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Research

Synthesis On The Effectiveness Of Rumble Strips

Minnesota Local Road Research Board

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This report describes the results of studies on the use and effectiveness of rumble strips, including a survey of Minnesota county engineers and a simulation conducted at the University of Minnesota Human Factors Laboratory.

Sixty-eight of 87 counties responded to the survey. Of the 68 respondents, 56 install in-lane rumble strips. The survey also asked respondents to describe the guidelines that they used to designate areas for rumble strip installation. As part of the simulation study, test subjects drove in a simulator through a designed experiment to measure the effectiveness of in-lane rumble strips. The results of this study showed different braking patterns between intersections with in-lane rumble strips and those without rumble strips. Those with rumble strips braked earlier and harder.

The report recommends that shoulder rumble strips be used in areas with high rates of run-off road crashes. Before-and-after studies have shown conclusively that shoulder rumble strips have reduced run-off road crashes by 20 to 72 percent. It also recommends a follow-up study on in-lane rumble strips involving drivers that are sleep deprived, under the influence of alcohol, or driving in poor conditions.

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SYNTHESIS ON THE EFFECTIVENESS OF RUMBLE STRIPS

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EXECUTIVE SUMMARY

One way in which highway departments have been combating driver inattention and fatigue is to install rumble strips—both in-lane and along the edge (shoulder and centerline). There has been a growing concern regarding the effectiveness of rumble strips.

The focus of this report was to synthesize information on the usage and effectiveness of rumble strips by surveying county engineers and by analyzing the results of a simulation conducted at the University of Minnesota Human Factors Laboratory.

Literature searches were conducted to gain a national perspective of the use and effectiveness of rumble strips. The majority of the literature was in agreement with Mn/DOT's conclusion on shoulder rumble strips—they are effectives reducing run-off road type crashes. Very little information was available on the effectiveness of in-lane rumble strips.

A brief questionnaire was sent to all Minnesota County Engineers. Sixty-eight of 87 counties responded to the survey. Of the 68 responding, 56 install in-lane rumble strips. The survey also asked respondents to describe the guidelines used to designate areas for rumble strip installation. Of the 32 counties that responded to this question:

- 11 counties had criteria that limited installations to intersections with trunk highways, safety problem areas and/or areas that had visibility problems.
- 18 counties had policies that provided installation at most, if not all, paved intersections.
- 3 had polices that were somewhere in between.

Additionally, the county agencies were asked for an opinion on the effectiveness of rumble strips. The responses varied from:

- very supportive
- the perception that rumble strips work for a while but lose effectiveness
- discontinued use due to liability concerns.

The study at the University's Human Factors Laboratory consisted of conducting a driver simulation study where test subjects drove a simulator through a designed experiment to measure the effectiveness of in-lane rumble strips. The results of this study conclusively showed different braking patterns between intersections with in-lane rumble strips and those without rumble strips. Those with rumble strips braked earlier and harder. However, there was no significant difference in the location where deceleration began. It should be noted that this study did not test for inattentive or fatigued drivers or for limited sight conditions. **The researchers highly recommend this be investigated.**

Given the information currently available on the use of shoulder, centerline and in-lane rumble strips; this study makes the following recommendations:

- Shoulder rumble strips should be used in areas with high rates of run-off-road crashes. Before and after studies have shown conclusively that shoulder rumble strips have reduced run-off road type crashes by 20 to 72 percent. Mn/DOT's Technical Memorandum in Appendix B provides detailed drawings for shoulder rumble strip placement, spacing and depth. The Technical Memorandum can be used to minimize the problems associated with bicycle use.

- Mn/DOT has recently installed centerline rumble strips on high-volume, two-lane routes that have high rates of head-on type collisions. Mn/DOT should produce a report documenting their effectiveness after a suitable amount of time has passed to document "after" results.

- A follow-up study on in-lane rumble strips involving drivers that are sleep deprived, under the influence of alcohol, or driving in poor conditions should be conducted at the University of Minnesota's Human Factors Lab to determine the effectiveness of in-lane rumble strips for inattentive and/or impaired drivers, rumble strips in the travel lane.

INTRODUCTION

The National Highway Traffic Safety Administration has identified driver inattention (internal or external distraction, preoccupation with other thoughts and/or drowsiness) as a major contributor to highway crashes. The Administration estimates that at least 25 percent of police-reported crashes involve some form of driver inattention. Issues surrounding driver inattention have gained interest as the availability of new technologies inside vehicles has grown. Devices such as cellular telephones, navigation systems, climate control systems, televisions and stereo systems have the potential for the driver to compete with the task of driving. In addition to technological devices being a distraction, many drivers are undertaking tasks (shaving, putting on makeup, reading, eating, etc.) that have traditionally occurred outside the use of a motor vehicle. These distractions, when combined with a population that is becoming increasingly sleep deprived, leads to a number of preventable crashes.

One of the ways in which state highway departments have been combating driver inattention and driver fatigue is to install rumble strips on the shoulders of urban and rural highways. The use of the shoulder rumble strip has been implemented in a number of states to help driver's regain attention before they drive off of the roadway. While the rumble strips do not prevent the causes of the distraction, or prevent their recurrence, rumble strips provide the driver with an audible cue that they are about to travel out of their lane. In addition to the placement of shoulder rumble strips, much discussion has occurred regarding the installation of in-lane rumble strips at STOP conditions and at railroad crossings. Like the argument in favor of shoulder rumble strips, many have argued that in-lane rumble strips provide the driver with an audible cue that road conditions are about to change.

This document is intended to provide the reader with information regarding the use of rumble strips. For the reader's convenience, the document is divided into five sections:

Section 1: Types of Rumble Strips and Methods of Installation
Section 2: Use of Rumble Strips
Section 3: Benefits of Using Rumble Strips
Section 4: Concerns with Using Rumble Strips
Section 5: Findings and Recommendations

CHAPTER 1:

TYPES OF RUMBLE STRIPS AND METHODS OF INSTALLATION

This section of the report defines what a rumble strip is, discusses the two basic types of rumble strips and describes the methods for installing rumble strips. Most of the information for this section of the report is summarized on the Federal Highway Administration's Web site (http://safety.fhwa.dot.gov/programs/rumble.htm).

Rumble Strip Definition

According to the Federal Highway Administration, a rumble strip is a raised or grooved pattern on or in travel lanes and shoulder pavements. The texture of the rumble strip is different than the road surface on or in which it is installed. When vehicle tires pass over the strip, they produce a sudden rumbling sound and cause the automobile to vibrate. The intent of the rumble strip is to alert errant or drowsy drivers before they run off of the road, cross the center lane into oncoming traffic, go through a railroad crossing or pass through an intersection without stopping.

Types of Rumble Strips

There are two basic types of rumble strips: in-lane strips and longitudinal strips. A description and the intended purpose of the two types are provided below.

In-Lane Rumble Strips

In-lane rumble strips are installed in or on the driving lane, perpendicular to the traveling vehicle, in order to alert a driver of changing road conditions (i.e., a STOP condition, a railroad crossing, road divergence, etc.). In-lane rumble strips can cover the entire driving lane or can be set up to only run the width of a vehicle's wheelpath. In-lane rumble strips that are as wide as a wheelpath are designed to allow drivers familiar with the area to straddle the rumble strip in order to avoid driving over it. Figure 1-1 shows in-lane rumble strips that traverse the entire driving lane. Figure 1-2 depicts in-lane rumble strips that cover a vehicle's wheelpath.

Figure 1-1: In-lane rumble strips, full width

Figure 1-2: In-lane rumble strips, wheelpath

Longitudinal Rumble Strips

Longitudinal rumble strips are installed on the shoulder or centerline of the roadway. The strips are placed parallel to the traveling vehicle. If a vehicle strays from the driving lane into the shoulder, the vehicle's tires pass perpendicularly over the individual rumble bars signaling the driver that they have drifted onto the shoulder. Longitudinal rumble strips can be continuous or clustered. Continuous rumble strips are milled or rolled into the pavement surface all along the corridor. The bars that make up the strips are evenly spaced, without any long stretches of undisturbed pavement between the bars. The clustered rumble strips consist of evenly spaced bars with sections of undisturbed pavement at regular intervals. Figure 1-3 depicts continuous longitudinal rumble strips and Figure 1-4 illustrates clustered rumble strips.

