (FHWA definition).

   **Center Line Rumble Strip** is a longitudinal safety feature installed at or near the center line of a paved roadway. It is made of a series of milled or raised elements intended to alert inattentive drivers (through vibration and sound) that their vehicles have left the travel lane (FHWA definition).

| Roadway Type | None | Left Shoulder (median) | Center Line | Right Shoulder (outside) |
|---|---|---|---|---|
| **Urban multilane divided highways** | | | | |
| **Urban multilane undivided highways** | | | | |
| **Urban two-lane roads** | | | | |
| **Rural multilane divided highways** | | | | |
| **Rural multilane undivided highways** | | | | |
| **Rural two-lane roads** | | | | |

5) **What conditions impact your agency's SHOULDER rumble strip policy or guidelines?** Please identify and provide minimum required values.

| Condition | Yes | Minimum Required Value | Comment |
|---|---|---|---|
| Shoulder width: | | | |
| ADT: | | | |
| Pavement type: | | | |
| Pavement condition: | | | |
| Crash frequency/rate: | | | |
| Alignment: | | | |
| Speed Limit: | | | |
| Other (please specify): | | | |

6) **What conditions impact your agency's CENTER LINE rumble strip policy or guidelines?** Please identify and provide minimum required values.

| Condition | Yes | Minimum Required Value | Comment |
|---|---|---|---|
| Lane width: | | | |
| ADT: | | | |
| Pavement type: | | | |
| Pavement condition: | | | |
| Crash frequency/rate: | | | |
| Alignment: | | | |
| Speed limit: | | | |
| Other (please specify): | | | |

**Design/Installation Practices—General**

**7) Do you apply a sealant over rumble strips?**

Yes

No

Yes, but not standard practice

**8) Please explain why.**

**9) Do you field check installed rumble strip dimensions?**

Yes

No

**10) Do you use a standard (fully defined) method to check dimensions?**

Yes

No

**11) What field dimensions are measured?**

Length

Width

Depth

Spacing

Pattern

**12) Do you have an electronic database of your installed locations?**

Yes

No

**13) Are these data records tied to a location reference system?**

Yes

No

**14) Does your agency have specifications regarding the AUDIBLE ranges that a rumble strip should produce?**

**Audible is the noise generated as the motor vehicle tires pass over the rumble strip thus providing an audible warning to the motorist.**

| | Check all that apply | Audible Ranges |
|---|---|---|
| **None** | | |
| **Inside vehicle** | | |
| **Outside vehicle** | | |

**15) Does your agency have specifications regarding the TACTILE ranges that a rumble strip should produce?**

**Tactile is the vibration induced in the motor vehicle by the rumble strips which can be referred to as the "tactile warning."**

| | Yes or No | Tactile Ranges |
|---|---|---|
| Tactile specifications? | | |

**16) Does your agency have specifications regarding the PATTERN to be used for a rumble strip?**

| | Yes or No | Comments |
|---|---|---|
| Pattern specifications? | | |

**Design/Installation Practices—Shoulder Rumble Strip**

**17) How close to the edge line does your agency install shoulder rumble strips? Please provide value in inches.**

**18) Is the placement dependent on the location of the edge joint?**

Yes

No

**19) What type of shoulder rumble strips are installed by your agency?**

**Bicycle Gap Pattern (gap plus cycle) consists of a gap clear of rumbles (typically between 10 and 12 feet) and then a cycle of rumbles (typically 40 to 60 feet).**

| Type | Yes | Pattern (where applicable) | Why Is This Pattern Used? |
|---|---|---|---|
| **Continuous** | | | |
| **Pattern (gap/cycle)** | | | |
| **Bicycle gap pattern** | | | |

**20) Does your agency install shoulder rumble strips intermittently?**

**Intermittent Gap is a gap created between continuous application of the rumble line, for pre-determined situations such as intersections, major driveways, bridge decks, etc. . . .**

Yes

No

**21) What factors determine where you avoid placing rumble strips?**

Noise

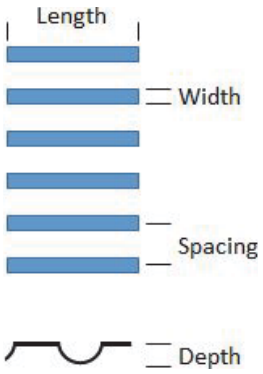
Bicycles

Special Users

Bridge Decks

Other (required answer)

