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Rumble Strips: Existing Literature and the State of the Practice in New Mexico, Final Report

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PREFACE

The research reported herein reviews the state of the practice for rumble strips. The purpose of this work is to provide updated guidance to the New Mexico Department of Transportation for rumble strips.

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DISCLAIMER

This report presents the results of research conducted by the author(s) and does not necessarily reflect the views of the New Mexico Department of Transportation. This report does not constitute a standard or specification.

ABSTRACT

The Western Transportation Institute (WTI) conducted research on behalf of the New Mexico Department of Transportation (NMDOT) to document the current practice among transportation agencies regarding the design, installation, and use of rumble strips. State-of-the-practice information was collected and synthesized through a literature review. In addition, researchers conducted interviews with NMDOT district traffic engineers to document the current use of rumble strips throughout the state. Based on the information learned through these sources, guidelines are proposed with regard to four types of rumble strip installations: shoulder, centerline, centerline and shoulder (used in combination), and transverse. Where applicable, the guidelines include recommendations to accommodate roadway usage by bicyclists.

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INTRODUCTION

The New Mexico Comprehensive Transportation Safety Plan 2010 Update indicates that 65% of all fatalities and 44.5% of all serious injuries occurring on New Mexico roadways from 2004 to 2009 can be categorized as lane departure crashes (1). Low-cost safety measures are identified as a potential strategy for addressing lane departure crashes. Rumble strips have been employed as a low-cost safety measure to address lane departure crashes.

Transportation agencies install rumble strips as a countermeasure to alert drivers and help prevent lane departure crashes. Four types of rumble strip applications are most frequently used: the shoulder rumble strip, the rumble stripe, the centerline rumble strip, and the transverse rumble strip. A midlane rumble strip has been proposed; however, no state department of transportation has implemented it. Shoulder rumble strips have been in use for the longest period of time, since about the 1990's. Centerline rumble strips have become more prevalent since the early 2000's. Rumble stripes and transverse rumble strips seem to be more prevalent since the mid-2000's.

Each of the four commonly used rumble strips has a different purpose. Shoulder rumble strips and rumble stripes are intended to mitigate run-off-the-road crashes. Centerline rumble strips are intended to reduce the occurrence of head-on crashes or lane departure crashes to the left. Transverse rumble strips are intended to alert a driver to an upcoming traffic control device, tolling station, or unexpected geometric changes (i.e. sharp horizontal curve, steep hill, etc.). The literature related to rumble strips can be contradictory as a result of various definitions for rumble strip dimensions. Therefore, the following definitions, adopted from NCHRP Project 641, will be used in this report. A is defined as the offset. B is defined as the length. C is defined as the width. D is defined as the depth. E is defined as the spacing between each bar in a rumble strip. F is the recovery area. G is the gap between applications of rumble strips. I is the lateral clearance. Note that for a rumble stripe, A will be zero. For centerline rumble strips, A, F and I will not apply. Similarly, for transverse rumble strips, A, F, G and I will not apply. These definitions will be highlighted in **bold** text with () around them throughout the document.



FIGURE 1 Dimensions of shoulder rumble strips (Image source: NCHRP Report 641 [51])

The New Mexico Department of Transportation (NMDOT) currently provides standard drawings for milled centerline rumble strips (approved in 2008), transverse rumble strips at intersection approaches (approved in 2005), and milled rumble strips (shoulder rumble strips) (approved in 2006). These standards are presented in Appendix A for the reader's reference. As the popularity of rumble strips has grown, advancement in knowledge through research and application has provided more recent guidance related to rumble strips. Additionally, cultural shifts within the United States now require that a holistic consideration of users, like bicyclists, be taken into account when designing roadways. Therefore, the NMDOT has funded this study to review the literature available on current knowledge of the different rumble strip types and applications. In addition, through this study, the NMDOT would like to gain a better understanding of how each of the six districts throughout the state currently applies rumble strips. The outcome of this study will be to provide guidelines that the NMDOT can use for each type of rumble strip.

On December 14, 2012, the Western Transportation Institute team met with the project advisors to gain a better understanding of the history of this research project. Bicyclist concerns with rumble strips were identified as a driving force behind the project. Some of the questions that developed as a result of the conversation include:

- 1. Should NMDOT recommend installing the rumble strip along the edgeline instead of in the shoulder?
- 2. How does reducing the rumble strip width affect the surface type?
- 3. What does the current literature say about rumble stripes?
- 4. Do directional rumble strips exist?
- 5. Is milling in rumble strips the state of the practice?

A few points of clarification should be added with regard to the questions identified above. Question two came about when considering the differences between concrete and asphalt pavements. For question four, directional rumble strips were defined by the project advisor as those that would help notify a driver who was traveling the wrong-way down a roadway. The project advisors expressed an interest in having a final product in the form of a table that featured components like average annual daily traffic (AADT), functional classification of roadway, qualitative expression of bicycle use, percentage of heavy traffic, shoulder width, and cost. They also wanted to obtain guidance related to bridge decks and transverse rumble strips. When performing the literature review, it was requested that international experience be incorporated. The project sponsors also indicated that they were interested in seeing examples of standard drawings from other states. All of these considerations were taken into account and addressed in the following sections.

The first section is the literature review, which presents individual studies on shoulder rumble strips, rumble stripes, centerline rumble strips, and transverse rumble strips, followed by studies that address more than one type of rumble strip. Within each of these subsections, the research studies are organized chronologically. This order helps to illustrate how more recent research results or knowledge may have changed compared to past results or conclusions.

The second section presents a summary of the interviews conducted with each of the district traffic engineers. During the aforementioned meeting, the project advisors requested that each of the district traffic engineers be contacted to gain more information about the current application of rumble strips within the State of New Mexico. After reviewing the literature, the research team developed a proposed list of questions to ask each district traffic engineer. The research team then provided these to the project advisor for comment. After approval was received, the research team approached each district traffic engineer to initiate the interview process.

The third section presents a summary based on the results of the literature review and interviews. The summary specifically addresses the issues and questions that NMDOT had proposed at the kick-off project meeting. In addition, this section identified the gaps that remain, and recommendations for future research.

The fourth and final section presents the guidelines developed by the research team, based on the results of this research.

LITERATURE REVIEW

SHOULDER RUMBLE STRIPS

Khan and Bacchus examined the economic feasibility of shoulder rumble strips for the Ontario Ministry of Transport in 1995 (2). By considering the costs of rumble strip installation (type not specified) and crashes versus the benefits from the potential reduction in crashes (and corresponding crash costs), the researchers calculated a series of benefit-cost ratios. These ratios ranged from 1.09 and 4.78, depending on crash history, facility type and traffic levels.

In 1998, Perrillo examined the use and effectiveness of continuous shoulder rumble strips for the FHWA New York Division (*3*). Specifically, the work focused on the considerations, costs, effects and benefits of shoulder rumble strips. Considerations for use/placement included:

- Roadway environment (urban/rural);
- Functional classification;
- Environmental conditions (weather, pavement, etc.);
- Noise effects; and
- Effects on bicycles.

Based on experience following the installation of continuous shoulder rumble strips on the New York State Thruway, the researcher calculated that they produced a benefit-cost ratio of 182.0. The primary benefit of rumble strips was a reduction in crashes over a 6 year service life. Collectively, continuous shoulder rumble strips installed throughout the state had reduced single vehicle run-off-the-road crashes by 70 percent.

In 1999, Moeur completed a rumble strip gap study in Arizona. The purpose of the work was to determine the optimum length for gaps in continuous shoulder rumble strips to allow bicyclists to cross the rumble strip without having to enter the pattern (4). The rumble strips in use at the time of the work (1999) were 12 inches in length (**B**), 7 inches in width (**C**), 0.50 inches deep (**D**) and spaced on 12 inch centers (**E**). Volunteer bicyclists were asked to ride through different rumble strip patterns and provide their observations and perceptions. A bicyclist speed of 25 mph was assumed when testing simulated rumble strips on a residential street in Phoenix. The results of observations of bicyclist behavior and performance when riding through the different gap patterns indicated the optimum gaps for rumble strips on non-controlled access highways should be 12 feet in length (**G**) spaced at 40 to 60 foot intervals.

Elefteriadou, et al. sought to develop new rumble strip configurations for the Pennsylvania Department of Transportation that decreased the level of vibrations experienced by bicyclists (5, 6). This included evaluating Pennsylvania's existing (2000) configuration and developing new configurations that were bicycle friendly. Design configurations were evaluated through simulation models and field tests. Test patterns that were evaluated included:

- 1) 16 inches length (**B**), 7 inches width (**C**), 0.50 inches depth (**D**) and 5 inch spacings (Pennsylvania design then in use);
- 2) 16 inches length (**B**), 5 inches width (**C**), 0.50 inches depth (**D**) and 7 inch spacings;

- 3) 16 inches length (B), 5 inches width (C), 0.375 inches depth (D) and 7 inch spacings;
- 4) 16 inches length (**B**), 5 inches width (**C**), 0.50 inches depth (**D**) and 6 inch spacings;
- 5) 16 inches length (**B**), 5 inches width (**C**), 0.375 inches depth (**D**) and 6 inch spacings;
- 6) 16 inches length (**B**), 5 inches width (**C**), 0.25 inches depth (**D**) and 5 inch spacings;

While pattern 6 was determined to be the most bicycle friendly, it produced the least amount of warning noise for motorists. Consequently, testing found that pattern 5 produced adequate motorist warning noise and did not produce discomfort for bicyclists. Therefore, pattern 5 was recommended for use on non-freeways with low speed limits (45 mph or lower). Pattern 3 was recommended for use on non-freeways with higher speed limits (ex. 55 mph). The provision of gaps versus continuous shoulder rumble strips was not discussed by the researchers.

In 2001, Outcalt compared three styles of rumble strips to find a design that would provide motorist warning and leave shoulders usable for bicyclists (7). The designs examined included:

- Colorado's standard milled in asphalt rumble strip; 12 inches in length (**B**), 5 inches wide (**C**), 0.375 inches deep (**D**), 12 inch gaps on center (**E**).
- A new two inch groove rumble strip; 12 inches in length (**B**), 2 inches wide (**C**), 0.50 inches deep (**D**), 7 inch gaps on center (**E**).
- Colorado's standard concrete rolled in rumble strip; 18 inches in length (**B**), 2.375 inches wide (**C**), 0.50 inches deep (**D**), 3.5 inch gaps on center (**E**) (7).

When non-continuous rumble strips were installed, twelve feet of rumble strip was interrupted by a six foot gap (G). The different designs were evaluated by having volunteer bicyclists assess and compare rumble strip sections based on comfort and controllability. Based on the tests, Outcalt recommended that the bicyclist-preferred rumble strip was essentially the existing Colorado design, with milled in grooves spaced 12 inches on center (E), a depth of 0.375 inches (D) and 12 foot pattern gaps (G) provided every 48 feet. This design provided adequate sound and vibration while also allowing a bicycle to cross without a loss of control.