Figure 1-3: Longitudinal rumble strips, continuous

Figure 1-4: Longitudinal rumble strips, clustered

Installation Techniques

There are three different methods of installing rumble strips. Each is described along with its associated advantages and disadvantages.

Formed or Rolled Rumble Strips

These rumble strips are comprised of rounded or v-shaped grooves that are pressed into hot asphalt during the compaction phase of the construction or reconstruction process. A roller that has a steel pipe welded to its drum creates the strip. The steel pipe, which is raised higher than the surface of the drum, makes a depression as it passes over the asphalt. The formed or rolled rumble strips are generally 1.25 inches (32 millimeters) deep and 1.6 inches (40 millimeters) wide.

The advantage of this type of rumble strip is that it is inexpensive. Actual costs are not available because the strips are created during the normal course of construction or reconstruction at the compaction stage. The disadvantages of this type of strip are that installation can only be done during the construction or reconstruction process and the strips do not produce as loud a noise as other types of rumble strips. Please refer to Figure 1-5 below for an example of formed or rolled rumble strips.

Figure 1-5: Formed/Rolled Rumble Strip

Source: FHWA Web Site – Rolled Rumble Strips

Raised Rumble Strips

Raised rumble strips come in many forms. They can be made of asphalt, a rubber-like material or plastic reflectors. Raised rumble strips can be thought of as raised, narrow stickers that are affixed to the road surface. Raised strips vary in width from 2 inches to 12 inches (50 millimeters to 305 millimeters) and are generally 1/4 inch to 1/2 inch (6 millimeters to 13 millimeters) high. They can be rounded or rectangular and are often referred to as "raised buttons."

There are advantages to using this type of rumble strip. Because the material is affixed to the road, materials such as glass beads can be added to give the strip retroreflectivity (as long as the rumble strips are not made out of asphalt). The retroreflectivity enables drivers to see the strip easily at night. Additionally, bicyclists may prefer this strip to the milled or formed strips because there is little or no disruption to the rider. Finally, the raised rumble strips can be applied at any time; the road does not need to be undergoing construction or reconstruction.

The disadvantage of this type of rumble strip is that, in snow belt areas, snowplows tend to remove them. Additionally, the raised rumble strips are likely to be more costly to install than the formed strips. Raised rumble strips can vary in cost from $500 to $1,000 for two approaches. Please refer to Figure 6 below for an example of raised rumble strips.

Figure 1-6: Raised Rumble Strip

*Source: Premark Adhesive Rumble Strips**

The above photograph was taken from the Premark Web site. This report does not endorse any brand of adhesive rumble strips.

Milled Rumble Strips

Milled rumble strips, as their name implies, are milled (or ground) into the road surface. A machine with a cutting head that creates a smooth, uniform and consistent groove in the pavement surface is used to make milled rumble strips. Milled rumble strips are generally installed with a longitudinal width of 7 inches (180 millimeters) and a transverse width of 16 inches (400 millimeters). Longitudinal applications are generally set off of the travel line by 12 inches to 16 inches (300 millimeters to 400 millimeters). Tires that pass over these strips drop approximately 1/2 inch (13 millimeters) into the groove.

Milled rumble strips have some advantages over other rumble strips. First, they can be installed on new or existing asphalt and Portland Cement surfaces. Second, even though they are ground into the road, they are not reported to negatively impact the structure of the roadway. Finally, they produce greater levels of noise than the other types of strips. This is especially important for large commercial vehicles that have substantial ambient noise. The disadvantage of this type of rumble strip is that it is more expensive to install than the other types. They can range in price from $0.13 to $0.35 per linear foot, depending upon the number of miles that are milled. Milled rumble strips are also non-reflective. Figure 1-7 shows an example of a milled rumble strip.

Figure 1-7: Milled Rumble Strip

CHAPTER 2:

USE OF RUMBLE STRIPS

This section provides general information on the use of rumble strips. Rumble strips have served many purposes for different agencies over the years. They have been used in travel lanes in rural areas to forewarn drivers of upcoming stops, intersections and railroad crossings. They have also been used in cities as a form of traffic calming. Highway departments have even used them in construction zones. Recently, however, rumble strips have become increasingly popular with departments of transportation because of their success in reducing run-off-road accidents. Typical locations and rationale for using rumble strips are described below.

Travel Lane Usage

Historically, rumble strips have been used to alert drivers to upcoming conditions (i.e., intersections, stop or yield conditions, railroad crossings and areas with poor geometrics or large numbers of accidents). While this use of the rumble strip continues to be popular, little documentation of before and after accident rates/crashes has been published.

One report, *NCHRP Synthesis 191 – Use of Rumble Strips to Enhance Safety – A Synthesis of Highway Practice*, published in 1993, summarizes information found on travel lane usage. The author of this report indicates that most of the before and after studies are small, not statistically significant, poorly designed and difficult to quantify. Given the limitations of the information available, the author of the report was able to draw only limited conclusions. He indicated that:

- Despite the lack of rigor in their accident evaluation designs, the study results in the literature generally indicate that rumble strip installation in the travel lane can be effective in reducing accidents. However, the study results are not reliable enough to quantify the expected accident reduction effectiveness.

- Rumble strip installation in the travel lane should be considered at locations where rear-end accidents and ran-STOP-sign accidents involving an apparent lack of driver attention are prevalent.

- Care should be taken not to overuse rumble strips by placing them in too many locations in the travel lane.

- Normally, placement of the rumble strips in the travel lane should be considered only where a documented accident problem exists and only after more conventional treatments, such as signing, have been tried and been found to be ineffective (Harwood pp. 11-12).

Another source of information on in-lane use of rumble strips comes from a memo prepared by Howard Preston – *Effectiveness of Rumble Strips At Isolated Rural Intersections, 1995*. The study concluded that in-lane rumble strips are not an effective crash countermeasure. This study included a control group of intersections (no rumble strips) and compared them with a group of 26 rural through-stop intersections with rumble strips. However, in evaluating the conclusions of this study, one should consider the NCHRP report above and the following:

- Many of the intersections analyzed lacked detailed before and after traffic volumes and a significant number of intersections used the same volumes for the seven-year analysis period. This information could have influenced the results.

- It was not determined if rural intersections identified for analysis in the study had a crash problem that could be addressed by an in-lane rumble strip installation. In a subsequent survey of Minnesota counties completed as part of this report, it was determined that many Minnesota counties install rumble strips at all paved through-stop intersections, regardless of whether there is an identified problem. If a before and after analysis is done using these installations, it will likely show ineffectiveness because there was no safety or crash problem (problem with inattention or running stop) to begin with.

One of the difficulties in assessing in-lane rumble strip applications is the lack of good data and recordkeeping. Many agencies put in rumble strips purely on a policy basis. Some analyze the crash and geometric issues prior to installation. Very few counties or other agencies follow up to conduct after studies to see if the installation was effective in mitigating the problem.

Other older studies referenced in the above reports include a Transportation Research Board (TRB) study in 1967 and 1983, an Illinois Department of Transportation Study in 1970 and a Minnesota Department of Transportation Study (Mn/DOT) in 1977. The results of these studies are mixed. The TRB study was the most positive, indicating that rumble strips had a significant effect on traffic speed and stop sign observance. In addition, crashes were reduced at 28 percent of the locations where the rumble strips were present. The Illinois study indicated that no significant crash reduction occurred at locations studied.

Minnesota County Rumble Strip Survey

A survey of Minnesota counties was conducted in February 2001 to assess current practices and policies for the use of rumble strips within Minnesota. A list of five questions was developed and sent to all county engineers. Sixty-eight of 87 counties responded to the survey. Of the 68 responding, 56 install in-lane rumble strips. The counties were asked if they use one, two or three sets of rumble strips prior to the intersection or change in traffic control. Most counties (48) use two sets of rumble strips, four use one set and four use three sets.

Another question inquired about whether they used full-lane or wheel path rumble strips. The results were more evenly split, with 33 counties using full-width and 20 counties using wheel path and three counties using both.

The survey also asked respondents to describe the guidelines used to designate areas for rumble strip installation. Of the 32 counties that responded to this question, 11 counties had criteria that limited installations to intersections with trunk highways, safety problem areas and/or areas that had visibility problems. Eighteen counties had policies that provided installation at most, if not all, paved intersections and three had polices that were somewhere in between.

The final question asked for an opinion on the effectiveness of rumble strips. The responses varied from very supportive to the perception that rumble strips work for a while but lose effectiveness, to discontinued use due to liability concerns. A copy of the survey can be found in Appendix A.