**22) What are the typical dimensions for shoulder rumble strips?**




| | Dimensions (inches) |
|---|---|
| Length | |
| Width | |
| Spacing | |
| Depth | |

**23) Do any of the rumble strip dimensions vary by roadway type?**

| | Check One | | How? |
|---|---|---|---|
| | Yes | No | |
| Length | | | |
| Width | | | |
| Spacing | | | |
| Depth | | | |

**Design/Installation Practices—Center Line Rumble Strip**

**24) Where does your agency place the center line rumble relative to the roadway centerline pavement marking** (see photos from *NCHRP Report 641*)**?**

**Within pavement marking (rumble stripe)**

**Centerline rumble stripe is when the center line pavement marking is placed over the center line rumble strip.**

**Not within pavement marking (rumble strip)**

Rumble stripe

Rumble strip

Both

Other (required answer)

**25) What type of center line rumble strips are installed by your agency?**

**Bicycle Gap Pattern (gap plus cycle) consists of a gap clear of rumbles (typically between 10 and 12 feet) and then a cycle of rumbles (typically 40 to 60 feet).**

| Type | Yes | Pattern (where applicable) | Why is this pattern used? |
|---|---|---|---|
| Continuous | | | |
| Pattern (gap/cycle) | | | |
| Bicycle gap pattern | | | |

**26) Does your agency install center line rumble strips intermittently?**

**Intermittent Gap is a gap created between continuous application of the rumble line, for pre-determined situations such as intersections, major driveways, bridge decks, etc.**

Yes

No

**27) What factors determine where you avoid placing rumble strips?**

Noise

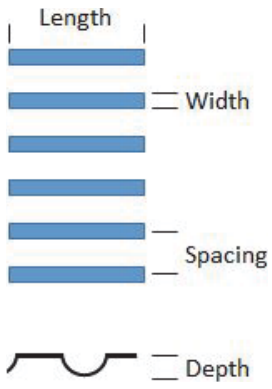
Bicycles

Special Users

Bridge Decks

Other (required answer)

**28) What are the typical dimensions for center line rumble strips?**




| | Dimensions (inches) |
|---|---|
| Length | |
| Width | |
| Spacing | |
| Depth | |

**29) Do any of the rumble strip dimensions vary by roadway type?**

| | Check One | | How? |
|---|---|---|---|
| | Yes* | No* | |
| Length | | | |
| Width | | | |
| Spacing | | | |
| Depth | | | |

**Design/Installation Practices—Rumble Stripe**

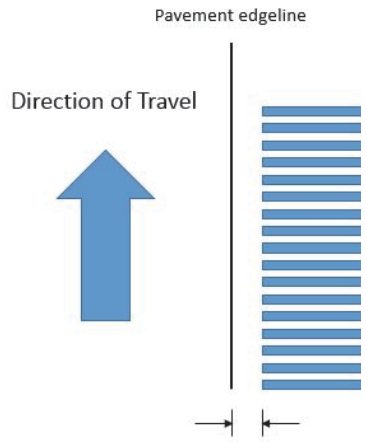
**30) Does your agency use edge line rumble stripes?**

**Edge line rumble stripe is a special type of shoulder rumble strip placed directly at the edge of the travel lane with the edge line pavement marking placed through the line of rumble strips.**

Yes

No

**31) Where is the rumble stripe placed relative to the pavement edge (use inches for any dimensions)?**




**32) Does your agency use center line rumble stripes?**

Yes

No

**33) Does your agency measure pavement marking retroreflectivity of the rumble stripe?**

**Retroreflectivity** is a measure of the ability of a material to reflect light back to the originating source.

Yes

No

**34) Please identify under which conditions these measurements are made:**

Dry

Continuous Wetting (during rain)

Wet Recovery (after rain)

All of the above

**35) Which pavement marking products are used for rumble stripe installations?**

Standard Acrylic Waterborne Paint

High Build Acrylic Waterborne Paint

Epoxy

Polyurea

Urethane

Sprayed Thermoplastic

Other (required answer)