In 2001, Bucko evaluated milled in and rolled in rumble strips for the California Department of Transportation (Caltrans) to determine a design that was effective in preventing run-off-the-road crashes while being bicycle friendly (8). As the result of instrumented and subjective testing at Caltrans' West Sacramento test facility, the report recommended that rumble strip dimensions should be changed from the existing (2001) design. This included changes to a length of 12 inches (**B**), a width of 5 inches (**C**), and a depth of 0.3125 inches (**D**). Additionally, it was recommended that a 5 foot shoulder should be present before installation of rumble strips is considered in order to accommodate bicycles. The report also stated that the use of rumble strips should be continued over bridge decks.

In 2001, Elefteriadou, et al. sought to develop approaches for placing rumble strips on roadways with narrow or non-existent shoulders in Pennsylvania (9). This involved accounting for the lateral width of the rumble strip and determining its placement. In looking at the roadway environment, the researchers recommended the following placement criteria using roadside hazard ratings:

- If the roadside had a hazard rating of 5 or higher, rumble strips should be placed within the roadway cross section to provide the greatest amount of recoverable area.
- If the roadside has a hazard rating of 4 or lower, rumble strips should be placed on the outside (right) of the shoulder as far as possible without compromising the integrity of the pavement.

In 2002, Daniel performed a review of then current literature on rumble strips and their safety impacts to bicyclists for the New Jersey Department of Transportation (10). Based on the observations made of this past work, a series of strategies for accommodating bicycles when shoulder rumble strips were present was developed. These strategies included:

- Minimum paved shoulder widths of 8 feet;
- Provide at least a 4 foot continuous riding surface;
- Provide an offset of 4 feet from the edge of the shoulder for bicycles;
- Move the rumble strip as close as possible to the travel lane;
- Use continuous rumble strips only on limited access facilities;
- Use 12 foot gaps (G) spaced every 40 to 60 feet; and
- Limit rumble strip width to 12 inches (**C**) (*30*).

Turochy performed a synthesis of then current (2003) practices and policies related to shoulder rumble strips (11, 12). The researcher noted that several states had reported reductions in runoff-the-road crashes of up to 70 percent. A survey of states completed as part of the synthesis found that of 36 agencies responding, 90 percent used milled in rumble strips that had dimensions consistent with those recommended by a 2001 FHWA technical advisory (length of 16 inches (**B**), width of 7 inches (**C**), 0.50 inched depth (**D**) and spaced 12 inches on center (**E**)). Approximately 30 percent of respondent states also reported the use of centerline rumble strips on rural, two lane roads.

In 2003, Marvin and Clark evaluated the effectiveness of shoulder rumble strips in reducing runoff-the-road crashes in Montana (13). Analysis of three years of before and after installation crash data from Interstate, National Highway System and primary highways showed a 14.0 percent reduction in run-off-the-road crashes had occurred that was attributable to shoulder rumble strips. A reduction of severity rates of 23.5 percent was also observed during this time. A benefit-cost ratio of 19.5 was calculated for shoulder rumble strip installations along Interstates.

In 2005, Smith and Ivan examined the effects of shoulder rumble strips on crash reduction in Connecticut (14). Analysis found that shoulder rumble strips reduced single vehicle fixed object crashes by 33 percent. Run-off-the-road crashes were also reduced throughout the state; the rate of reduction ranged from 12.8 to 48.5 percent, depending on the location.

A 2007 study by Miles and Finley evaluated factors that impacted the effectiveness of shoulder rumble strip design for the Texas Department of Transportation (TxDOT) (15). The focus of the work was on how vehicle speed, vehicle type (passenger car, pickup and commercial vehicle), pavement type (hot mix asphalt and chip seals), and rumble strip design (longitudinal and transverse) impacted the sound change heard by drivers. Based on field studies along Texas

highways, it was determined that all types of rumble strip designs produced adequate sounds to alert drivers of passenger cars and pickups. However, only milled rumble strips 12 inches in length or greater (**B**) provided enough sound to alert drivers of commercial vehicles. Consequently, a more aggressive rumble strip design in terms of width may need to be considered on routes with significant commercial traffic. Note that specific dimensions associated with the different rumble strip types were not provided; only general dimensions were listed as part of the research conclusions.

In 2008, Kirk evaluated the effectiveness of continuous shoulder rumble strips for the Kentucky Transportation Cabinet (16). Dimensions for Kentucky's shoulder rumble strips were 12 inches length (**B**), 7 inches width (**C**), depths of 0.50 to 0.625 inches (**D**), and a 12 inch spacing on center (**E**). An evaluation of crash data found that highway segments with rumble strips had a lower crash rate than those without them. The researcher recommended that a minimum paved shoulder width of one foot be present before using shoulder rumble strips to insure proper installation. Interestingly, the guidance recommended that no accommodation was necessary for bicyclists on rural two lane roads. Rather, since a bicyclist would be riding at the edge of the travel lane, a vehicle could simply pass that bicyclist as it would any other type of vehicle.

In 2012, El-Basyoun and Sayed evaluated the effectiveness of shoulder rumble strips in British Columbia. This included an estimation of both the immediate (one year) and permanent impacts of the treatment on crashes through modeling. Results found that shoulder rumble strips produced an immediate crash reduction of 24.9 percent one year after installation and a permanent reduction of 19.2 percent over the lifetime of the treatment (*17*).

Abdel-Rahim and Kahn examined the potential crash reduction benefits of shoulder rumble strips in Idaho (18). The researchers focused on two lane rural roadways, four lane rural roadways and rural freeways when conducting their before and after installation evaluation of crashes. The dimensions of the rumble strips in use in Idaho were not provided by the researchers. Based on different statistical analyses performed, a number of conclusions were drawn from the work. On two lane rural roads, shoulder rumble strips were found to reduce crashes by 15 to 23 percent, depending on the statistical approach employed. Severe crashes on these roads were reduced by 74 percent. Shoulder rumble strips on two lane rural road curves reduced crashes by 8 to 29 percent, depending on the design speed of the curve.

When the impact of rumble strips by traffic volume on two lane roads was examined, it was found that road sections with AADTs of less than 1,000 saw crash reductions of 33 percent. Roads with an AADT of approximately 2,500 had a minimal crash reduction of 3 percent, while roads with an AADT of between 3,500 and 4,000 saw reductions of 16 percent. Roads with an AADT of approximately 6,700 had a crash reduction of 24 percent.

On four lane rural roads, rumble strips produced crash reductions between 45 and 62 percent. Shoulder rumble strips on rural freeways produced crash reductions of 29 percent for all run off the road crashes, and reduced severe crashes by 67 percent. Finally, truck run off the road crashes on freeways were reduced by 42 percent. Although these results indicate that shoulder rumble strips produced crash reductions across the board, the researchers did not provide any guidance on future applications.

RUMBLE STRIPES

In 2006, Lindly and Narci evaluated rumble stripes in Alabama, looking at service life, life cycle costs, and wet-night visibility. The rumble stripe used in Alabama was milled with a length of 16 inches (**B**), a width of 7 inches (**C**), a depth of 0.50 to 0.625 inches (**D**), and a spacing of 12 inches on center (**E**). Results of life cycle cost analysis found that for a five year pavement marking life and an eight year life cycle, the cost per mile of rumble stripes was \$2,424 (2006 dollars) (*19*). Wet retroreflectivity was also found to be acceptable, even after the rumble stripes had been in service over the course of many years. Based on the findings of the work, it was recommended that rumble stripes be implemented in the future on projects where paved shoulders were constructed and where bicyclist issues and FHWA technical requirements could be met.

In 2009, Hallmark, et al. evaluated rumble stripes on low volume rural roads in Iowa (20). Vehicle lane position was used as a surrogate measure of safety due to a short post-installation period. The rumble stripes were milled in, with dimensions of 4 to 6 inches in width (\mathbf{C}) and 0.625 inches depth (\mathbf{D}). During field measurement, vehicle wheelpaths moved closer to the centerline at all study sites by an average distance of 1.5 feet (21). Average and 85th percentile speeds were also observed to increase following rumble stripe installation, although it was not clear why this occurred. Finally, qualitative assessment of pavement marking conditions two years after installation showed markings flush with the pavement surface were highly worn, while those in the milled areas were intact.

In 2012, Mitkey, et al. examined the retroreflectivity durability for rumble stripes versus painted edgelines (22). A comparison of the two alternatives was made along a two lane section of divided highway in Indiana before and after the winter season. The rumble stripe dimensions in use were 16 inches length (**B**), 7.5 inches width (**C**), 0.5 inches depth (**D**) and 12 inch spacings on center (**E**). Results of qualitative and quantitative analysis found that rumble stripes produced improved wet and dry retroreflectivity compared to edgelines. After one winter season, the coefficient of retroreflectivity for rumble stripes exceeded the painted edgeline by 95 percent for white and 80 percent for yellow under dry conditions. The conclusion drawn by the work was that rumble stripes provided improved durability against damage from winter plowing operations.

CENTERLINE RUMBLE STRIPS

In 2001, Outcalt evaluated centerline rumble strips on a 17 mile section of two lane mountain highway for the Colorado DOT (23). The centerline rumble strip had dimensions of 12 inches length (**B**), 7 inches width (**C**), and 12 inch spacings on center (**E**) (no depth dimensions were provided). In looking at 44 months of crash data from before and after installation, head-on crashes decreased from 18 to 14 and sideswipe crashes fell from 24 to 18, while ADT increased over the time period. Only slight increases in pavement marking wear were observed.

In 2003, Persaud, et al. examined the crash reduction of centerline rumble strips on rural two lane roads (24). Data from 210 miles of roads in seven states were used to examine before and after safety performance. The researchers found a 15 percent reduction in all injury crashes and a 25 percent reduction in frontal and opposing direction sideswipe crashes had followed centerline rumble strip installation. Based on these findings, they recommended that centerline

rumble strips be widely installed on rural two lane roads. Note that the design dimensions of the centerline rumble strips for the various study states/sites were not provided in this work.

Porter, et al. evaluated the effects of centerline rumble strips on lateral vehicle placement and speeds for the Pennsylvania DOT in 2004 (25). Lane widths examined by the study were 11 and 12 feet, and the centerline rumble strips had dimensions of 18 inches length (**B**), 7 inches width (**C**), 0.50 to 0.625 inches depth (**D**), and spacing between pairs of strips of 2 and 4 feet (**G**). Results of field data analysis found that for 12 foot lanes, vehicle placement shifted 5.5 inches inward from the centerline when rumble strips were present. A similar shift of 3 inches was observed for 11 foot lanes. An increase in mean vehicle speeds was observed at sites with 11 foot lanes, while no change in mean speeds was observed at 12 foot lane sites.