University of Minnesota Human Factors Research

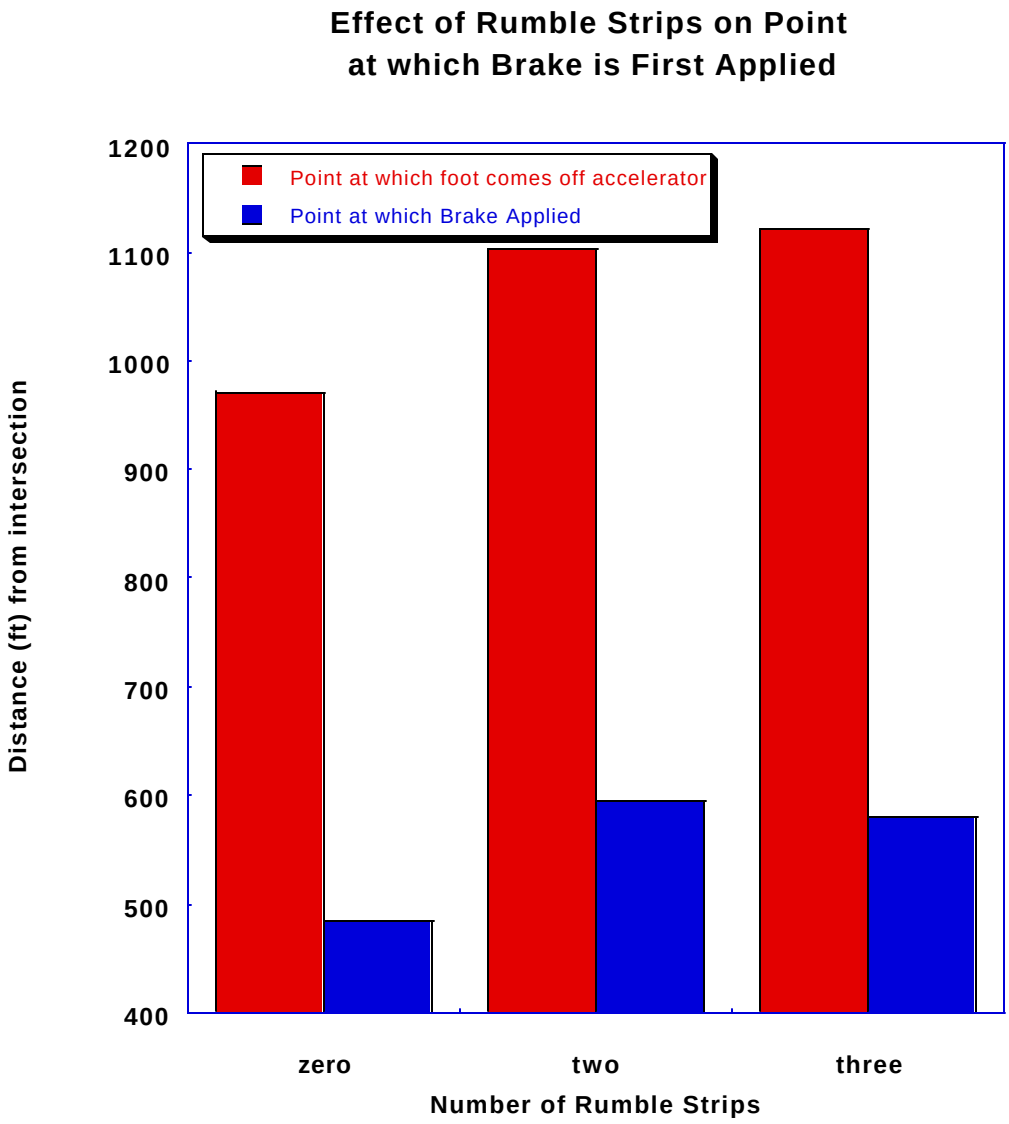
Due to the lack of conclusive data on in-lane rumble strips, the subcommittee working on this task suggested working with the University of Minnesota's Human Factors Research Laboratory to simulate scenarios of STOP conditions with and without the use of rumble strips. The subcommittee hoped that the simulation could provide insight into the effectiveness of in–lane rumble strips. While some good information was obtained, the simulation was not set up to test subjects that were sleep-deprived or inattentive. This would be the condition when rumble strips are likely to be most useful.

In April of 2001, the Human Factors Research Laboratory initiated an experiment designed to test driver reaction to the presence of rumble strips, the number of rumble strips and the type of intersections encountered. The conclusions of the study are as follows:

- Full-width rumble strips seem to be more effective than wheel path rumble strips in terms of braking pattern.
- There was no behavioral difference between the presence of two sets of rumble strips and three sets of rumble strips.
- There was a statistically significant difference when drivers applied the brake and the force at which the brake was applied. Drivers that approached STOP conditions with rumble strips applied the brake earlier and harder than at STOP conditions without rumble strips.
- The presence of rumble strips did not make a statistical difference in the point at which a driver removed his or her foot from the accelerator.
- There was also no statistically significant difference for the point at which a driver came to a complete stop.

Figure 2-1 shows the similarities and differences in accelerator control and braking patterns with and without the use of rumble strips.

Figure 2-1: Accelerator Control and Braking Patterns



The conclusions drawn from the experiments at the Human Factors Lab are for drivers that were alert, were tested under daylight conditions and had no adverse weather situations. Typically, rumble strips are not installed for these types of drivers. Often the decision to install a rumble strip (whether it be a shoulder rumble strip or a rumble strip at a STOP condition) is to gain the

attention of a driver who is distracted, drowsy, traveling in poor weather conditions (i.e., heavy fog, blowing and drifting snow, blizzard conditions, etc.) or driving at night in an unfamiliar area. Because drivers going through the simulator were not sleep deprived, were not alcohol impaired, were not tested under night conditions and were not faced with poor driving conditions, the University of Minnesota has suggested incorporating in-lane rumble strips as part of a larger study. This study will be conducted within the next year in which drivers will experience sleep deprivation, alcohol intoxication and night conditions. Researchers at the University believe that it is possible for drivers who are not alert or have some form of impairment (sleep deprivation, intoxication, etc.) to have a different response to rumble strips than alert drivers. A copy of the full report, *"The Effects of In-Lane Rumble Strips on the Stopping Behavior of Attentive Drivers"* is available from the Minnesota Department of Transportation.

Usage as Traffic Calming Devices

In addition to their use in travel lanes to forewarn drivers of upcoming conditions, rumble strips have been used for traffic calming purposes. Traffic calming is intended to slow vehicles as they enter or pass through an area. Traffic calming is usually done in residential areas where citizens have concerns about the speed of motor vehicles.

As with the use of rumble strips in the travel lane, there is limited comprehensive data available on the use of rumble strips for traffic calming. Research suggests that vehicle speed may or may not be impacted slightly with the installation of rumble strips. While the noise generated by the rumble strip may raise the driver's awareness, it is also likely be an irritation to local residents.

Use in Construction Zones

Rumble strips have been used in work zones since the 1950s; however, their use in this capacity has not been widespread. When rumble strips have been used in work zones, the strips have been used in conjunction with other warning devices such as signs, flagmen, variable message signs, barricades, etc. The intent is to provide the driver with an audible clue, along with visual clues, that road conditions are changing. In a majority of instances, the rumble strips are used to identify lane closures, crossovers, significant changes in speed and transition of driving lanes (FHWA, July 1989).

Edge Line/Shoulder and Centerline Usage

Many departments of transportation and county officials are beginning to use rumble strips at the edge lines/shoulders and centerlines of rural routes to alert drivers that they are going out of the normal travel lane. The focus of these installations has been at high run-off-road accident locations and along lengthy stretches of freeways or highways. Unlike the usage of rumble strips in the travel lane or as a traffic calming device, there is a significant amount of information available on the use of rumble strips at edge lines/shoulders and less information on their use on centerlines. However, Mn/DOT has recently installed centerline rumble strips on a number of higher volume two-lane routes such as TH 55 near Rockford, TH 23 near Paynesville and TH 169 near Garrison. The expectation is that these installations will reduce the number of head-on collisions where vehicles are cross the centerline. Much more information should be available on these installations in the next few years. Appendix B contains a copy of Mn/DOT's Technical Memorandum on edge line rumble strips. The Technical Memorandum includes design criteria and design details.