**36) Does your agency use any wet reflective media to enhance wet night visibility of the rumble stripes?**

Yes

No

Yes, but not standard practice

**Maintenance Practices—Rumble Strip**

**37) Over time, does your agency re-apply sealant over rumble strips?**

Yes

No

**38) How often is the sealant reapplied (in months)?**

**39) What triggers re-application of the sealant?**

Visual Inspection

Timed Maintenance

Condition Based Assessment

Other

**40) Does your agency have a life expectancy for a rumble strip (in terms of tactile and audible effectiveness) or is replacement based on pavement surface rehabilitation?**

| | Check One | | Life Expectancy (years) |
|---|---|---|---|
| | Yes* | No* | |
| Based on tactile and audible effectiveness | | | |
| Based on pavement surface rehabilitation | | | |

**41) Do winter maintenance operations vary based on the presence of rumble strips (snow removal, sanding, salt and brine applications)?**

Yes

No

**42) Please note how your agencies winter maintenance practices vary given the presence of rumble strips?**

**Maintenance Practices—Rumble Stripe**

**43) How does your agency maintain the pavement marking within the rumble strip?**

Remove existing markings prior to re-application

Paint over existing markings

**44) How many times do you re-apply over existing markings prior to impacting the rumble tactile and audible effectiveness?**

**45) Has your agency experienced differences in retroreflectivity by direction of travel for centerline rumble stripes?**

Yes

No

**46) How has your agency addressed this issue? For example, through varied installation methods, equipment, re-application frequencies?**

**Benefits**

**47) Has your agency established crash modification factors for installing rumble strips?**

Yes

No

**48) What are crash modification factor values that your agency uses for rumble strips?**

**49) Has your agency establish a cost–effectiveness value for installing rumble strips based on safety benefits?**

Yes

No

**50) What are the cost-effective values your agency uses when considering the installation of rumble strips?**

**51) There is anecdotal evidence that installing a pavement marking over the rumble strip extends the life of the marking. What is your agency's experience?**

| | Check One | | Life Expectancy (years) |
|---|---|---|---|
| | Yes* | No* | |
| Similar performance | | | |
| Extended life by less than 1-year | | | |
| Extended life by greater than 1-year | | | |
| Other | | | |

**52) Does your agency use rumble stripes as a wet night visibility solution?**

Yes

No

**53) Has this been measured? Do you have a wet condition retroreflectivity minimum or target?**

**54) Are there other benefits your agency considers from using rumble stripes?**

**Issues**

**55) Please identify the relative importance of the following rumble strip or stripe issues faced by your agency (5 being the most important issue faced).**

| | Relative Importance | | | | |
|---|---|---|---|---|---|
| | **5 (Highest)** | **4** | **3** | **2** | **1 (Lowest)** |
| Noise complaints | | | | | |
| Bicycle complaints | | | | | |
| Motorcycle complaints | | | | | |
| Pavement deterioration (center line joint) | | | | | |
| Pavement deterioration (edge line) | | | | | |
| Winter maintenance issues | | | | | |
| Pavement marking performance | | | | | |
| Rumbles on thin asphalt overlay/micro surface/chip seal | | | | | |

**56) Are there any other issues not listed above?** (please note)

**57) Does your agency rumble strip policy/guidance address noise concerns?**

Yes

No

Not Applicable

**58) Does this impact installation practices:**

In terms of locations selected for installation?

In terms of rumble strip design?

Other considerations? (please note)

**59) Does your rumble strip policy/guidance address bicycle safety complaints?**

Yes

No

Not Applicable

**60) Does this impact installation practices:**

In terms of locations selected for installation?

In terms of rumble strip design?

Other considerations? (please note)

**61) Does your rumble strip policy/guidance address Motorcycle safety complaints?**

Yes

No

Not Applicable

**62) Does this impact installation practices in terms:**

In terms of locations selected for installation?

In terms of rumble strip design?

Other considerations? (please note)

**63) Does your rumble strip policy/guidance address pavement deterioration issues?**

Yes

No

Not Applicable

**64) Does this impact installation practices in terms:**

In terms of locations selected for installation?

In terms of rumble strip design?

Other considerations? (please note)

**65) Does your rumble strip policy/guidance address winter maintenance issues?**

Yes

No

Not Applicable

**66) Does this impact installation practices in terms:**

In terms of locations selected for installation?

In terms of rumble strip design?