Noyce and Elango performed a safety evaluation of centerline rumble strips for the Massachusetts Highway Department in 2004 (26). This included a simple before and after comparison of crash trends at sites with centerline rumble strips installed, as well as a driving simulator study to examine driver behavior changes in response to centerline rumble strips. The crash comparison indicated that no change in crash frequencies had occurred following centerline rumble strip installation. Results of the simulator study found that 27 percent of participants made an initial leftward correction when encountering a centerline rumble strip. No improper corrections were observed when a shoulder rumble strip was encountered. The conclusion of the researchers was that consideration should be given to alternative configurations of centerline rumble strips to produce a different tone and eliminate the potential for driver confusion.

Russell and Rys summarized U.S. experiences with centerline rumble strips for the NCHRP Synthesis 339 in 2005 (27). A survey of agencies found that a variety of dimensions were used for centerline rumble strips at the time, including:

- Lengths between 5 and 30 inches (**B**);
- Widths between 6.5 and 7 inches (C);
- Depths between 0.50 and 0.63 inches (**D**);
- Spacings between 12 and 48 inches.

Usage in most states at the time was limited to no passing zones, although a limited number of agencies used them in all types of locations. The researchers noted that the benefits of centerline rumble strips had not yet been proven and that agencies were taking a cautious approach while waiting for the results of further research on their effectiveness.

In 2005, Bahar and Parkhill synthesized the characteristics of centerline rumble strip applications in Canada and internationally and provided recommendations on their installation based on that information. The researchers observed that the most common centerline rumble strip dimensions in use were a length of 12 to 15 inches (**B**), a width of 7 inches (**C**), a depth of 0.50 inches (**D**), and a space of 12 inches (*28*). Focusing on dimensions used in North America, the researchers recommended Canadian highway centerline rumble strips be 12 inches long (**B**), 6 inches wide (**C**), 0.325 inches deep (**D**) and spaced 12 inches on center (**E**). Further, the researchers indicated centerline rumble strip use should be discontinued within 650 feet of residential areas

and 200 feet in advance of bridge decks and intersections. The bridge deck restriction was based on existing British Columbia guidelines, although the basis of these guidelines was not provided.

In 2005, Chen and Cottrell developed guidelines for the use of centerline rumble strips for the Virginia Department of Transportation (29). Based on an evaluation of crash trends in the state, the following guidance was developed:

- Centerline rumble strips should be used at:
 - Locations where studies indicate a high number of cross over the centerline crashes have occurred.
 - Priority should be given to roads on the primary system because of their higher functional classification.
- The use of centerline rumble strips should only be made under certain conditions, including:
 - On asphalt pavements.
 - On roads at least 20 feet wide.
 - On roads with good structure and pavement.
- Centerline rumble strips should not be used under certain conditions, including:
 - In passing zones, especially on two lane roads.
 - On bridge decks [Note, no rationale for this was provided.]
 - On subdivision streets.
 - Within the limits of two way left turn lanes.

Furthermore, the researchers recommended that the decision to install centerline rumble strips should take noise into account in residential areas, and should consider the impact of vehicle-bicycle interactions.

In 2005, Hirasawa, et al. examined the development and use of centerline rumble strips in addressing head on crashes in Japan (*30*). Three dimensions/patterns were examined, including:

- Length of 13.5 inches (**B**), width of 5 inches (**C**), depth of 0.354 inches (**D**) and spacing of 6.8 inches;
- Length of 13.5 inches (**B**), width of 5.5 inches (**C**), depth of 0.50 inches (**D**) and spacing of 6 inches; and
- Length of 13.5 inches (**B**), width of 6 inches (**C**), depth of 0.60 inches (**D**) and spacing of 5.5 inches.

Through experimental testing and field installation observations, the researchers found that rumble strips would provide warning in a safer manner than centerline posts or chatter bars for vehicles such as motorcycles while effectively reducing head on crashes. From field installation observations, an extrapolation after the use of rumble strips began indicated that 18.8 crashes could be expected over two years, compared to 42 crashes observed before installation. This resulted in an expected crash reduction of 55.2 percent.

A 2005 study by Rasanen examined how the installation of a centerline rumble strip changed lane keeping on a roadway curve in Finland (31). The rumble strip was milled with a length of

12 inches (**B**), a width of 6 inches (**C**), a depth of 0.60 inches (**D**) and a spacing of 10 inches. Observations at the site indicated the wheelpath of oncoming vehicles moved 6 to 8 inches closer to the edgeline after installation. An added benefit of this shift was thought to be that it extended the life of the pavement marking (less wear from tires hitting the markings).

In 2008, Miller examined the effects of centerline rumble strips on non-conventional vehicles (motorcycles) for the Minnesota Department of Transportation (*32*). A review of crashes in the state from the first installation of centerline rumble strips in 1999 indicated only 29 crashes involving motorcycles had occurred at locations with rumble strips. A review of the reports associated with these crashes found no mention of rumble strips being a primary or contributing factor in the crash. Roadside observations conducted for 44 hours along rural roads showed no unusual behavior or directional changes by motorcyclists that could be associated with centerline rumble strips. Controlled test-track observations showed that riders needed no steering, braking or throttle adjustments when crossing centerline rumble strips; in addition, when interviewed after testing, riders expressed no concerns about crossing them. Based on the findings of this work, it was concluded that centerline rumble strips pose no hazard to motorcycles.

A 2009 *Public Roads* article discussed findings from Arizona on the reduction of lane departure crashes associated with centerline rumble strips (*33*). Fourteen highway segments on rural two lane highways (AADT 800 – 14,000) had centerline rumble strips installed by 2002. Analysis of three years of before and three years of after crash data found that the average rate for fatal and serious injury centerline crossover crashes fell by 50 percent at the sites. Based on the findings of the work, it was recommended that Arizona should install centerline rumble strips with dimensions of 12 inches length (**B**) (no width or depth specified), spaced in pairs of 12 inches on center (**E**) and 24 inches between pairs (**G**). This paired spacing would provide a differentiated sound and sensation from shoulder rumble strips.

In 2011, Olson, et al. evaluated the effectiveness of centerline rumble strips (CLRS) for the Washington State Department of Transportation (*34*). The dimensions of the centerline rumble strips examined were 12 inches in length (**B**), 7 inches width (**C**), 0.50 inches depth (**D**) and 12 inch spacings on center (**E**). Of special note was the omission of centerline rumble strips within 25 feet of bridge approach slabs. A follow-up interview with the primary author determined that the WSDOT discontinues centerline rumble strips over bridge approach slabs because they have concerns that rumble strips may cause undesirable harmonic vibrations in a bridge structure. An evaluation of crash data found that centerline rumble strips reduced crashes for all injury severities by 24.9 percent and fatal and serious injury crashes by 37.7 percent. Centerline rumble strips were also found to reduce cross centerline crashes by 59.0 percent on tangent roadway sections and 26.8 percent on curves. One more notable figure from the study was a comparison of centerline rumble strips miles per year versus the crossover crash rate. As the CLRS miles increased over time, the crossover crash rate decreased.



FIGURE 2 Miles of CLRS per year vs. crossover crash rate (Image source: Olson, et al. [34])

Based on the results of the analysis, it was recommended that centerline rumble strip installation priority be given to sites with AADT less than 8,000, combined lane and shoulder widths of 12 to 17 feet, and speed limits of 45 to 55 mph. Unfortunately, the AADT value discussed within the document comes with the disclaimer that, "The weighted VMTs or AADTs used in this analysis are only specific to this analysis and should not be assumed to be valid for other uses or analysis." This statement is made because an AADT was developed for the segment. Therefore, at certain points within a segment, it may not be representative of the actual AADT. It is a drawback of the analysis method.

A November 2011 FHWA Technical Advisory provided updated information and guidelines on the design and installation of centerline rumble strips (35). Centerline rumble strips should be used along two lane corridors where significant opposing direction and driver inattention crashes have occurred. The dimensions recommended for use were 16 inches length (**B**), 7 inches width (**C**), and a depth of 0.50 inches (**D**), with only milled in rumble strips used for centerline applications (note these were the dimensions that were most commonly cited in the literature examined by the FHWA). Pavement markings must be restored after the milling process. The application of centerline rumble strips was suggested for the length of a corridor as opposed to spot locations to maximize effectiveness. To address potential bicyclist issues, it was recommended that 14 feet of pavement beyond the edge of the centerline rumble strip be available.

In 2012, Rys, et al. examined shoulder and centerline rumble strip performance for the Kansas Department of Transportation (*36*). This involved observations of driver behavior, as well as before and after analysis of the safety effectiveness of centerline rumble strips using Bayesian methods. Kansas uses both football-shaped and rectangular centerline rumble strips, although the dimensions of these were not provided by the work. Results from observations of driver behavior indicated that on roadways with narrow shoulders, drivers operated closer to the centerline. When medium-width shoulders were present, drivers operated closer to the centerline if shoulder rumble strips were not present and closer to the edgeline if they were present. On roadways with wide shoulders, drivers operated near the centerline if only centerline rumble strips were present and closer to the edgeline otherwise. Results of statistical analyses indicated total crashes were reduced by 29.2 percent following the installation of centerline rumble strips, while cross over crashes were reduced by 67.2 percent. Based on the results of the work, it was recommended that shoulder rumble strips be used on all roads with AADT greater than 200

vehicles per day and centerline rumble strips be used on roadways with AADT less than 5,750 vehicles per day. For roadways with AADT between 3,000 and 5,750 vehicles per day, both shoulder and centerline rumble strips could be used together.

In 2012, Savolainen, et al. assessed the influence of centerline rumble strips on vehicle lateral placement when passing bicycles (*37*). Data were collected in two field studies along high speed rural two lane roads in Michigan; one roadway with centerline rumble strips and one without them. The centerline rumble strip dimensions in use were a length of 16 inches (**B**), a width of 7 inches (**C**), a depth of 0.4375 inches (**D**) and a spacing of 5 inches. Four foot paved shoulders were present at each study site. Study results found that the presence of centerline rumble strips impacted the lateral placement of vehicles as they passed bicycles, with vehicles less likely to cross over the centerline when rumble strips were present. The location of the bicyclist also was a factor, particularly when the bicycle was riding on the edge of the travel lane/left of the shoulder. In such cases, vehicles were more likely to cross the centerline rumble strip, unless opposing traffic was present.

Savolainen, et al. evaluated the short term impacts of centerline rumble strips on pavement performance in 2012 (*38*). This entailed a measurement of crack propagation over a two year period on high speed rural two lane roads in Michigan. Pavement imagery data from the study sites was compared to data from control segments where centerline rumble strips had not been installed. When other factors including AADT, pavement age and geographic region were accounted for, centerline rumble strips were not found to significantly impact the rate of crack propagation.