The studies that have been conducted on edge line indicate that the rumble strips are very effective in reducing run-off-road accidents. Section 3 of this document will discuss the benefits of rumble strips more in depth. Figures 2-2 and 2-3 depict the use of rumble strips along the edge line and centerline of roadways.

Figure 2-2: Rumble Strips Along the Edge Line/Shoulder

Figure 2-3: Rumble Strips at the Centerline

CHAPTER 3:

BENEFITS ASSOCIATED WITH THE USE OF RUMBLE STRIPS

There are significant accident reduction benefits associated with some rumble strip applications. Most of the literature on rumble strips addresses the benefits associated with shoulder rumble strips. There are few comprehensive studies that highlight statistically significant results for the use of rumble strips in the travel lane. As a result, this report will focus on the benefits associated with the use of rumble strips at centerlines and edge lines.

Increased Driver Awareness and Reduction of Accidents

Run-off-road crashes occur when fatigued or inattentive drivers, who are either tired or not paying attention, drive off the shoulder into the ditch or hit an object alongside the road. Many head-on crashes occur when drivers are drowsy and cross the centerline into oncoming traffic. Nationally, run-off-road crashes account for approximately one-third of all traffic-related fatalities and two-thirds of rural area fatalities. Edge line and centerline rumble strips have proven very effective in warning drivers that they are leaving the road or are crossing over into oncoming traffic.

Numerous states have installed rumble strips on edge lines on freeways and highways. Reports from the states vary somewhat, but it is estimated that the use of rumble strips has reduced run-off-road crashes from anywhere between 20 and 72 percent. Listed below are the states that have used rumble strips on the edge line/shoulder with the results of their efforts.

- New York – 72 percent decrease in run-off-road crashes at a time when overall crash rates increased more than 11 percent.

- California – 49 percent reduction in run-off-road crashes. Follow-up evaluations of freeway segments where shoulder rumble strips have been in place for three or more years indicate an average reduction of 33 percent.

- Maine – Studies conducted by the state indicated that continuous shoulder rumble strips could reduce run-off-road accidents by 20 to 50 percent. Studies also indicate

that installing rumble strips along the entire rural Interstate system would result in a benefit-cost ratio of 5:1 to 20:1.

- Pennsylvania – 60 to 65 percent reduction of run-off-road accidents.
- Massachusetts – 42 percent reduction of run-off-road accidents on rural turnpike.
- Washington – 18 percent reduction of run-off-road accidents on six selected roads.
- Kansas – 34 percent reduction of run-off-road accidents on rural turnpike.
- New Jersey – 34 percent reduction of run-off-road accidents on rural turnpike.

There is less information available on the use of rumble strips in the centerline. Many states, including Minnesota, are conducting tests on their effectiveness. The state of Maryland, which has used centerline rumble strips on its two-lane roads, has not conducted any formal studies on their effectiveness, but has indicated that there are fewer transgressions (Garder and Alexander, p. 11).

Most of the information that is currently available for edge line and centerline applications is on the state level. Very little information is available from units of government at the county and city levels. However, given that most drivers do not know if they are on a state, county or local roadway, the applicability of edge line and centerline rumble strips should apply on most major routes. Because edge line applications usually provide a break for all public access points, application of edge line rumble strips may only be applicable were there is fairly limited access or where the agency has good access control.

Positive Benefit-Cost Ratio

While the cost of rumble strips can vary by type and installation, they have been shown to be an economical way to significantly reduce crashes. Rumble strips can cost very little if they are rolled in during a construction or reconstruction project. When done this way, all that is needed is the roller with the attached pipe. Milled strips, however, are more expensive. They can range in price from $0.13 to $0.35 per linear foot, depending upon the number of miles that are milled.

The states listed above all found positive benefit-cost ratios for installing rumble strips (even if they were milled). The Federal Highway Administration's Web site highlights economic benefits for the states of New York, Nevada and Maine. These states found benefit-cost ratios ranging from 30:1 to 182:1, depending upon the location. Additionally, conservative estimates from Khan and Bacchus in their report, *Economic Feasibility and Related Issues of Highway Shoulder Rumble Strips*, indicate at least a 4:1 ratio. Overall, the literature that was reviewed seemed to indicate that edge line and centerline rumble strips enhance public safety at minimal cost.

Because the benefit for in-lane use of rumble strips has not been documented, little information is available in regards to benefit-cost ratios. In reviewing the Minnesota county survey information, it appears that many of the counties feel that these types of installations are inexpensive and, from their perspective, provide a good benefit.

CHAPTER 4:

CONCERNS REGARDING THE USE OF RUMBLE STRIPS

Several concerns have been raised regarding the use of rumble strips in the travel lane and on the shoulder. The following highlights the more common concerns with rumble strips. It should be noted that many of these concerns could be addressed with additional planning, and that others such as noise are more difficult to resolve.

Noise

The intent of a rumble strip is to gain the attention of a driver. Naturally, the byproduct of this measure is a loud rumbling noise. In isolated areas, this usually is not a problem. However, when installed in a suburban or urban area, the noise from the rumble strips can be quite disruptive to nearby residents. The noise issues should not be underestimated or dismissed easily. A number of testimonials from county engineers indicate that a number of installations had to be removed after complaints were received from adjacent residents. It is therefore recommended that road authorities carefully weigh the noise implications of rumble strips if they are to be located in populated areas.

Avoidance

If a survey of automobile owners were taken, it would be likely that a majority of the owners would indicate that they do not like to drive over rumble strips. Many motorists do not like the sound of the rumble strip or the vibrations that they feel as they pass over them. Others believe that rumble strips cause damage to their vehicles. As a result, some motorists will avoid driving over the in-lane rumble strips by moving over to straddle them, driving in the opposite lane or on the shoulder. As a result, avoidance maneuvers can lead to additional safety problems. Avoidance is not an issue for rumble strips that are placed on the shoulder or on the centerline, since drivers are not typically on that part of the road.

One state addressed this issue by having the rumble strip cross onto the other travel lane. This is rarely done because it may cause confusion for the drivers in the opposite lane since they are not approaching a condition that warrants heightened attention. Another potential solution is to have rumble strips that are discontinuous and that extend across only the normal wheelpath areas on the travel lane. This enables drivers familiar with the strips to drive around them (straddle) without leaving the travel lane. Motorists who are not familiar with the area or those who are not paying attention are likely to drive over the strip because it covers the normal wheelpath area.

Snowplowing

Certain types of rumble strips can cause problems with snowplowing activities. If raised rumble strips are placed in the travel lane, it is likely that they will be damaged or removed if the snowplow blade (especially underbody blade which have become very common) strikes them. In order to prevent damage from occurring, the blade of the snowplow would have to be lifted. Snowplows cause little or no damage to milled rumble strips.

One additional snowplowing concern is the placement of longitudinal or edge line rumble strips. Snowplow drivers do not like to have to drive on the strips in order to clear the lane or shoulder area. This situation can be remedied by moving the strips further out into the shoulder. Mn/DOT suggests that edge line rumble strips be placed at least 8 inches (200 millimeters) off the travel lane.

Durability

The durability of the rumble strip depends upon the type of strip and how it is used. For example, milled or rolled rumble strips placed on the edge line or shoulder areas will generally last as long as the pavement of the surrounding roadway. In the 1980s, the state of California began using continuous rumble strips along its freeways and highways. The state found that the rumble strips have remained as durable as the material in which they were placed. This is likely attributable to the fact that the strips do not have high traffic volumes crossing over them on a daily basis.

However, raised rumble strips in Minnesota's climate do not exhibit the same durability. These strips are likely to be damaged because of plowing.

Shoulder Usage

The use of edge line rumble strips also may inhibit the use of the shoulder as a travel lane when doing construction and/or maintenance operations. This may increase the cost of the project and/or traffic control measures required during the project.

Bicycle Usage

Bicyclists have complained about the use of rumble strips for a number of years, especially in urban areas. While there is not significant information on any actual damage or harm caused to bicyclists or their bicycles as they pass over rumble strips, most find the experience of riding over strips annoying. The concern of the bicyclist is not as prevalent in rural areas, but it still is an issue with the use of rumble strips along the edge line and in the travel lane.

Many departments of transportation are looking at ways to improve the use of the rumble strips so that they do not interfere with bicyclists. In some areas, rumble strips are not being installed unless there is a separate designated bike lane available. In other areas, shoulders have been widened to allow for both bicyclists and rumble strips. Southern states that can use the raised rumble strips made out of rubber-like material or reflective plastic material are finding that these strips cause few problems for bicyclists because tires can fit between the raised surfaces. Additionally, clustered strips can offer bicyclists a reprieve from continuously traveling over the rumble strips by providing necessary gaps for them to use paved shoulder areas without rumble strips.