Other considerations? (please note)

**67) Please rate your agency's experience on the level of public complaints regarding rumble strips:**

| | **Frequency of Complaints** | | |
|---|---|---|---|
| | **Low*** | **Medium*** | **High*** |
| Noise complaints | | | |
| Bicycle complaints | | | |
| Motorcycle complaints | | | |
| Pavement deterioration (center line joint) | | | |
| Pavement deterioration (edge line) | | | |
| Winter maintenance issues | | | |
| Pavement marking performance | | | |
| Rumbles on thin asphalt overlay/micro surface/chip seal | | | |

**68) Has your agency developed fact sheets/brochures regarding the benefits of rumble strips to communicate with the public?**

Yes

No

Other (required answer)

**69) Please provide an example or link for either rumble strips or stripes.**

**70) Has your agency developed Public Service Announcements (web, radio, TV) to communicate the benefits of rumble strips?**

Yes

No

Other (required answer)

**71) Please provide an example or link for either rumble strips or stripes.**

**72) Please add any general comments on the topic.**

# APPENDIX B
# Survey Participants

**State DOT Respondents**

Alabama Department of Transportation

Alaska Department of Transportation

Arizona Department of Transportation

Arkansas State Highway and Transportation Department

California Department of Transportation

Colorado Department of Transportation

Connecticut Department of Transportation

Delaware Department of Transportation

Florida Department of Transportation

Georgia Department of Transportation

Indiana Department of Transportation

Iowa Department of Transportation

Kansas Department of Transportation

Kentucky Transportation Cabinet

Louisiana Department of Transportation and Development

Maryland State Highway Administration

Maine Department of Transportation

Massachusetts Department of Transportation

Michigan Department of Transportation

Minnesota Department of Transportation

Mississippi Department of Transportation

Missouri Department of Transportation

Montana Department of Transportation

Nevada Department of Transportation

New Mexico Department of Transportation

New York Department of Transportation

North Carolina Department of Transportation

North Dakota Department of Transportation

Ohio Department of Transportation

Oklahoma Department of Transportation

Oregon Department of Transportation

Pennsylvania Department of Transportation

Rhode Island Department of Transportation

South Carolina Department of Transportation

South Dakota Department of Transportation

Texas Department of Transportation

Vermont Agency of Transportation

Virginia Department of Transportation

Washington Department of Transportation

Wisconsin Department of Transportation

Wyoming Department of Transportation

**Canadian Respondents**

Nova Scotia Transportation and Infrastructure Renewal Department

Saskatchewan Ministry of Highways and Infrastructure

# APPENDIX C

# Selected Agency Survey Responses

This appendix provides summary information for all of the state DOTs that responded to the survey on the following topics:

- General rumble strip and stripe practices
- Shoulder rumble strip practices
- Centerline rumble strip practices
- Installation practices
- Maintenance practices
- Policy issues
- Benefits

**General Rumble Strip and Stripe Practices**

| State | Rumble Strips (Yes/No) | Rumble Stripes (edgeline) | Rumble Stripes (centerline) | Policy for Rumble Strips/Stripes | Fact Sheets/Brochures | Public Service Announcements |
|---|---|---|---|---|---|---|
| AK | Yes | Yes | Yes | Yes | Yes | |
| AL | Yes | Yes | | | | |
| AR | Yes | Yes | Yes | Yes | | |
| AZ | Yes | Yes | Yes | Yes | | |
| CA | Yes | Yes | | Yes | | |
| CO | Yes | | Yes | | | |
| CT | Yes | No | Yes | Yes | Yes | |
| DE | Yes | Yes | Yes | Yes | Yes | |
| FL | Yes | Yes | Yes | Yes | | |
| GA | Yes | | Yes | Yes | | |
| IA | Yes | | Yes | Yes | | |
| IN | Yes | Yes | Yes | Yes | | |
| KS | Yes | | Yes | Yes | | |
| KY | Yes | Yes | Yes | Yes | | |
| LA | Yes | Yes | Yes | Yes | | |
| MA | Yes | | | Yes | | |
| MD | Yes | Yes | Yes | Yes | | |
| ME | Yes | Yes | Yes | Yes | Yes | |
| MI | Yes | | Yes | Yes | In Progress | Yes |
| MN | Yes | Yes | Yes | Yes | Yes | |
| MO | Yes | Yes | Yes | Yes | | |
| MS | Yes | Yes | Yes | | | |
| MT | Yes | | Yes | Yes | | |
| NC | Yes | Yes | Yes | Yes | | |
| ND | Yes | Yes | Yes | Yes | | Yes |
| NM | Yes | Yes | Yes | | | |
| NV | Yes | Yes | Yes | Yes | | |
| NY | Yes | No | Yes | Yes | | Yes |
| OH | Yes | Yes | Yes | Yes | | |
| OK | Yes | | | Yes | | |
| OR | Yes | Yes | Yes | Yes | | |
| PA | Yes | Yes | Yes | Yes | Yes | |
| RI | Yes | Yes | Yes | Yes | | |
| SC | Yes | Yes | Yes | Yes | | Yes |
| SD | Yes | Yes | Yes | Yes | | |
| TX | Yes | Yes | Yes | Yes | | |
| VA | Yes | Yes | Yes | Yes | | |
| VT | Yes | | Yes | Yes | Yes | |
| WA | Yes | Yes | | Yes | Yes | |
| WI | Yes | Yes | Yes | Yes | Yes | |
| WY | Yes | | | Yes | | |