In 2013, Kay, et al. evaluated the impacts of a "Share the Road" sign on vehicle behavior near bicyclists in Michigan (*39*). This included an evaluation of a roadway segment with centerline rumble strips and one without them. At the site with the centerline rumble strip present, vehicles were found to reduce buffer distances (the distance between the vehicle and bicycle) and increase the prevalence of crowding (passing with a buffer distance of 5 feet or less). The presence of oncoming traffic at centerline rumble strip sites also produced these effects.

TRANSVERSE RUMBLE STRIPS

Gorrill completed a review of existing (2007) literature on transverse rumble strips for the Minnesota Department of Transportation at stop controlled intersections (40). The primary observations were that transverse rumble strips produced speed reductions of 1 to 5 mph and that no study showed a link between transverse rumble strips and crash reductions. The synthesis did not provide any specific dimensions or layouts for transverse rumble strips, but did note that they should not be used on roadways with bicycle traffic unless a clear path of four feet was available at the edge of the roadway.

In 2010, Srinivasan, et al. evaluated the effectiveness of transverse rumble strips on reducing crashes at stop-controlled intersections in Minnesota and Iowa (*41*). In Minnesota, up to five sets of transverse grooves may be used, with a minimum of three recommended. The first set of grooves was located approximately 250 feet in advance of the "Stop Ahead" sign, and the last set was located approximately 500 feet ahead of the stop sign (see FIGURE 3). (Note: Minnesota used metric dimensions.) The grooves were approximately 3.3 feet in width (**B**), placed in each

wheelpath of a lane, with a space of approximately 3 feet between the wheelpaths left ungrooved. The total length of each groove set was approximately 4.9 feet, with six inch individual groove lengths (\mathbf{C}), 0.40 inch depths (\mathbf{D}) and 11.8 inch spacings on center (\mathbf{E}).



FIGURE 3 Minnesota transverse rumble strip layout (Image source: Srinivasan, et al. [41])

In Iowa, three sets of transverse rumble strips were the standard, with the first set 200 feet ahead of the Stop Ahead sign (see FIGURE 4), and the last set located 300 feet ahead of the stop line (the center set spaced midway between these). Each panel was a total width of 12 feet (**B**) (or a single lane width, depending on location), 24 feet in length, with 25 grooves spaced at one foot intervals. An 18 inch width of pavement was left ungrooved at the outside edge of the pavement to accommodate bicyclists. Individual groove lengths were 4 inches (**C**), with 12 inch spacings on center (**E**) and a depth of 0.375 inches (**D**).



FIGURE 4 Iowa transverse rumble strip layout (Image source: Srinivasan, et al. [41])

A before and after analysis of crashes found that for the combined sample of intersections for both states, there was a 21 percent reduction in fatal, incapacitating injury and non-injury crashes. When considering only fatal and incapacitating injury crashes, a larger reduction of 39 percent was found. However, with the reduction in injury crashes, there was an increase in property damage only crashes. A limited economic analysis did indicate that there was still a \$6,600 reduction in crash harm per intersection per year resulting from the installation of transverse rumble strips.

In 2011, Liu, et al. studied the impacts of transverse rumble strips in reducing vehicle speeds and crashes at pedestrian crosswalks on low volume rural roads in China (42, 43). The dimensions of the transverse rumble strips that were installed were a width of 6 inches (**C**), a depth of 0.35 inches (**D**) and a spacing of 17.7 inches (no length dimension was provided, although diagrams indicated that the rumble strip was spread across the entire travel lane). The spacing of rumble strip groups (three grooves per transverse set) was between 26 and 50 feet, with closer spacing of groups when closer to the crosswalk. A total of seven sets of transverse rumble strips were used on the approaches to crosswalks, with the initial set located 340 feet in advance of the crosswalk and the final set located 50 feet from it. A before and after study at 366 sites found that the use of transverse rumble strips reduced total pedestrian crashes by 25 percent (types of crashes were not specified). Additionally, speed data collected at 12 sites with posted speed limits between 35 and 50 mph showed significant reductions in mean and 85th percentile speeds. Mean speeds at the study sites fell between 5.7 and 7.4 mph after installation, while 85th percentile speeds fell between 5.6 and 7.5 mph.

MULTI-FOCUSED STUDIES

Although not specifically a research study, the FHWA discussed maintenance concerns associated with rumble strips, particularly the potential for pavement deterioration to occur (44). Based on observations and feedback from states, new pavements do not appear to deteriorate when rumble strips are installed, nor do they present any issues with open graded pavements. Older pavements that had rumble strips installed did degrade more quickly (although the speed was not defined), but the rumbles continued to perform their function. Weather, particularly freeze and thaw cycles and their interaction with rumble strip grooves, did not appear to play a role in pavement durability issues. In only one case, Oregon in the later 1990s, were any issues related to deterioration of pavements and rumble strips observed. However, this deterioration appeared to stem from winter maintenance practices that were in use at the time. Specifically, plow vehicles equipped with tire chains and a shoe on the plow board traveled with their right steering and drive wheels on the rumble strip as standard practice. This resulted in deterioration that was not observed in any other state. As this issue occurred in the 1990s, it is reasonable to conclude it has been addressed in Oregon and not occurred elsewhere by the lack of discussion in literature.

Harwood discussed the use of rumble strips to enhance safety in NCHRP Synthesis 191 (45). At the time (1993) no studies had established the safety effectiveness of transverse rumble strips. The survey of state agencies found a range of transverse rumble strip dimensions were in use, including lengths typically covering a full travel lane, widths between 2 and 8 inches (C), depths between 0.188 and 0.75 inches (D), spacings on center between 12 and 24 inches (E), and a general placement of 100 to 1,550 feet in advance of the intersection. The number of bars in each

set ranged from 5 to 26. Note that varying layouts and spacing between transverse rumble strip sets were employed based on different design situations. Shoulder rumble strips were found to reduce run-off-the-road crashes by 20 percent at the time. Agencies indicated overuse of shoulder rumble strips was not a concern, as they were only encountered by errant vehicles. The use of shoulder rumble strips on bicycle routes did need to be carefully considered given the potential to create control issues for riders. It was recommended that rumble strips be moved two feet or more inward from the edge of the travelled way to accommodate bicycles, which differed from existing practices. In general applications, it was recommended the edge of the rumble strip should be placed one foot inward from the edge of the travelled way to minimize interference with snow plowing.

Corkle, et al. conducted a synthesis on the effectiveness of rumble strips for the Minnesota Department of Transportation (46). This entailed a survey of county engineers in the state, as well as a driver simulation study. The county engineer survey found that at the time (2001), 56 counties had installed transverse rumble strips at intersections. Specific dimensions of these transverse rumble strips were not provided by the researchers; however, it is likely that the dimensions used were similar to those cited for the state in Srinivasan, et al. (41). The driver simulator study found that drivers braked earlier and harder at intersections with transverse rumble strips than at locations without them. With regards to shoulder rumble strips, at that time, only a limited number of counties had installed shoulder rumble strips (note that counties were not asked if shoulder rumble strips were in use by the survey). The primary conclusion drawn from the work was that the effectiveness of shoulder rumble strips identified during a literature search warranted their increased use by counties in the future.

In 2005, Anund, et al. evaluated the placement and design of centerline and shoulder rumble strips in Sweden using a driving simulator (47). The focus of the work was on narrow roads (less than 30 foot width), examining driver behavior in conjunction with different milled in rumble strip designs and placements. Rumble strip designs included:

- A Pennsylvania rumble strip with a 20 inch length (**B**), a 6.7 inch width (**C**), a 0.50 inch depth (**D**) and a 12 inch spacing;
- A Swedish rumble strip with a 20 inch length (**B**), a 12 inch width (**C**), a 0.40 inch depth (**D**) and a 20 inch spacing;
- A "Malilla" rumble strip with a 13.7 inch length (**B**), a 6 inch width (**C**), a 0.40 inch depth (**D**) and a 48 inch spacing;
- A Finnish rumble strip with a 6.8 inch length (**B**), a 0.75 inch width (**C**), a 0.60 inch depth (**D**) and a 12 inch spacing.

The first simulated placement was a spacing of rumble strips 11.5 feet apart between the centerline and shoulder rumble strip edges. The second placement location was 10.6 feet between the centerline and shoulder rumble strip edges. Behavior data collected through the simulation effort did not show any difference between the types of strips used and their placement, but the researchers recommended the use of more aggressive rumble strip design types (ex. Pennsylvania and Sweden). They also recommended that shoulder rumble strips be placed further out on the shoulder to avoid the perception that the roadway was too narrow, and to provide more room for bicycles in locations where shoulder width is limited.

Miles, et al. looked at the traffic operational impacts of transverse, centerline and edgeline rumble strips for the Texas Department of Transportation (48, 49, 50). This work entailed field observations of driver behaviors in conjunction with each of these types of rumble strip. All of the transverse rumble strips were used on rural roadways with posted speed limits between 55 and 70 mph to provide advanced warning at two and four way stop signs. The rumble strips were raised pieces of white rubber consisting of three rumble "bumps" spaced three inches. These sets of rumbles were placed in sets of five, with two foot spacing between each set of rumbles (see FIGURE 5). The sets of rumbles were four feet in width, one inch in length, 0.4 inches in height, spaced 1.5 inches end to end and placed in each wheelpath. Two sets of transverse rumble strips were used on each approach, with the first set located 250 feet ahead of the intersection warning sign and the second located 500 feet beyond this set. Transverse rumble strips at stop controlled intersections were found to produce only marginal speed reductions (2-5 mph) but did not cause drivers to perform any erratic maneuvers. Their use at horizontal curves produced similar results. In examining behaviors in areas with centerline rumble strips, no erratic maneuvers were observed, nor were any other signs of changes in driver behavior evident. Edgeline rumble strip observations indicated that shoulder encroachments decreased by 50 percent after installation. The researchers recommended further study into the safety performance of transverse rumble strips to determine if they were effective in providing warning and reducing crashes. There was no evidence from field observations that current installations of centerline or edgeline rumble strips should be removed. Finally, it was recommended that centerline and edgeline rumble strips have different spacings to minimize the potential for driver confusion in the future.



FIGURE 5 General layout of experimental Texas transverse rumble strips (Images source: Miles, et al.[48])

National Cooperative Highway Research Program (NCHRP) Report 641 provided guidance for the design and application of shoulder and centerline rumble strips (*51*). This document details the safety effectiveness of rumble strips on different roadway types, discusses the optimal

dimensions of rumble strips, and presents application and design criteria. Collectively, the information presented in the report provides practitioners with a comprehensive reference for the state of the practice as well as critical considerations and guidance in the use of rumble strips.

The discussion of rumble strip safety impacts is divided between shoulder and centerline rumble strips. A review of past literature indicated that shoulder rumble strips have reduced crash frequencies between 10 percent and 80 percent, depending on the specific highway type on which they were installed (51). Centerline rumble strips have reduced crash frequencies between 14 percent and 90 percent, once again depending on the highway type (51). These results show that rumble strips are an effective safety countermeasure in a variety of settings.