CHAPTER 5:

FINDINGS AND RECOMMENDATIONS

This section of the report summarizes information found throughout the document and makes recommendations based upon the result of the information obtained during the synthesis process.

Findings

- Longitudinal rumble strips are typically used on-shoulders and centerlines to warn drivers when their vehicle strays out of the travel lane.

- Shoulder rumble strips have typically been installed on higher volume rural arterial routes. Before and after studies have shown conclusively that shoulder rumble strips have reduced run-off road type crashed by 20 to 72 percent.

- Benefit-cost ratios of shoulder rumble strips range from 5:1 to 20:1.

- Limited before and after studies have been done on centerline rumble strips. Mn/DOT has recently installed these on high-volume, two-lane routes that have high rate of head-on type collisions.

- Currently, the use of longitudinal rumble strips by counties is limited or non-existent.

- In-lane rumble strips are used to warn drivers of upcoming traffic control or changes in conditions.

- Fifty-six of the 68 Minnesota Counties responding to the rumble strip survey use in-lane rumble strips. Many of the counties indicated that they install them at all paved road intersections that have a STOP condition.

- Studies of the effectiveness of in-lane rumble strips have been inconclusive. A 1993 NCHRP report indicated that most studies are small, poorly designed, with results that are difficult to quantify.

- Some motorists may avoid driving over the in-lane rumble strips by straddling them, by driving on the shoulder, or by moving into opposing traffic.

- In-lane rumble strips are not listed in the MUTCD (Minnesota Manual on Uniform Traffic Control Devices) as an approved traffic control device.

- A University of Minnesota study conclusively shows different braking patterns between intersections with in-lane rumble strips and those without rumble strips. Those with rumble strips braked earlier and harder. However, there was no significant difference in the location where deceleration began. Also, this study did not test for inattentive or fatigued drivers or for limited sight conditions.

- One of the biggest problems with the installation of rumble strips is the noise that they create for nearby residents. This has led to many complaints and some removals.

- There is no evidence that the presence of rumble strips causes quicker pavement deterioration.

- Location of edgeline rumble strips is important to avoid problems during snowplow operations and to minimize the problems associated with bicycle use.

- Some motorists will avoid driving over the in-lane rumble strips by moving over to straddle them, driving in the opposite lane or on the shoulder.

Recommendations

- Shoulder rumble strips should be used in areas with high rates of run-off-road crashes. Before and after studies have shown conclusively that shoulder rumble strips have reduced run-off road type crashes by 20 to 72 percent. Mn/DOT's Technical Memorandum in Appendix B provides detailed drawings for shoulder rumble strip placement, spacing and depth. The Technical Memorandum can be used to minimize the problems associated with bicycle use.

- Mn/DOT has recently installed centerline rumble strips on high-volume, two-lane routes that have high rates of head-on type collisions. Mn/DOT should produce a report documenting their effectiveness after a suitable amount of time has passed to document "after" results.

- A follow-up study on in-lane rumble strips involving drivers that are sleep deprived, under the influence of alcohol, or driving in poor conditions should be conducted at the University of Minnesota's Human Factors Lab to determine the effectiveness of in-lane rumble strips for inattentive and/or impaired drivers.

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Appendix A

Minnesota County Engineer Survey

SURVEY OF COUNTY ENGINEERS – FEBRUARY 5, 2001

1. Does your county install in-lane rumble strips in advance of stop signs?
   (Yes or No)

2. If yes to 1, does your county install one, two, or three rumble strip areas in advance of the intersection?
   (1, 2 or 3)

3. If yes to 1, does your county construct full lane width or wheel path rumble strips?
   (Full or Wheel Path)

4. If yes to 1, does your county have guidelines for selecting the intersections where in-lane rumble strips will be installed?
   (Yes or No)

5. If yes to 4, please e-mail or mail your guidelines.

Please feel free to add your perspectives about the use and effectiveness of in-lane rumble strips to increase driver awareness.

Thank you on behalf of the LRRB RIC "Rumble Strip" Project team for your assistance.

Table A-1

County	Answer 1		Answer 2			Answer 3		Answer 4		Answer 5	Perspective
	Y	N	1	2	3	Full	Path	Y	N		
Aitkin	X			X		X			X		The general feeling in our County is that rumble strips are effective. We are looking at expanding the use of rumble strips, so I am very interested in the results of this study.
Anoka		X									
Becker	X			X		X					Maintaining the rumble strips over the years seems to be the biggest problem. We would be interested in looking at any guidelines that you come up with.
Big Stone	X			X			X		X	County Engineer's judgment on a case-by-case basis is used. I intend to put them where posted speed limit is at least 50 mph and ADT is greater than 100 on stopping leg of intersection.	Most importantly, at intersections where sight distance is jeopardized in any way.
Blue Earth	X			X		X			X	Select locations based on crash history, traffic volumes, sight distance, and other risk factors.	I think they are effective. Public requests for specific locations, also complains about noise.
Brown	X			X		X		X		All intersections.	A lawsuit is presently ongoing which involves an intersection with a trunk highway that has rumble strips.

County	Answer 1		Answer 2			Answer 3		Answer 4		Answer 5	Perspective
	Y	N	1	2	3	Full	Path	Y	N		
Carlton	X			X		X			X		The county got away from the bumps of asphalt stuck on top of the surface as they did not stand up. The routered strips are not the safety concern for traffic, and seem to make enough noise to get the attention desired. I don't have the numbers, but I don't have calls of all the traffic going through the stops.
Carver	X			X		X			X		
Cass	X			X			X		X		
Chippewa	X			X		X		X		County has determined that advance warning rumble strips will be placed on paved surfaces, at stop condition, where the speed limit is greater than 45 mph.	
Clay	X			X			X	X		Problem intersections, usually with THs, where vehicles are not stopping.	I feel they are very effective along with double stop signs and double stop ahead signs.
Clearwater	X			X			X		X		

County	Answer 1		Answer 2			Answer 3		Answer 4		Answer 5	Perspective
	Y	N	1	2	3	Full	Path	Y	N		
Crow Wing	X			X		X			X		Perceptions: Most public comments or reaction is positive - there seems to be a perceived idea that they are helpful and contribute to overall safety particularly at intersections, which may have a tendency to "sneak-up" on a driver. Over the years I have to say that I have had more requests to install them than I have had to remove them. And, when we have resurfaced and not re-installed rumble strips we have had complaints or requests to re-install. However, at one location we did receive complaints from a couple of nearby residents who wanted them removed due to noise problems. We did a study without taking extensive measurements and convinced the MPCA that we were not in violation, and that ended the issue. But, at higher traffic volumes and closer proximity of residents, I came to the conclusion that noise issues could be a legitimate problem at some locations.

County	Answer 1		Answer 2			Answer 3		Answer 4		Answer 5	Perspective
	Y	N	1	2	3	Full	Path	Y	N		
Dakota		X									I believe that significant benefit can be derived by clear analysis of the location and identifying the real cause of vehicle crashes. There is a danger of increasing driver warning at some locations and not others (non-uniformity). The devices are not part of the MUTCD. What is the real effect of using traffic devices not identified in the manual?
Dodge	X				X	X			X		We do not track effectiveness. We just figure they help.
Douglas		X									
Faribault	X			X			X		X	We install rumble strips at all stop signs.	I believe the rumble strips are a good idea. I have received positive comments on the rumble strips.
Fillmore	X			X		X			X		
Freeborn	X			X		X			X		
Goodhue	X			X		X		X		We install two full width rumble strips at all paved rural roads that have a stop sign.	
Hennepin		X									

County	Answer 1		Answer 2			Answer 3		Answer 4		Answer 5	Perspective
	Y	N	1	2	3	Full	Path	Y	N		
Isanti	X			X			X		X	Potential factors/locations are 4–legged paved intersections with only a two way stop; east/west routes due to sun; limited sight distance at intersections; high accident areas;	Whether or not RS are effective or not, the public seems to feel they provide additional safety at intersections and in some instances they probably do; residents living near RS on the other hand can be extremely unhappy with RS due to the noise factor.
Itasca	X			X			X		X		Have received complaints on rumble strips at rural intersections where there are homes nearby. We typically add oversize signing as a first response to concerns, and rumble strips as a second response if it appears those concerned cannot be satisfied.
Jackson		X									
Kandiyohi	X			X		X	X		X		
Kittson	X			X			X	X		Stop conditions, no other guidelines.	
Koochiching		X									Koochiching County does not have any rumble strips on its system. However, I would use them if I had a problem at a certain location. I would favor installing them just in the wheel track instead of across the entire lane.
Lac qui Parle	X			X		X		X		Dead end bituminous roads.	
Lake of the Woods	X		X				X		X		