**Shoulder Rumble Strip Practices**

| State | Continuous | Pattern (Gap/Cycle) | Bicycle Gap Pattern |
|---|---|---|---|
| AK | Yes | Yes | Yes |
| AL | Yes | | |
| AR | Yes | | Yes |
| AZ | Yes | Yes | |
| CA | Yes | | |
| CO | Yes | Yes | |
| CT | Yes | | |
| DE | Yes | Yes | Yes |
| FL | Yes | Yes | |
| GA | Yes | | Yes |
| IA | | | Yes |
| IN | Yes | Yes | |
| KS | | Yes | |
| KY | Yes | | |
| LA | | | Yes |
| MA | Yes | | Yes |
| MD | Yes | Yes | Yes |
| ME | Yes | Yes | Yes |
| MI | Yes | Yes | Yes |
| MN | Yes | | Yes |
| MO | Yes | | |
| MS | Yes | | |
| MT | | | Yes |
| NC | Yes | Yes | Yes |
| ND | Yes | | Yes |
| NM | | Yes | |
| NV | Yes | | |
| NY | Yes | | |
| OH | Yes | Yes | Yes |
| OK | Yes | | Yes |
| OR | | | Yes |
| PA | Yes | | Yes |
| RI | | Yes | |
| SC | Yes | | Yes |
| SD | Yes | | Yes |
| TX | Yes | | Yes |
| VA | Yes | | Yes |
| VT | Yes | | |
| WA | Yes | | Yes |
| WI | Yes | | |
| WY | Yes | | Yes |

**Centerline Rumble Strip Practices**

| State | Continuous | Pattern (Gap/Cycle) | Bicycle Gap Pattern |
|---|---|---|---|
| AK | Yes | | |
| AL | | | |
| AR | Yes | | |
| AZ | Yes | Yes | |
| CA | Yes | | |
| CO | Yes | | |
| CT | Yes | | |
| DE | Yes | Yes | |
| FL | Yes | | |
| GA | Yes | | |
| IA | Yes | | |
| IN | Yes | | |
| KS | Yes | | |
| KY | Yes | | |
| LA | Yes | | |
| MA | | | |
| MD | Yes | Yes | |
| ME | Yes | Yes | |
| MI | Yes | | |
| MN | Yes | | |
| MO | | Yes | |
| MS | Yes | | |
| MT | Yes | | |
| NC | | Yes | |
| ND | Yes | | |
| NM | | Yes | |
| NV | Yes | | |
| NY | Yes | | |
| OH | Yes | | |
| OK | | | |
| OR | | Yes | Yes |
| PA | Yes | | |
| RI | Yes | | |
| SC | | | Yes |
| SD | Yes | | |
| TX | Yes | | |
| VA | Yes | | |
| VT | | Yes | |
| WA | Yes | | |
| WI | | | |
| WY | | | |