Of interest to the current project is the summary of existing (2009) rumble strip practices and policies in North America that was completed as part of the overall research. The summary was compiled from a survey of agencies and a review of past survey results completed by other projects. The work sought information on the typical dimensions and criteria used to guide rumble strip installations. The survey responses indicated that a majority of agencies had implemented a written rumble strip policy (25 of 31 responses), with most installations made on urban and rural freeways (51). Agencies indicated that rumble strips were installed between zero and 30 inches from the edgeline. Common determinants of offset distance were available shoulder width, facility type, location (urban/rural), bicycle presence, and lateral clearance. The minimum shoulder width for installations ranged from 2 to 6 feet, while lateral clearance requirements ranged from 2 to 7 feet (51). Some agencies had minimum traffic volumes required along a route before shoulder rumble strips were used, their spacing ranged from 10 to 12 feet (**G**), with 40 to 60 foot cycles between gaps (51). The only recent changes to rumble strip policy indicated by respondents was the discontinuance of rolled in rumble strips.

Most agencies did not have a written centerline rumble strip policy, although 14 out of 22 respondents did use that type of rumble strip. The majority of installations were made on rural, undivided two lane roads with no minimum lane width or traffic volume requirements. Only 11 of 23 respondents used centerline rumble strips in conjunction with shoulder rumble strips.

In terms of rumble strip dimensions, the following information was established by the agency survey. Offsets for rumble strips ranged from zero to 30 inches from the edgeline, with 6 to 12 inch offsets (**A**) being most common. Rumble strip dimensions were an average length of 16 inches (**B**) (ranging from 6 to 16 inches); an average width of 7 inches (**C**) (ranging from 5 to 8 inches); an average depth of 0.5 to 0.625 inches (**D**) (ranging from 0.375 to 0.625 inches); and an average spacing of 12 inches (ranging from 11 to 18 inches) (*51*). Periodic gaps of 10 to 12 feet (**G**) were often provided at intervals of 40 to 60 feet to accommodate bicyclists. Typical dimensions for centerline rumble strips were an average length of 12 to 16 inches (**B**) (ranging from 12 to 24 inches); an average width of 7 inches (**C**) (ranging from 5 to 8 inches); an average depth of 0.5 inches (**D**) (ranging from 0.375 to 0.625 inches) (**C**) (ranging from 12 to 24 inches); an average width of 7 inches (**C**) (ranging from 5 to 8 inches); an average depth of 0.5 inches (**D**) (ranging from 0.375 to 0.625 inches); an average depth of 0.5 inches (**D**) (ranging from 12 to 24 inches); an average width of 7 inches (**C**) (ranging from 5 to 8 inches); an average depth of 0.5 inches (**D**) (ranging from 0.375 to 0.625 inches); and an average spacing of 12 inches (**D**) (ranging from 0.375 to 0.625 inches); and an average spacing of 12 inches (**D**) (ranging from 0.375 to 0.625 inches); and an average spacing of 12 inches (**ranging from 10 to 48 inches**) (*51*).

One of the more significant contributions of NCHRP Report 641 was the identification of optimum dimensions for rumble strips. The report points out that the dimension identified in the

survey that varies the most between agencies was length (6 to 18 inches for milled in and 5 to 8 inches for rolled in). The concern with narrow groove lengths was whether the rumble strip would provide sufficient noise/vibration. To determine optimum rumble strip dimensions, the researchers conducted field studies to collect noise data. With this data, they developed models to predict noise responses within a passenger vehicle. Data were collected for milled and rolled in rumble strips on the shoulder and centerline on asphalt and concrete pavements. A variety of facility types and rumble strip dimensions were observed during the course of the field study.

Based on the results of the modeling effort, the following guidance was provided for rumble strip dimensions on different facilities:

- Freeway shoulder rumble strips (55 to 65 mph)
 - Length -12 inches (**B**);
 - Width 6 inches (C);
 - Depth -0.375 inches (**D**);
 - o Spacing -12 inches (51).
- Rural two lane roadway shoulder rumble strips (45 to 55 mph)
 - Length 6 to 16 inches (**B**) (varies depending on rumble strip pattern);
 - Width -5 inches (C);
 - Depth -0.375 inches (**D**);
 - Spacing -11 to 12 inches (51).
 - Designed with bicycles in mind.
- Rural two lane roadway centerline rumble strips (35 to 55 mph)
 - Length -8 to 12 inches (**B**) (varies depending on rumble strip pattern);
 - Width -5 inches (C);
 - Depth -0.375 inches (**D**);
 - o Spacing -12 inches (51).

In general, these optimum dimensions provide a reasonable starting point for consideration when determining the dimensions of different rumble strips on a road based on its characteristics.

The final aspect of rumble strips that NCHRP Report 641 covers is application and design criteria. This includes discussion on the placement of shoulder rumble strips relative to the edgeline, gap patterns, centerline rumble strip placement, and other topics. Based on an analysis of past research findings, it was indicated that rumble strips placement on rural freeways should be as close as possible to edgelines. However, on other roadways types, no evidence was identified that suggested a specific offset distance had an impact on safety. Instead, factors such as bicyclists should be considered, with a minimum offset of one foot between the rumble strip and the travel lane/edgeline used (**A**), along with a 4 foot minimum lateral clearance from the rumble strip to the outside edge of the paved shoulder (**I**) (51). This resulted in a total shoulder width of five feet, not including the width of the rumble strip itself. To accommodate bicycles, an intermittent gap of 10 to 12 feet (**G**) should be provided in 40 to 60 foot cycles (51). Centerline rumble strip placement can vary, with the most common approach being the rumble strip protruding into the travel lane.

While NCHRP Report 641 is a comprehensive discussion of shoulder and centerline rumble strips, there are some aspects of the subject that are not covered. This includes the use of rumble strips on bridge decks. Additionally, rumble stripes and transverse rumble strips were not discussed at any point in this work.

In 2010, Torbic et al. provided guidance on the design and application of rumble strips based on the work of NCHRP Report 641. Based on that work, the paper made the following recommendations:

- Place shoulder rumble strips as close as possible to the edgeline on rural freeways.
- Where it is desirable to provide lateral clearance for bicycles or when installing rumble strips on narrow shoulders, rumble strips with a relatively narrow length (**B**) (6 inches) may be used;
- The safety benefits of centerline rumble strips on curves and tangents are identical (52).

Aside from these points, the researchers noted that there was still a need to determine the optimal placement of shoulder rumble strips on rural two lane roads and the safety effectiveness of dual (centerline and shoulder) rumble strip applications.

In 2010, Sayed, et al. performed a before and after study of the safety performance of shoulder and centerline rumble strips on rural, two-lane roads in British Columbia (*53*). Shoulder rumble strips were found to reduce crashes by 22.5 percent, while centerline rumble strips reduced crashes by 29.3 percent. When used together, shoulder and centerline rumble strips reduced crashes by 21.4 percent.

A November 2011 FHWA Technical Advisory provided updated information and guidelines for the design and installation of shoulder and edgeline rumble strips (54). The Advisory documented that milled in, raised, rolled in and formed types of rumble strips were all in use at the time. The most commonly cited edgeline and shoulder rumble strip dimensions cited in literature were 16 inches length (**B**), 7 inches width (**C**), and 0.50 inches depth (**D**). Edgeline and shoulder rumble strips with a narrow offset (**A**) (less than 9 inches) from the edgeline have been found to be the most effective placement location. To accommodate all road users, a paved shoulder at least four feet beyond the rumble strip edge (**I**) was recommended. Gaps for bicycles of 10 to 12 feet (**G**) should be provided at 40 to 60 foot intervals. The use of edgeline or shoulder rumble strips was recommended systemwide on rural freeways and highways with speed limits of 50 mph or greater, as well as on corridors with a history of run-off-the-road crashes.

The 2012 American Association of State Highway and Transportation Officials' (AASHTO) "Guide to Bicycle Facilities, 4th Edition" provides guidance on how rumble strips can be designed to accommodate bicyclists (55). It is recommended that a minimum of four feet of paved shoulder be available beyond the edge of the rumble strip or five feet to a curb, guardrail or other obstacle (**I**). Twelve foot gaps (**G**) spaced at 40 to 60 foot intervals should be provided to allow for bicyclists to enter or leave the shoulder. Wider gaps may be needed on downgrades to account for higher bicycle speeds. In addition to spacing guidance, design dimensions for bicycle-tolerable rumble strips are also provided. While no length dimension was provided, a width of 5 inches (**C**), a depth of 0.375 inches (**D**) and a spacing of 11 to 12 inches on center (**E**) were recommended. When centerline rumble strips are present, shoulder rumble strips should only be used where a six foot shoulder is available, or a four to five foot clear path from the edge of the rumble strip to the shoulder edge is provided.

INTERVIEWS

This section summarizes the findings from interviews conducted with NMDOT traffic engineers to inventory the types of rumble strips in use, and how NMDOT currently uses them.

While reviewing the literature available on rumble strips, the research team identified gaps and diverging approaches to applying rumble strips. As a result of this, the authors developed eleven questions to document current usage of rumble strips in each of the six districts within NMDOT. In addition, there was a general question asking the traffic engineers whether they would like any additional guidance related to rumble strips. All six district traffic engineers were first emailed with the questions that were developed. Subsequently, the research team followed up with the district traffic engineers with a telephone call. Only one district traffic engineer elected to respond to the questions via email only. Every district traffic engineer provided input, although some provided more details. The questions along with the grouped responses are provided in Appendix B. In some cases, multiple lines of the responses may have been from one district engineer. An attempt was made to generalize the information so as to allow some anonymity with regards to the responses. What follows is a summary of the responses that highlights key findings.

QUESTION 1

When asked if there is a typical shoulder width required before rumble strips are applied, traffic engineers provided a range of responses. One district indicated that due to concerns about the pavement quality of the shoulders, rumble strips could not be applied along many roadways. This does not include interstates. Another district reported 4 feet as the typical width for installing rumble strips on shoulders, and yet another reported 6 feet as the minimum width. Finally, one district addresses the issue only when safety concerns warrant it. In this case, the district indicated that they would add shoulders as necessary as a part of the project.

During the course of the discussion regarding question one, many of the district traffic engineers indicated that they generally follow the state guidelines.

The discussion related to question one also brought up an interesting point regarding the impact of bicycles. Recent State of New Mexico rules have allowed bicyclists on rural interstates in order to support bicycle touring (56). As a result, there are existing installations of continuous rumble strips on freeways where bicyclists were previously not allowed. Therefore, there was some discussion of the need to include the recommended gaps for bicyclists to cross over rumble strips as facilities are rehabilitated.

QUESTION 2

The second question addressed the current practice of each district with regard to milling or rolling in rumble strips. From the responses received, it appears that every district typically mills in rumble strips. Most districts (although not all) require that the rumble strips be milled. In addition, some rumble strips that were rolled in during earlier installations may still exist.