County	Answer 1		Answer 2			Answer 3		Answer 4		Answer 5	Perspective
	Y	N	1	2	3	Full	Path	Y	N		
Le Sueur	X			X		X			X		Le Sueur County only has a few intersections with rumble strips. Maybe 10 to 20 intersections total. Many of the rumble strips are placed at the direction of the County Board.
Lincoln	X			X		X			X		Lincoln County has just started installing rumble strips on an experimental basis.
Lyon		X									I would like to start using rumble strips in Lyon County. I personally have found them to be helpful as I have driven through other counties that use them.
Martin		X									
McLeod	X			X			X		X		We believe that they have not been proven effective… so we shy away… have conceded 5 or 6 intersections around county
Mille Lacs		X									
Morrison	X			X		X		X		Four leg intersections with all legs paved or history of running the intersections.	
Murray	X		X			X		X		We place rumbles at all our County Road intersections with stopping conditions. We place them at the stop ahead sign location.	We find them valuable and have something to fall back on when people say they didn't see our sign and still have an accident. We say didn't you hear/feel the rumble strips either? We find a lot of the accidents are a result of inattentive driving.

County	Answer 1		Answer 2			Answer 3		Answer 4		Answer 5	Perspective
	Y	N	1	2	3	Full	Path	Y	N		
Nicollet	X			X			X	X		County Board adopted policy... only for 55 MPH, minimum 450 ADT, County routes approaching State Highways that have no traffic signal or flashing lights* inplace. *There are instances where the flashing lights have gone in after the rumble strips, so still remain.	
Nobles	X			X		X		X		Rumble Strips are installed at all paved road intersections with stop condition.	
Norman	X		X				X		X		
Olmsted	X			X		X		X		Speed greater than 50 MPH. Approaches to THs.	
Otter Tail		X									Otter Tail County does not use in-lane rumble strips currently. Our interest in this project is to determine the effectiveness of the in-lane rumble strips and if effective, to develop a policy outlining their use.
Pennington	X			X	X	X	X				Mn/DOT has a drawing on location of rumble strip locations.
Pipestone	X			X		X			X		No official guidelines however, we have rumble strips on nearly all stop locations.

County	Answer 1		Answer 2			Answer 3		Answer 4		Answer 5	Perspective
	Y	N	1	2	3	Full	Path	Y	N		
Polk	X			X			X	X		We do all intersections that are stop conditions.	We think that they are effective and cut them in within a year of paving a road. We delay it a year as we have found out the fresh mat has a tendency to tear when we cut them in. As stated before, all of ours are cut-in in order to reduce maintenance. When installed as built-up, they would be sheared off during winter maintenance operations.
Pope	X			X		X			X		
Ramsey		X									
Red Lake	X				X		X		X		
Redwood	X			X		X		X		All paved roads.	We feel they are very effective and the public likes them. We put two sets (500' & 1000') back from all stop signs on hard surfaced roads. They are routed into the pavement.
Renville	X		X			X			X	Pretty much all major CSAH Routes.	I like the rumble strips with 3 consecutive strips in 1 location in advance of stop sign.
Rock	X			X		X		X		We installed rumble strips in year 2000 at our rural stop signs, we did not install rumble strips on roads that are included in our five-year construction plans for upgrades or improvements.	

County	Answer 1		Answer 2			Answer 3		Answer 4		Answer 5	Perspective
	Y	N	1	2	3	Full	Path	Y	N		
St. Louis		X									We used to place rumble strips at a few locations in the County, but have discontinued their use due to liability issues.
Scott	X			X			X	X		An old version of the Minnesota Traffic Engineering Manual Page 11-9	We are very selective in where we use rumble strips. We consider their use only after study of the intersection and the accident reports clearly show motorists are not realizing that a stop is ahead ("running" the stop). We also do not install near residences as the noise/vibration is problematic. Even with some residences quite a distance away we have modified the rumble strips by filling in some of the grooves to dampen the noise/vibration. One problem with the full coverage rumble strip is that it can "encourage" motorists to drive around the strips rather than stay in the lane. Finally, we feel that the rumble strips are very effective when used appropriately.
Sherburne	X			X			X		X	Maintenance Supervisor judgment.	
Sibley	X			X		X		X		All paved roads.	
Stearns	X			X			X		X		

County	Answer 1		Answer 2			Answer 3		Answer 4		Answer 5	Perspective
	Y	N	1	2	3	Full	Path	Y	N		
Steele	X			X		X		X		Rumble strips will be installed at all stop conditions on county roads in Steele County, except in incorporated areas. When there is sequence of installation, efforts will be made to construct these strips at intersections with State Highways first. The second priority will be rumble strip construction at intersections of two county roads. All others will follow. (10/7/98 – revised 11/9/99)	
Stevens	X			X			X		X		
Swift	X			X		X		X		We do all, but not in town.	Most people, when asked, seemed to like them.
Todd	X			X			X	X		If pavement is due for overlay or reconstruction, we generally wait a year or two until work is done if intersection presently does not have them. We are milling the higher volume roads first. Approximately 70% of system has them.	Personally I feel that if drivers must be alerted by "noise" (rumbling) to know that signs are ahead, they should not be on the road in the first place, but I suspect that 50% of the driving public believes they are a good thing. (50%) also seem to be "dodging" them by changing paths.
Wabasha	X				X	X		X			I do not feel rumble strips are necessary, but some still want to see them at certain locations.

County	Answer 1		Answer 2			Answer 3		Answer 4		Answer 5	Perspective
	Y	N	1	2	3	Full	Path	Y	N		
Wadena	X			X			X		X		
Waseca	X			X		X			X	Case by case.	
Watonwan	X			X		X		X		All stop sign approaches	
Wilkin	X			X		X		X		All major intersections.	We use Mn/DOT's guidelines and saw the rumble strips into the roads. We have definitely cut down on intersection accidents.
Winona	X			X		X		X		Repetitive accident history on failures to stop.	People complain about the noise. Seem to work for the first year or two and then accidents start reoccurring. They are effective but not totally effective.
Wright	X			X		X	X		X		
Yellow Medicine	X			X		X		X		We ask the sheriff to monitor stop sign violations and accidents-to date we have installed rumble strips at six intersections all at the sheriff's request.	

Appendix B

Mn/DOT Technical Memorandum
No. 00-08-DS-01

Technical Memorandum No. 00-08-DS-01

MINNESOTA DEPARTMENT OF TRANSPORTATION
Program Support Group
Technical Memorandum No. 00-08-DS-01
May 9, 2000

TO: Distributions 57, 612, 618, 650

FROM: Patrick C. Hughes
Director, Program Support Group
Assistant Commissioner

SUBJECT: Rumble Strips on Shoulders of Rural Trunk Highways

Expiration
This Technical Memorandum supersedes Technical Memorandum 99-15-DS-01 and Section 4-4.0 of the Road Design Manual. It will be in effect until December 24, 2005, or until included in the Road Design Manual, which ever comes first.

Implementation
This policy shall be in effect for all projects with a scheduled letting date after July 1, 2000. District personnel should make every effort to implement this policy for projects which have been let prior to July 1, 2000 and on which rumblestrip construction has not yet begun.

Introduction
This Technical Memorandum establishes a policy for placement of rumble strips on shoulders of rural, state-owned highways. Rural is defined as roadway segments that have minimal residential or commercial development and little or no further development is anticipated in the near future.

Purpose
To provide rumble strips to reduce run-off-the-road (ROR) accidents and to guide motorists during snowy conditions when striping visibility is poor.

Guidelines
Rumble strips shall be placed on all rural highway projects where shoulders are constructed, reconstructed, or overlayed and where the posted speed limit is 50 mph (80 kph) or greater. This applies to both multi-lane and two-lane highways with shoulders 6 feet (1.8 m) or greater in width. They shall also be placed on the left shoulder of multi-lane roads. Districts should also consider placing rumble strips on inplace shoulders at locations with a high ROR accident rate and on which no reconstruction is scheduled in the near future. The District Materials Engineer should make recommendations regarding the structural adequacy of inplace shoulder to receive rumble strips.