## Installation Practices

| State | Check Rumble Dimensions | Standard Method to Check | Installation Location (electronic database) | Locations Tied to LRS | Audible Specs (inside vehicle) | Audible Specs (outside vehicle) | Tactile Specs |
|---|---|---|---|---|---|---|---|
| AK | Yes | | | | | | |
| AL | Yes | Yes | | | | | |
| AR | | | Yes | Yes | Yes | | Yes |
| AZ | Yes | | | | | | |
| CA | Yes | | Yes | | | | |
| CO | | | | | | | |
| CT | Yes | | Yes | | | | |
| DE | Yes | | | | | Yes | |
| FL | Yes | | Yes | Yes | | | |
| GA | | | | | | | |
| IA | | | | | | | |
| IN | | | | | | | |
| KS | Yes | Yes | Yes | Yes | | | |
| KY | | | | | | | |
| LA | Yes | Yes | | | | | |
| MA | Yes | | | | | | |
| MD | Yes | Yes | | | | | |
| ME | | | Yes | Yes | | | |
| MI | Yes | | | | | | |
| MN | Yes | | | | | | |
| MO | | | Yes | Yes | | | |
| MS | Yes | | | | | | |
| MT | Yes | Yes | | | | | |
| NC | Yes | | | | | | |
| ND | Yes | | Yes | Yes | | | |
| NM | Yes | | | | | | |
| NV | Yes | Yes | Yes | | | | |
| NY | Yes | | Yes | Yes | | | |
| OH | Yes | | | | | | |
| OK | | | | | | | |
| OR | Yes | | | | | | |
| PA | Yes | Yes | Yes | Yes | | | |
| RI | | | Yes | | | | |
| SC | Yes | | Yes | Yes | | | |
| SD | | | | | | | |
| TX | Yes | | | | | | |
| VA | | | Yes | Yes | | | |
| VT | | | Yes | Yes | | | |
| WA | Yes | | Yes | Yes | | | |
| WI | Yes | Yes | | | | | |
| WY | Yes | | Yes | Yes | | | |

**Maintenance Practices**

| State | Apply Sealant (new rumble) | Re-Apply sealant (in service) | Maintain markings on Rumbles | Measure Retroreflectivity | Use Stripes for Wet Night Visibility |
|---|---|---|---|---|---|
| AK | | | Paint over | | |
| AL | | | Paint over | Dry | |
| AR | | | Paint over | | |
| AZ | Yes, but not standard practice | Yes | Paint over | | |
| CA | Yes | | Paint over | | |
| CO | | | Remove existing | | |
| CT | | | Remove existing | | |
| DE | Yes, but not standard practice | | Paint over | | |
| FL | | | Paint over | Dry | Yes |
| GA | | | Paint over | | |
| IA | Yes | | Paint over | | |
| IN | Yes | | Paint over | Dry | Yes |
| KS | | | Paint over | | |
| KY | | | Paint over | | Yes |
| LA | | | Paint over | Dry | |
| MA | | | Paint over | | |
| MD | | | Paint over | | |
| ME | Yes | | Paint over | | |
| MI | | | Paint over | Dry | Yes |
| MN | Yes, but not standard practice | | Paint over | Dry | Yes |
| MO | | | Paint over | Dry/Wet Recovery | Yes |
| MS | | | Remove existing | Dry/Wet/Wet recovery | Yes |
| MT | Yes | | Paint over | | |
| NC | | | Remove existing | Dry | |
| ND | Yes | | Paint over | | Yes |
| NM | | | Remove existing | Dry/Wet/Wet recovery | |
| NV | Yes, but not standard practice | Yes | Paint over | | Yes |
| NY | Yes | Yes | Paint over | | |
| OH | | | Paint over | | |
| OK | Yes, but not standard practice | | Paint over | | |
| OR | Yes, but not standard practice | | Paint over | Dry | |
| PA | | | Paint over | | |
| RI | | | Remove existing | | |
| SC | | | Paint over | Dry | Yes |
| SD | Yes | | Paint over | | |
| TX | | | Paint over | Dry | |
| VA | Yes | Yes | Paint over | | Yes |
| VT | Yes | | Paint over | | |
| WA | Yes | | Paint over | | |
| WI | | | Paint over | Dry | |
| WY | Yes | Yes | Paint over | | |