QUESTION 3

The third question asked how each district applies rumble strips in different pavement types. The districts reported that few have concrete roadways. Therefore, installing rumble strips in concrete does not seem to be a concern. Where concrete was encountered in a span of rumble strips, such as on bridges, the districts would stop the rumble strips at this point.

QUESTION 4

The fourth question asked if rumble strips were used in residential areas. Most districts reported not using rumble strips in residential areas. One even reported a policy of not using rumble strips when the speed limit was below 45 mph. One district did indicate that rumble strips were applied on an interstate that traverses through a more urban area. However, the district indicated that it did not receive any negative feedback from the residents.

QUESTION 5

The fifth question asked whether rumble strips were discontinued within a certain proximity to residential areas. Two districts received complaints from residents regarding the installation of rumble strips. In one example, the rumble strips in question were reportedly within 2 miles of the residents. In the second example, the installation of the rumble strips was made at the request of a local government entity. Therefore, the public feedback was directed to that entity.

QUESTION 6

The sixth question asked if areas of continuous rumble strips exist. Almost every district reported the presence of some rumble strips that do not provide gaps. However, many of the districts indicated that bicycling interest in the communities within their district is non-existent. One of the districts indicated that they are replacing the continuous stretches of rumble strips when projects allow.

QUESTION 7

The seventh question asked if sections of both centerline and shoulder/edgeline installations existed. Two districts reported not having any centerline rumble strip installations. There were only two roadways that were identified as having both centerline and shoulder/edgeline rumble strips: US 550 and US 54.

QUESTION 8

The eighth question asked if the possibility of use by bicyclists was taken into account when deciding whether or not to use rumble strips. Only one district reported not taking into consideration bicyclist use when applying rumble strips; however, this district reported low interest in bicycling. Other districts reported an increasing awareness of considering bicyclists when installing rumble strips.

QUESTION 9

The ninth question asked if rumble strips were used on a bridge. The unanimous response from districts regarding rumble strips on bridges was that they do not use them.

QUESTION 10

The tenth question asked if transverse rumble strips were used in the district. One of the things that districts seemed to have in common was that they all have implemented transverse rumble strips. Many locations were identified when talking with the district traffic engineers.

QUESTION 11

The eleventh question asked if rumble *stripes* were present in the district. Two districts indicated that they used rumble stripes. One district specifically identified the rumble stripe as being applied on US 64.

QUESTION 12

The final question allowed district traffic engineers to provide input on additional guidance that they need regarding rumble strips. Two district traffic engineers indicated that providing guidance on whether rumble strips should be used based on the roadway classification would be useful. One district traffic engineer indicated that guidance on the advantages and disadvantages of rumble stripes and centerline rumble strips would be useful. This district traffic engineer also provided a specific example where guidelines would be useful: on a three lane section, where two lanes are in the uphill direction and one is in the downhill direction, are rumble strips needed between the opposing directions and between the two uphill lanes? Another requested guidance on whether centerline rumble strips should be carried through both passing and no-passing zones.

SUMMARY

LITERATURE REVIEW FINDINGS

The following tables are summaries of the information presented previously in the Literature Review. This will allow the reader to more easily see trends associated with each of the rumble strip types. They are ordered in the same sequence as presented in the Literature Review section; however, the Multi-Focused Studies are shown in blue within the tables.

TABLE 1: Shoulder Rumble Strips

Year	Authors	B (in)	C (in)	D (in)	E (in)	G (ft)	Crash Impact	Benefit/Cost Ratios	Notes
1993	Harwood						ROR reduction = 20%		
1995	Khan and Bacchus							1.09-4.78	
1998	Perrillo						SV ROR Reduced by 70%	182.0	
1999	Moeur	12	7	0.5	5 12	2 12			
2000	Eleftenia dou et el	16	5	0.375	i (6			Recommended for non-freeways with speed limits ≤ 45 mph
2000	Elenenadou et al.	16	5	0.375	5	7			Recommended for non-freeways with higher speed limits
2001	Outcalt			0.375	5 12	2 12			Bicycle preferred rumble strip
2001	Bucko	12	5	0.3125	5				Only install on roadways with shoulders ≥ 5 feet; continue application through bridge decks
									Roadsize hazard rating of \geq 5, place rumble strips within cross section; roadsize hazard rating of \leq 4,
2001	Elefteriadou et al.								place rumble strips as far right as possible without degrating integrity of pavement
2003	Daniel	12				12			
2003	Turochy	16	7	0.5	5 12	2			36 agencies used 2001 FHWA Technical Advisory dimensions
2003	Marvin and Clark						ROR Reduced by 14%	19.5 (for interstates)	
2003	Iviai vili aiki Ciai k						Severity Rate Reduced by 23.5%		
2005	Smith and Ivan						SV FO Reduced by 33%		
2005							ROR Reduced by 12.8-48.5%		
2005-2006	Miles et al.								Shoulder encroachments reduced = 50%
2007	Miles and Finley	12							Commerical vehicles
2008	Kirk	12	7	0.5-0.625	12	2			
2009	NCHRP Report 641	6-16	5-8	0.375-0.625	11-18	10-12	Frequency reduced = 10-80%		
2010	Torbic et al.								Place as close as possible to edgeline on rural freeways
2010	Sayed et al.						Crashes reduced = 22.5%		
2011									Recommended systemwide on rural freeways and highways with speed limits ≥ 50mph
2011	FIIWA	16	7	0.5	5				Recommended on corridors with a history of ROR crashes
2012	AASHTO		5	0.375	11-12	12			Provide 4' veyond edge of rumble strip, or 5' to a curb, guardrail or other obstacle
2012	EL Basyoun and Saved						Immediate crash reduction rate = 24.9%		
2012	2 EI-Basyoun and Sayeu						Permanent crash reduction rate = 19.2%		
							Two-lane rural roads, crash reductions = 15-23%		
	Abdel-Rahim and Kahn						Two-lane rural roads, severe crash reduction = 74%		
2012							Two-lane rural roads, crash reductions on curves = 8-29%		
							Four-lane rural roads, crash reductions = 45-62%		
							Rural freeways, crash reductions for all ROR = 67%		
							Freeway, truck ROR crash reductions $= 42\%$		
SV = Single Vehicle						-			
ROR = Run-	off-the-road								
FO = Fixed Object									

TABLE 2: Rumble Stripes

Year	Authors	B (in)	C (in)	D (in)	E (in)	Notes
2006	Lindly and Narci	16	7	0.5-0.625	12	Cost per mile of treatment = $$2,424$ (2006 \$)
2009	Hallmark et al.		4-6	0.625		Vehicle wheelpaths moved closed to cetherline on average by 1.5 feet
						Average and 85th percentile speed increased
2009	NCHRP Report 641					Crash frequency reduced = 14-90%
2012	Mitkey et al.	16	7.5	0.5	12	Coefficient of rumble stripes exceeded painted edgeline by 95% for white and 80% for yellow
TABLE 3: Centerline Rumble Strips

Year	Authors	B (in)	C (in)	D (in)	E (in)	G (ft)	Crash Impact	Notes
2001	Outcalt						HO: decreased from 18 to14, SS: decreased from 24 to 18	
2003	Persaud et al.		. 7				All injury reduced 15%	
		12			12		Frontal, opposing direction SS reduced 25%	
2004	Porter et al.	18	7	0.5-0.625		2-4		Vehicles shifted 5.5 inches and 3 inches inward for 12 and 11 foot lanes, respectively
								An increase and no-change in mean vehicle speeds for 11 and 12 foot lanes, respectively
2004	Noyce and Elango						No change in crash frequency	
2005	Russell and Rys	5-30	6.5-7	0.50-0.63	12-48			Survey of state use
2005	Bahar and Parkhill							Recommended dimensions
								Discontinue within 650' of residential areas
		12	6	0.325	12			Discontinue within 200' of bridge decks and intersections
2005	Chen and Cottrell							Guidelines developed for Virginia DOT
2005	Hirasawa et al.						Crash reduction = 55.2%	
2005	Rasanen	12	6	0.6	10			Wheelpath moved 6-8 inches closer to edgeline
2008	Miller							No hazard to motorcycles
2009	Public Roads	12	2		12	. 2	Rate for fatal and serious injury centerline crossover crashes reduced by 50%	
2009	NCHRP Report 641						Crash reduction = 14-90%	
2010	Sayed et al.						Crash reduction = 21.4%	
2011	Olson et al.						All injury severity reduced 24.9%	Discontinue within 25 feet of bridge approach slabs
							Fatal and serious injury reduced 37.7%	
							Cross centerline, tangent reduced 59.0%	
		12	. 7	0.5	12		Cross centerline, curves reduced 26.8%	
2011	FHWA	16	5 7	0.5				14' pavement beyond edge of centerline rumble strip should be available
2012	2 Rys et al.						Total crashes reduced by 29.2%	
							Crossover crashes reduced by 67.2%	
2012	Savolainen et al.	16	5 7	0.4375	5			
2012	Savolainen et al.							Do not impact rate of crash propogation
2013	Kay et al.							Vehicles reduced buffer distances
HO =	head-on							
SS = s	sideswipe							
DOT	= department of transpo	rtation						

TABLE 4: Transverse Rumble Strips

Year	Author	Crash Impact	Speed	Notes
1993	Harwood			Were in use
2001	Corlda at al			56 counties had installed them
2001	COIKIE et al.			Drivers braked earlier and harder
2005, 2006	Miles et al.		2-5 mph reduction	
2007	Gorrill		1-5 mph reduction	
		Fatal, incapacitating injury, non-injury, reduced 21%		
2010	Srinivasan et al.	Fatal and incapacitating injury, reduced 39%		
2010		Property damage only, increased		
		Reduction of \$6,600 crash harm/intersection/year		
2011	Lin, at al	Total pedestrian crashes reduced 25%	Mean speeds reduced 5.7-7.4 mph	
2011	Liu et al.		85th percentile speeds reduced 5.6-7.5 mph	

MILLED VS. ROLLED

During the project kick-off meeting, the project advisors posed several questions that they wanted answers to as a result of the research. They were:

- 1. Should NMDOT recommend installing the rumble strip along the edgeline instead of in the shoulder?
- 2. How does reducing the rumble strip width affect the surface type?
- 3. What does the current literature say about rumble stripes?
- 4. Do directional rumble strips exist?
- 5. Is milling in rumble strips the state of the practice?

With regard to question one, it appears that for rural freeways and highways the best recommendation at present is to install the rumble strips on or very near the edgeline. This has conclusively been shown to produce the largest safety benefit. Unfortunately, there is scarce literature available for other functional classes of roadways.