Types and applications of rumble strips can be found in Table 1. See Figures 1 and 2 for section and plan views of rumble strips on bituminous shoulders. The intermittent pattern is shown in Plan View B in Figure 2. Figure 3 gives section and plan views of structural rumble strips in concrete pavement that have been modified for safety. Guidelines for appropriate breaks in the rumble strips due to entrances, turn lanes, acceleration lanes, intersections, and deceleration lanes on all roads can be found in Figure 4. Rumble strips in bituminous shoulders should be produced by the milling method. Districts may fog seal rumble strips milled into bituminous pavement.

TABLE 1 B Types and Applications of Rumble strips

Applications	Rumble Strip Types
Freeway right shoulders[1]	***Type 1A B 1' 4@ (400 mm) Continuous*** Continuous milled rumble strips used on bituminous shoulders that are 1' 4@ (400 mm) wide and located 2= (600 mm) from the painted edge-line (see Figures 1 and 2).
Freeway left shoulders[1]	***Type 1B B 1' 4@ (400 mm) Continuous*** Continuous milled rumble strips used on bituminous shoulders that are 1'4@(400 mm) wide and located 4@ (100 mm) from the painted edge-line (see Figures 1 and 2).
Two-lane roadway shoulders (left and right) Multi-lane roadway right shoulders	***Type 2 B 1' (300 mm) Intermittent*** Intermittent milled rumble strips used on bituminous shoulders that are 1' (300 mm) wide and located 4@ (100 mm) from the edge-line. Intermittent rumble strips shall be milled in a 60= (18 m) cycle. (48= (14.4 m) of rumble strip followed by a 12= (3.6 m) gap as shown in Figures 1 and 2)
Multi-lane roadway left shoulders	***Type 3 B 1' (300 mm) Continuous*** Continuous milled rumble strips used on bituminous shoulders that are 1' (300 mm) wide and located 4@ (100 mm) from the painted edge-line (see Figures 1 and 2).
Multi-lane and two-lane highways with 27= (8 m) wide concrete pavement (new or existing) in lieu of Type 2.	***Type 4 B Modified Structural*** Structural rumble strips shall be modified such that they are 3= (1 m) long and placed on every other concrete panel. They shall be centered at the mid-point of the panel. The right edge of the painted edge-line shall be placed adjacent to the left edge of the rumble strip (see Figure 3).

1Type 4 rumble strips may be used on 27' (8 m) wide concrete pavement on freeways in lieu of Type 1A and Type 1B at the Designer=s discretion.

Shoulder widths of 4 feet (1.2 m) or less with rumble strips will not adequately accommodate bicycles. Therefore, rumble strips should not be placed on these roadway sections unless the District Traffic Engineer has documented a serious ROR accident problem and little or no bicycle traffic is expected. Districts shall contact the State Bicycle Coordinator to determine the amount of bicycle traffic on a roadway.

Because rumble strips will require bicycles to ride farther out from the vehicle induced wind sweep shoulder edge, brooming may be necessary to remove debris to safely accommodate the bicyclist in bike use areas.

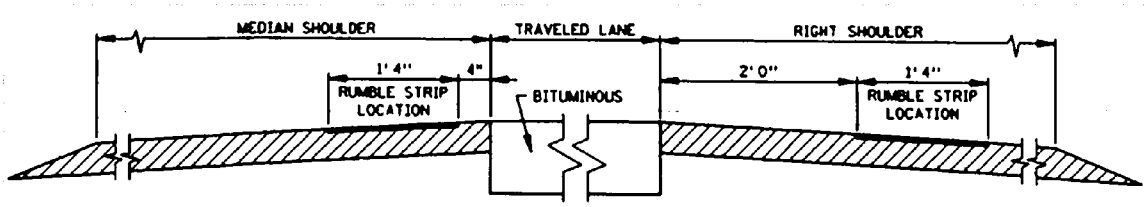
Questions
Any questions regarding the content or implementation of this technical memorandum should be referred to Amr Jabr, Design Standards Engineer (651/296-4859).

Any questions regarding the publication or distribution of this technical memorandum should be referred to Amr Jabr, Design Standards Engineer (651/296-4859) or Susan Berndt, Office and Administrative Specialist (651/296-9570).

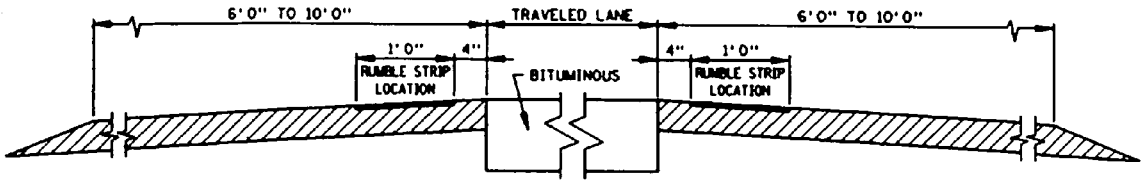
Attachments:

Figure 1: Shoulder Rumble Strip - Section View (English)
Figure 2: Shoulder Rumble Strip - Plan View (English)
Figure 3: Modified Structural Rumble Strip (English)
Figure 4: Shoulder Rumble Strip - Appropriate Breaks (English)

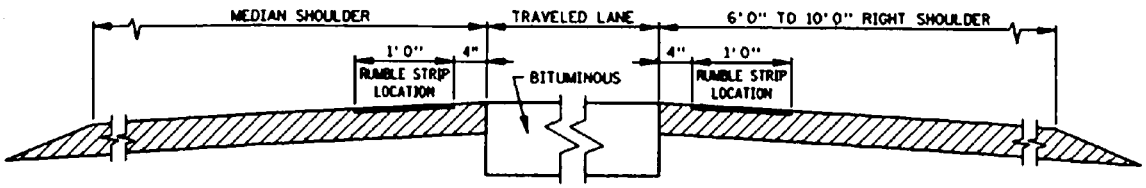
Figure 1: Shoulder Rumble Strip - Section View (English)



SECTION VIEW OF FREEWAY - Type 1
(ONE ROADWAY SHOWN)



SECTION VIEW OF TWO-LANE ROADWAY - Types 2 or 3
(WITH 6'0" TO 10'0" PAVED SHOULDERS)