**Policy Issues**

| State | Noise Issues | Bicycle Safety | Pavement Deterioration |
|---|---|---|---|
| AK | Yes | Yes | Yes |
| AL | Yes | Yes | |
| AR | Yes | Yes | Yes |
| AZ | | | |
| CA | | Yes | |
| CO | | | |
| CT | | Yes | Yes |
| DE | Yes | Yes | |
| FL | Yes | Yes | Yes |
| GA | | Yes | |
| IA | | Yes | Yes |
| IN | Yes | Yes | |
| KS | Yes | Yes | Yes |
| KY | Yes | | |
| LA | Yes | Yes | |
| MA | Yes | Yes | |
| MD | Yes | Yes | Yes |
| ME | Yes | Yes | Yes |
| MI | | Yes | |
| MN | Yes | Yes | |
| MO | Yes | Yes | |
| MS | | | |
| MT | Yes | Yes | |
| NC | Yes | Yes | |
| ND | Yes | | |
| NM | Yes | Yes | Yes |
| NV | | | |
| NY | | Yes | Yes |
| OH | Yes | Yes | Yes |
| OK | Yes | Yes | Yes |
| OR | Yes | Yes | Yes |
| PA | | Yes | |
| RI | Yes | Yes | Yes |
| SC | | Yes | |
| SD | | Yes | |
| TX | Yes | Yes | Yes |
| VA | Yes | Yes | Yes |
| VT | Yes | | |
| WA | Yes | Yes | Yes |
| WI | Yes | Yes | Yes |
| WY | | Yes | |

**Benefits**

| State | CMFs | Cost Effectiveness |
|---|---|---|
| AK | Yes | |
| AL | | |
| AR | | |
| AZ | | |
| CA | | |
| CO | Yes | Yes |
| CT | | |
| DE | | |
| FL | | |
| GA | Yes | |
| IA | | Yes |
| IN | | |
| KS | | |
| KY | | Yes |
| LA | | |
| MA | | |
| MD | | |
| ME | | |
| MI | Yes | Yes |
| MN | | Yes |
| MO | Yes | |
| MS | | |
| MT | | |
| NC | Yes | Yes |
| ND | | |
| NM | | |
| NV | | |
| NY | | Yes |
| OH | | |
| OK | | Yes |
| OR | Yes | Yes |
| PA | Yes | Yes |
| RI | | |
| SC | | |
| SD | | |
| TX | Yes | Yes |
| VA | Yes | |
| VT | | |
| WA | | |
| WI | | |
| WY | | |

*Abbreviations and acronyms used without definitions in TRB publications:*

| | |
|---|---|
| A4A | Airlines for America |
| AAAE | American Association of Airport Executives |
| AASHO | American Association of State Highway Officials |
| AASHTO | American Association of State Highway and Transportation Officials |
| ACI–NA | Airports Council International–North America |
| ACRP | Airport Cooperative Research Program |
| ADA | Americans with Disabilities Act |
| APTA | American Public Transportation Association |
| ASCE | American Society of Civil Engineers |
| ASME | American Society of Mechanical Engineers |
| ASTM | American Society for Testing and Materials |
| ATA | American Trucking Associations |
| CTAA | Community Transportation Association of America |
| CTBSSP | Commercial Truck and Bus Safety Synthesis Program |
| DHS | Department of Homeland Security |
| DOE | Department of Energy |
| EPA | Environmental Protection Agency |
| FAA | Federal Aviation Administration |
| FAST | Fixing America's Surface Transportation Act (2015) |
| FHWA | Federal Highway Administration |
| FMCSA | Federal Motor Carrier Safety Administration |
| FRA | Federal Railroad Administration |
| FTA | Federal Transit Administration |
| HMCRP | Hazardous Materials Cooperative Research Program |
| IEEE | Institute of Electrical and Electronics Engineers |
| ISTEA | Intermodal Surface Transportation Efficiency Act of 1991 |
| ITE | Institute of Transportation Engineers |
| MAP-21 | Moving Ahead for Progress in the 21st Century Act (2012) |
| NASA | National Aeronautics and Space Administration |
| NASAO | National Association of State Aviation Officials |
| NCFRP | National Cooperative Freight Research Program |
| NCHRP | National Cooperative Highway Research Program |
| NHTSA | National Highway Traffic Safety Administration |
| NTSB | National Transportation Safety Board |
| PHMSA | Pipeline and Hazardous Materials Safety Administration |
| RITA | Research and Innovative Technology Administration |
| SAE | Society of Automotive Engineers |
| SAFETEA-LU | Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (2005) |
| TCRP | Transit Cooperative Research Program |
| TDC | Transit Development Corporation |
| TEA-21 | Transportation Equity Act for the 21st Century (1998) |
| TRB | Transportation Research Board |
| TSA | Transportation Security Administration |
| U.S.DOT | United States Department of Transportation |

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