With regard to question two, literature was limited on the application of rumble strips in concrete. However, in the study by Outcalt (7), the rumble strips that were tested were longer, wider, and the rumbles spaced closer on center. Therefore, it would appear that a smaller rumble strip can be applied on asphalt.

The majority of the current literature on rumble stripes investigates concerns related to the retroreflectivity of the edgeline. Rumble stripe applications do appear to provide an advantage with respect to maintaining retroreflectivity for a longer period of time. This is attributable to the paint material placed within the milled groove, which helps preserve it from wear due to traffic, plowing, and other factors. While paint on the roadway surface loses retroreflectivity over time, the paint in the groove retains its reflective capacity, providing a measure of safety. The lack of more detailed analysis into aspects of rumble stripes, such as safety performance, is likely the result of the relative newness of this particular rumble application.

From what is shown in the literature, directional rumble strips do not exist. Both domestic and international sources were considered. At this time, it appears that no agency or company has sought to develop a rumble strip that makes different tones depending on the direction a vehicle is traveling.

Milling seems to be the state of the practice for installing rumble strips. This appears to be the result of the greater accuracy of milling equipment to produce uniform rumble dimensions, combined with the capability of milling to install rumble strips outside of the context of an existing pavement rehabilitation project. The results would recommend requiring that all future rumble strip installations in New Mexico use a milling process.

The NMDOT also requested guidance on whether or not rumble strips should be continued over bridge decks. Only four studies mentioned rumble strips in relation to bridge decks. One of the studies was on shoulder rumble strips. It recommended continuing the shoulder rumble strips over the bridge decks. The other three studies were on centerline rumble strips. All three studies recommended discontinuing rumble strips over bridge decks. However, little information was provided as to how these recommendations were developed. A follow-up interview with a Washington State Department of Transportation employee indicated that they had concerns that harmonic vibrations of the structure might occur if rumble strips were installed over a bridge. Therefore, the answer to whether or not rumble strips should be continued over bridge decks is inconclusive and warrants further study.

As a result of the background information provided by the project sponsors, the authors attempted to include information regarding rumble strip designs sensitive to bicyclists. During the course of the research, they identified an existing "New Mexico Bike Routes" map. It can be found at: <u>http://dot.state.nm.us/content/dam/nmdot/BPE/2012-StateBikeRoutesMap.pdf</u>. The following routes were identified as existing New Mexico Bike Routes: 1, 1A, 2, 5, 7, 9, 14, 15, 18, 20, 53, and 66. Special consideration should be taken when deciding whether and how to implement rumble strips on these routes.

Appendix C provides examples of standard drawings for the installation of rumble strips within other states. One of the most progressive states in implementing and evaluating their installations of rumble strips is Washington. Washington also has an active bicycling community. As a result, the information taken from this state is presented first, including some information obtained through a discussion with Dave Olson, Design Policy, Standards, and Research Manager for the Washington State Department of Transportation. Examples from the remaining states are presented in alphabetical order.

GUIDELINES

As a result of the literature review, the following guidance is recommended for NMDOT with regard to the design, installation, and use of rumble strips. The recommendations cover the following topics:

- Milled vs. rolled rumble strips;
- Designing for commercial vehicles;
- Shoulder rumble strips;
- Centerline rumble strips;
- Shoulder and centerline rumble strips used in combination; and
- Transverse rumble strips

The recommendations do not include guidance regarding AADT and percentage of trucks because the available literature does not provide specific, sufficient, or conclusive information on these issues. In addition to the guidance discussed here, the reader should refer to Appendix C, specifically the information from Washington State, when considering an approach to the application of rumble strips in different settings and accommodation of the bicycling community. In general, a comparison of existing New Mexico rumble strip plan sheets shows many similarities to the guidelines presented in the following sections. These similarities, as well as differences, are discussed below.

MILLED VS. ROLLED

It is recommended that NMDOT no longer use rolled rumble strips. The use of milled in rumble strips is preferable because it allows for consistent installation dimensions. This conclusion was further supported by one of the NMDOT District Traffic Engineers who indicated that he had problems with the installations of rolled rumble strips. The District Traffic Engineer indicated that the depth was not consistent when using rolled rumble strips. Therefore, the rumble strips may not provide the appropriate vibratory characteristics. This recommendation conforms with current NMDOT design plan recommendations that indicate the use of milled rumble strips.

COMMERCIAL VEHICLES

Where bicyclists are not expected to use the facility and commercial vehicle use is expected, rumble strips of 12 inches or wider are recommended. Note that this dimension is narrower than the guidance provided by the FHWA's technical advisory, but it is consistent with what was observed as being widely reported and in use by the literature. No additional results were provided in the literature on how other dimensions (namely width and depth) of the rumble strips may be affected; therefore, no additional guidance can be provided. This topic may suggest a future research need.

SHOULDER RUMBLE STRIPS

For shoulder rumble strips, the literature only provided a definitive recommendation for rural freeways and highways. When speeds are greater than or equal to 50 mph, installation of shoulder rumble strips, as close to the edgeline as possible (i.e. rumble stripes if possible), are

recommended. However, a sufficient shoulder width should be provided (5 feet where lateral obstructions are present, 4 feet otherwise) to accommodate bicyclists.

The most recent Federal Highway Administration guidelines recommend a rumble strip with a length of 16 inches, a width of 7 inches, and a depth of 0.5 inches. However, some of the more recent literature recommends reducing the width to 5 inches and the depth to 0.375 inches on roadways that might be utilized by bicyclists. A spacing of 12 inches on center between the rumble strips is recommended. Providing a 12 foot gap with 40 to 60 foot cycles of rumble strips is recommended. The reader should examine the information presented in Appendix C, specifically that of Washington State, when considering different designs.

The recommended shoulder rumble strip dimensions of 16 inches length, 7 inches width and 0.5 inches depth for shoulder rumble strips based on those frequently employed in other states are similar to those currently used in New Mexico (12 inch length, 7.5 inch width and 0.5 to 0.625 inch depth). The recommendation of placing the rumble grooves as close to the edgeline as possible is a departure from current practice, which employs a 16 inch offset. This recommendation should be considered in conjunction with the other aspects and needs of pavement design and maintenance, such as the use of open graded friction courses.

CENTERLINE RUMBLE STRIPS

Centerline rumble strips should be applied where there is a history of opposing direction and driver inattention crashes. The most recent FHWA guidelines recommend a rumble strip with a length of 16 inches, a width of 7 inches, and a depth of 0.5 inches. These dimensions are nearly identical to those already in use in New Mexico (aside from a current width of 7.5 inches). When bicyclists are expected to use a roadway where centerline rumble strips are to be applied, 14 feet of pavement should be available beyond the centerline of the rumble strip. Centerline rumble strips are not recommended in subdivisions or on roadways with two-way left-turn lanes.

The available literature presents some contradictory conclusions when considering no-passing zones. Some literature recommends discontinuing the centerline rumble strips; others recommend a continuation. The Washington State Department of Transportation continues their centerline rumble strips through passing zones because the crashes that centerline rumble strips are intended to address still occur in these zones. In light of the potential safety benefits that centerline rumble strips offer in warning drivers in no passing zones, their continuation in such locations in New Mexico is recommended.

SHOULDER & CENTERLINE RUMBLE STRIPS

Studies addressing a combination of shoulder and centerline rumble strips are still limited. Therefore, the best guidance available at present is as follows. When both shoulder and centerline rumble strips are utilized, a 6 foot shoulder is recommended, with a 4-5 foot clear path from the edge of the rumble strip to the shoulder edge.

TRANSVERSE RUMBLE STRIPS

There are many gaps in the literature with regard to transverse rumble strips. Additionally, while some studies conclude that there are safety benefits, others indicate that the results are inconclusive. As the District Traffic Engineers throughout the state identified many locations

with the application of transverse rumble strips, it is recommended that the NMDOT pursue further research in this area, possibly teaming with other states in a pooled-fund study to examine their effectiveness, particularly with regard to their safety benefits. Considering the limited information provided by the current studies, when bicyclists are present, it is recommended that at a minimum, 18 inches of pavement be left ungrooved at the outside edge of the pavement, or 4 feet be available beyond the edge of the roadway.

Current practice in New Mexico is the use clusters of twelve rumble strips/grooves over an 11 foot, 4 inch distance for each transverse section. These clusters are laid out in varying distances from the stop bar, depending on the posted speed limit at a site. A review of literature found that other agencies use different pattern variations and cluster spacings identified, with no preferred pattern evident. Consequently, New Mexico should continue their use of the current cluster pattern and spacing.

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APPENDIX A: NMDOT STANDARD DRAWINGS

Shoulder Rumble Strips



Centerline Rumble Strips



Transverse Rumble Strips



APPENDIX B: INTERVIEW RESPONSES

1. Is there a typical shoulder width that you use on roadways where rumble strips are applied? Do they vary by functional class of the roadway?

Have to be 4 feet or more. Has to be in good condition. In the old highways, they have continuous rumble strips. As new projects are implemented, they include the gap. No idea of the mileage. No inventory.

Ideally, they use a minimum of 6 feet. Yes, the application varies by roadway.

Rumble strips are mostly just on the interstates in this district. It's typically 8 feet on the outside and 4 feet on the inside. Most of their roads don't have shoulders, or the quality of the pavement is not good enough to install rumble strips on them. Installation is more defined by pavement quality.

Minimum of 4 feet clear width for bicycles; six feet wide. Interstates all have continuous rumble strips. Whenever they redo them, they put in the gaps for bicyclists. Quite a lot of mileage of roadways need to be updated based on the current NMDOT guidelines. Out of the 1080 miles of interstates in the district, they probably have about 800 miles of continuous rumble strips. They are now allowing bicyclists on the interstates.

If they would determine that a road needed them for safety reasons, they would look at extending the shoulder.

2. How are rumble strips installed within your district (rolled in, milled)?

Most of them are milled. Last longer with milled. It's more pronounced. The majority of the contractors do the milled.

Milled.

Milled. Typically what contractors do. May have some that are rolled, but the majority are milled.

Older installations of rumble strips were allowed to be rolled in; however, now they're milled. They were having problems with getting the proper indentation in the pavement with the rolled rumble strips.

From his understanding, their district likes to mill them in. From what the district traffic engineer heard, it's difficult when the asphalt is hot to press them in. The pay item is a milled rumble strip.

3. Do you have applications of rumble strips on both asphalt and concrete? If there are applications on concrete, how are the rumble strips installed (i.e. rolled in or formed by an attachment on the slipform machine)? Are any special considerations made when applying them to one type of pavement over the other?

They don't deal much with concrete because of the cost. The traffic engineer doesn't have an idea of how they are installed since the district hardly has any. The rumble strips stop and end over the bridge. The concrete already has a groove diamond for the water.

We have minimal use of concrete in our District and no long line pavements with it.

Don't have much concrete.

They don't put them in concrete.

Anytime they go from asphalt to concrete, they don't continue the rumble strips into the concrete.