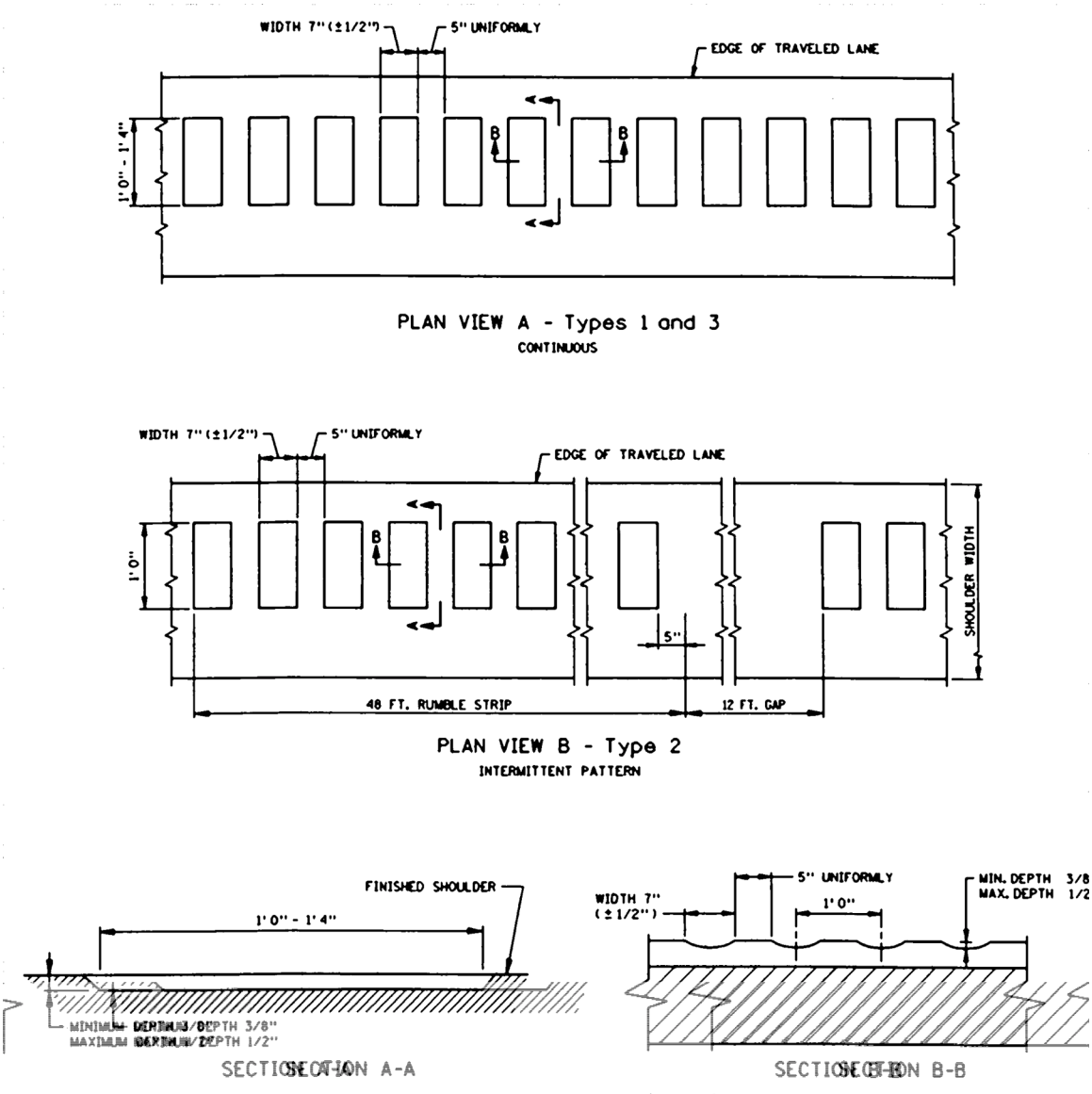


SECTION VIEW OF MULTI-LANE ROADWAY - Types 2 and 3
(ONE ROADWAY SHOWN)

NOTE:
FOR SHOULDERS 4'0" OR LESS SEE PAGE 2.

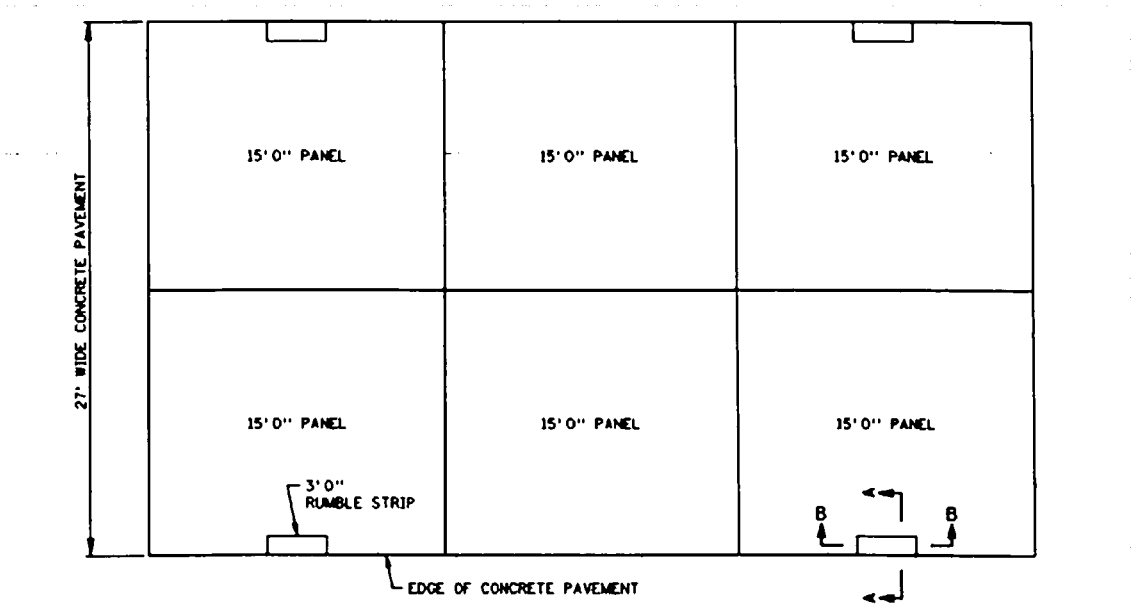
Revised July 28, 2000

Figure 2: Shoulder Rumble Strip - Section View (English)



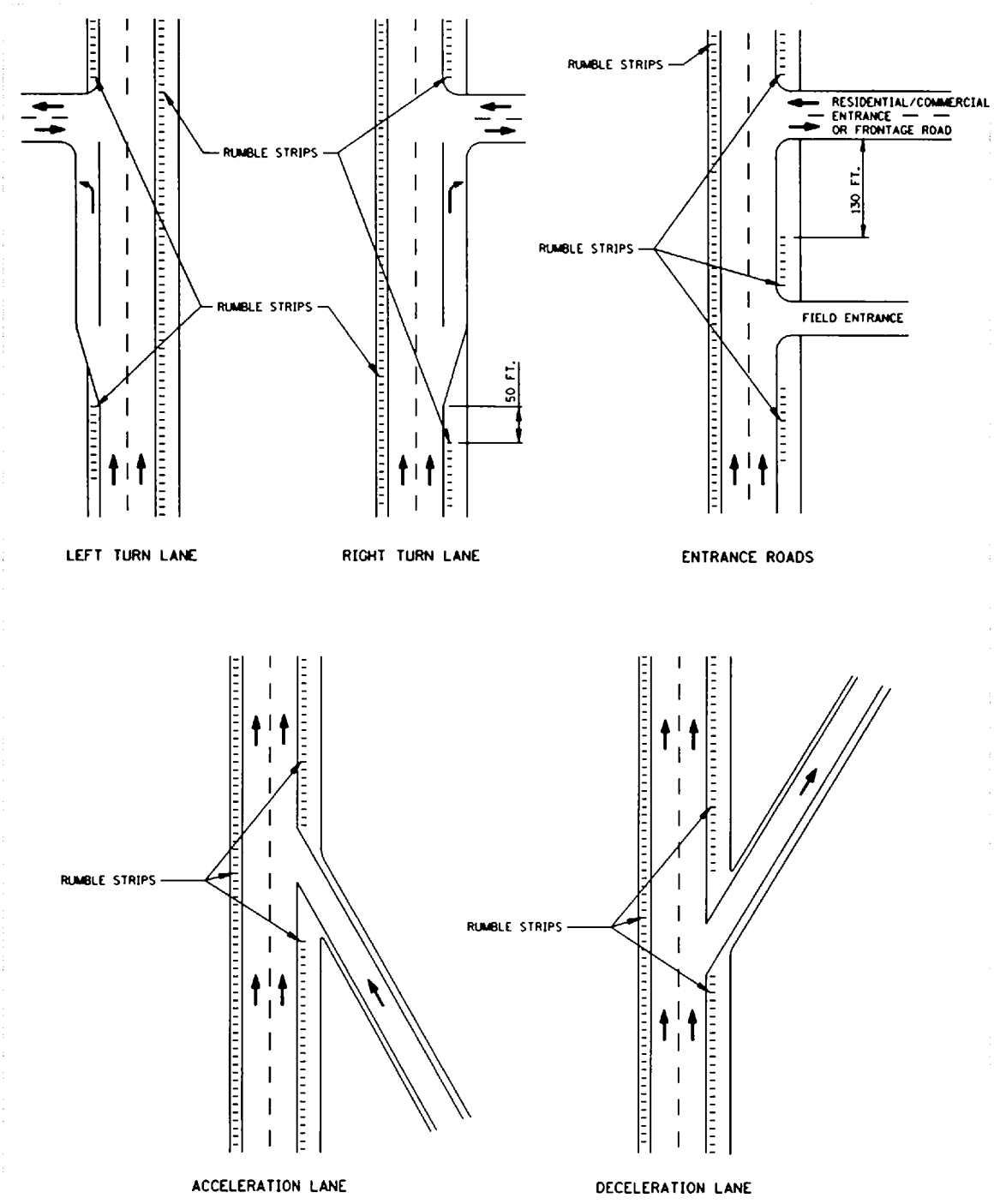
Revised July 28, 2000

Figure 3: Modified Structural Rumble Strip (English)



Revised July 28, 2000

Figure 4: Shoulder Rumble Strip - Appropriate Breaks (English)



Revised July 28, 2000