4. Are rumble strips used in residential areas?

No. Mostly all of their roads are rural.

Not to my knowledge, 45 mph or less, we don't use.

On the interstates, they go through Raton and Vegas. No feedback from residents.

No.

No.

5. Is any consideration given to discontinuing the use of rumble strips within a certain proximity to residential areas?

No rumble strips are present in the urban area. Therefore, it is not a concern for them.

Yes, 45 mph or less.

The district traffic engineer (within a more urban district) hasn't gotten complaints from residents.

No.

They get complaints from two miles from where the rumble strips were installed, especially at night.

No. They haven't run into that issue.

6. Do areas of continuous rumble strips exist (i.e. areas where there is no gap for bicyclists)?

Yes, there are areas with continuous rumble strips. The district is replacing them as projects allow.

Yes, long lines between cities and open road.

They just use the standards. They definitely do have continuous rumble strips, those that were installed before the current standards were provided. If they are not paving/repairing the shoulders, they don't touch the rumble strips. Only repave the driving lanes. Not much bicycling interest in this District.

There are some on major roads. The district traffic engineer was not sure of the total mileage. For the most part, they have gaps. Everything that the district traffic engineer has seen on their roads has gaps. In addition, bicycling has not been a concern for this particular district.

7. Do any of your roadways have sections of both centerline and shoulder/edgeline rumble strips? If so, how long?

There are no centerline rumble strips in the district.

No, not yet, but considering.

NM 550 has centerline in-ground rumble strips; it's at the edge of their District. It's mainly in District 5. (Note: It is unclear if there are shoulder/edgeline rumble strips installed at this location as well.)

Only one area with centerline rumble strips: US 54. They have shoulder rumble strips as well. It's at the Texas border. It's approximately 20 miles in length.

Yes. US 550 going to Farmington. There are 154 miles. There are double rumble strips in the median. Once you leave Rio Rancho, they have the rumble strips. Now that they are repaying it, they are putting the gap to take into consideration bicyclists.

The district traffic engineer believes that they are present on US 550.

8. Do you take into account the possibility of use by bicyclists when you decide whether or not to use rumble strips?

Yes. They need to accommodate the bicyclists. In the Silver City area, Las Cruces area, they have a lot of bicyclists. Areas like Lordsburg and Deming, they do not have a large population of bicyclists at this time.

More and more.

Yes.

Yes. They already consider them. When the shoulders are 4 feet; 8 foot shoulders or 10 foot shoulder, they don't put open grade friction surface across it.

They don't.

9. Do you use rumble strips on a bridge?

No.

We don't.

No.

No.

No.

10. Are transverse rumble strips used in your district? For example, does the district have any application as warning on rural stop-controlled intersection approaches?

Just installed some transverse rumble strips at a roundabout, at the intersection of 404 and 213, on all approaches.

Yes, we use both rumble strips milled and thinner profile thermoplast.

No rumble strips that the district traffic engineer is aware of. NM47 (4 lane facility – will be done on SB approach only, there is a hill on a blind curve) approaching NM 147; near Isleta Pueblo; passed the Casino and Travel Complex; want to do some advance warning because they are experiencing higher crash rates. They'll be putting them in in a couple of weeks. They tend to shy away because they have snow plows that go through and they need to maintain the rumble strips. The maintenance engineer has concerns about pavement maintenance when they install transverse rumble strips in the ground. They feel it is not a very good solution.

Coors is theirs. They won't re-implement the transverse rumble strips because they see deterioration of the asphalt when rumble strips are present. This is the direction that the maintenance engineer has asked the District to take.

A district received complaints with regards to some of the transverse installations. Tucumcari, US 54 and Rte 66. By the K-Mart. The district put them in as a result of a request by the city. They are only installed on US 54. Some of the cars weren't stopping or coming too fast into the signalized intersection. They're by the "signal ahead" sign.

Yes. There are transverse rumble strips at the intersection of 84 to 85/285; 285 is the minor roadway. The transverse rumble strips are on 285. They also have them on the intersection of 60 with 41. 41 is the minor leg. It has the rumble strips. There may be others.

They put raised rumble strips on NM12 where it intersects with US 60. (This needs to be verified.) The district traffic engineer is not sure if they reviewed the crash history prior to installing the transverse rumble strips at this location. They received phone calls from people who were concerned about the intersection.

11. Do you have any rumble stripes in your district (i.e. a rumble strip on an edgeline)? If so, what is the length of the section, and what is the functional class of the roadway?

No.

I am putting in a couple hundred miles of it in a safety grant project. Lane departure mitigation effort.

No.

US 64. The rumble strip is closer to the travel lane to allow 4 feet for the bicyclist. It was installed about 5 years ago. The rumble strip is on the edgeline (i.e. a rumble stripe).

No. The only district that has used these so far is District 4.

12. General questions/comments

This district traffic engineer was not really familiar with rumble stripes or centerline rumble strips and the criteria that would recommend to use or not to use them. The district traffic engineer would appreciate more information concerning the advantages and disadvantages of these types of rumble strip applications.

The District Traffic Engineer sees the benefit of rumble strips, especially on the interstate, particularly edgeline rumble strips. We have such a large number of run-off-the-road crashes. In a more urban area, the maintenance part of it becomes a problem.

Only started to use centerline rumble strips recently, about 2 years ago, based on guidance from the NMDOT. New Mexico 68 is where they applied the centerline rumble strips. They extend from about MP 17 to MP 35 (for a total of about 18 miles). It's just a centerline installation.

A district traffic engineer wanted to know whether or not centerline rumble strips should be continued through both no-passing and passing zones. The district traffic engineer also wanted to know if he/she should use rumble strips where there is a dashed line? The district traffic engineer's understanding was that they should only be used in no-passing zones. Therefore he/she would like clarification.

A district traffic engineer posed a specific example with regards to a question. For a 3 lane section, where two lanes are traveling up-hill and one lane is downhill. Are rumble strips needed along the centerline, between the two lanes that are going up-hill and on the lane line?

The district mostly has shoulder rumble strips which are offset from the traveled way.

The district traffic engineer is not familiar with the guidance provided by NMDOT. The district traffic engineer would find guidance on what types of roads should be considered for applications of rumble strips useful. Rumble strips only came up when they were doing work on interstates. Rumble strip issues don't typically come up on state roads.

It would be nice to have guidelines on which roads rumble strips would be recommended for, and which roads they are not recommended for.

APPENDIX C: RUMBLE STRIP INSTALLATION DRAWINGS

WASHINGTON STATE Washington State's rumble strip policy can be found at: http://www.wsdot.wa.gov/Design/Policy/RumbleStrips.htm

Standard drawings can be found at: http://www.wsdot.wa.gov/Design/Standards/Plans.htm#SectionM

The section called, "What is the process for conducting an engineering analysis of shoulder rumble strips along undivided highways as referenced in Design Manual Chapter 1600?" provides a good process example.

Questions for Dave Olson of Washington State Department of Transportation 1/30/2013 360-705-7952 olsonda@wsdot.wa.gov

What is the difference between rumble strip types 1-4? Type 1: divided highways Type 2, 3, 4: undivided highways

Are bicyclists allowed on all facilities in Washington State? Generally: permitted on most facilities unless signing indicates they are prohibited – typically only in urban areas

Were all of the rumble strip design standards designed with bicyclists in mind? For Types 2, 3, 4, yes. Type 1 shoulder rumble strip is on divided highway system, high speed facilities, don't see bicyclists in the traffic lanes here; they would ride outside of rumble strips; with centerline rumble strips, they don't see any need for bicyclists to be in the centerline; they are discontinued in the vicinity of an intersection

Why do you omit centerline rumble strips over bridges? Is this because the horizontal offset is insufficient?

Generally don't install rumble strips in concrete; generally, it's cost-prohibitive and they're unsure about the performance; they're concerned it might result in harmonic vibrations in a structure.

Is there a reason why rumble strip standard design drawings aren't available for applications where both edgeline and centerline are installed?

Concerns if they put on the same standard plan, it might cause confusion. System-wide applications of centerline rumble strips are done, but not system-wide application of shoulders due to concerns with bicyclists. They want to do a crash benefit before they impact bicyclists.

The Washington State standards reference roadway rumble strips, which I've seen more often described as transverse rumble strips. Is there a standard drawing for them? No standard drawing. They're working on it. They're looking at placement for the advance warning sign. They don't typically use them a lot. They're stepping up to a standard detail. When a need is identified, they don't have a standard drawing. They use them at a history where people are going through stop signs, or roadway geometry is not readily visible on the approach.

Does Washington State install rumble strips systematically or based on a safety analysis? Shoulder is not a programmatic approach. They look at run-off-the-road hot spots. Centerline rumble strips are reprioritized based on crash experience.

Does Washington State continue rumble strips through passing zones? Yes.

What has your experience been thus far with rumble stripes?

History has determined their use of 6". Avoid some level of inadvertent contact. It still allows some room for corrective action as well. FHWA technical advisory shoulder width of 4' and 5'. A couple of short segments have rumble stripes where shoulders a narrow.

Where did the requirement "Do not place shoulder rumble strips on downhill grades exceeding 4% for more than 500 feet in length along routes where bicyclists are frequently present," stem from?

Longer downgrade, higher speeds of bicyclists, not placing rumble strips at all.

SPECIFIC TO THE PAPER:

Locations with the highest B/C were chosen for centerline installation in Washington State. Do you believe that the reductions observed as a result of the study could be a bit high considering it seems like locations with higher crashes may have been chosen for application of centerline rumble strips?

Likely to see greater crash reductions earlier in their program rather than at the tail end. They're addressing the worst locations first.

The statement, "The weighted VMTs or AADTs used in this analysis are only specific to this analysis and should not be assumed to be valid for other uses or analyses." Does this imply that the AADT is defined different than how AADT is traditional defined?

Determined what the VMT was for the segment. The AADT represents the entire segment. Would have to develop a modified AADT for a segment in question; looking at centerline and shoulder rumble strips in combination.

Report focused on undivided roadways









RUMBLE STRIP PLACEMENT AT INTERSECTIONS



SHOULDER RUMBLE STRIP TYPE 1 FOR DIVIDED HIGHWAYS STANDARD PLAN M-60.10-01

SHEET 4 OF 4 SHEETS APPROVED FOR PUBLICATION

















COLORADO (source: <u>http://www.coloradodot.info/business/designsupport/standard-plans/2012-m-standards-plans/2012-m-standards-pdfs/46-</u>rumble-strips/m-614-1-rumble-strips)






















KANSAS (source: http://kart.ksdot.org/StandardDrawings/info.aspx)







OKLAHOMA (source: http://www.okladot.state.ok.us/roadway/roadway99/pdf/m106f.pdf)



OREGON (source: http://www.oregon.gov/ODOT/HWY/ENGSERVICES/pages/details_traffic.aspx#permanent_traffic_markers)









