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SHOULDER RUMBLE STRIPS AND BICYCLISTS

FINAL REPORT

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Submitted by

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16. Abstract

This report provides a comprehensive review of existing research on the safety impacts of rumble strips to bicycles. Introduced in the early 1950s, shoulder rumble strips (SRS) have been extensively used as a countermeasure to single-vehicle run-off-the-road (ROR) accidents on freeways caused by driver inattention. Placed in the shoulder of a roadway, SRS provide motorists with both audible and tactile warning that the vehicle has left the roadway. Shoulder rumble strips have primarily been used on limited access roadways. The effectiveness of this treatment, however, has led to the consideration of using shoulder rumble strips for implementation on non-freeway roadways. There are concerns, however, that shoulder rumble strips may pose safety concerns to bicyclists using the shoulder as a bicycle path. Of concern is the potential for loss of control if the bicyclist strikes a rumble strip. Existing research on shoulder rumble strip design and placement may provide some guidelines for New Jersey in its design and placement of shoulder rumble strips.

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Table of Contents

List of Tables

EXECUTIVE SUMMARY

The objectives of the work performed under Task Order NCTIP-38, Project 2000-01, Shoulder Rumble Strips and Bicycles were to: develop a comprehensive report covering the design, installation and costs of shoulder rumble strips, identifying the impacts of these rumble strips on bicyclists; develop recommended policies and guidelines for implementing shoulder rumble strips so that they are compatible with bicyclists and beneficial to motorists as well; and to identify the most bicycle-friendly rumble configurations.

Shoulder rumble strips (SRS) have been implemented by many highway agencies and State Departments of Transportation (DOTs) across the United States. Introduced in the early 1950s, shoulder rumble strips have been extensively used as a countermeasure to single-vehicle run-off-the-road (ROR) accidents on freeways caused by driver inattention. Placed in the shoulder of a roadway, SRS provide motorists with both audible and tactile warning that the vehicle has left the roadway.

Shoulder rumble strips have primarily been used on limited access roadways. The effectiveness of this treatment, however, has led to the consideration of using shoulder rumble strips for implementation on non-freeway roadways. There are concerns, however, that shoulder rumble strips may pose safety concerns to bicyclists using the shoulder as a bicycle path. Of concern is the potential for loss of control if the bicyclist strikes a rumble strip. Although rumble strips are installed in only about half of the paved shoulder width, the area between the rumble strip and the outside edge of the shoulder is often littered with debris making it unusable for bicyclists. As a result, there is concern that rumble strips encourage bicyclists to ride in the traveled way of a roadway. Some have claimed that shoulder rumble strips may pose maneuverability problems for bicyclists who claim discomfort and loss of control of the bicycle as a result of riding over the rumble strips. As a result, several research projects have been initiated to develop policies and configurations of rumble strips that can meet the requirements of the motorists without affecting bicyclists' safety.

The research approach included two primary tasks: a literature review and a survey of SRS policies and practices of State Departments of Transportation. The literature review investigated several areas including: the design and placement of shoulder rumble strips and State design guidelines. The Design and Placement of Shoulder Rumble Strip review provided background on design and placement of shoulder rumble strips. The various types of shoulder rumble strips are identified including the noise and vibration levels of these rumble strip designs. A crash analysis of run-off-road accidents in New Jersey is also provided along with a discussion of bicycle safety issues.

A review of surveys performed to obtain State policies on the design and placement of shoulder rumble strips was also performed. A survey of State Departments of Transportation was conducted in this research to determine current design practices and bicycle policies related to the placement of shoulder rumble strips. The survey was

administered through email, with follow-up telephone calls made to agencies not responding to the email messages. Responses were received from 40 States.

There are four primary types of rumble strips: milled, rolled, formed or corrugated, and raised. Milled rumble strips are currently the most commonly used type of rumble strip among various highway agencies. FHWA, in their review of state practices, found that in order to provide more clear area in the shoulder for use by bicycles, some states have installed milled-in shoulder rumble strips 300 mm (12 in) in the direction perpendicular to the travel lane instead of the usual 400 mm (16 in). This was considered the minimum width as any smaller width may allow the tires of vehicles, especially for large trucks, to bridge the indentation and reduce the vibration level of the rumble strip.

In most cases, shoulder rumble strips are continuous for the length of the roadway and section where it is implemented. Shoulder rumble strips have also been placed intermittently in the shoulder using a gap pattern. Arizona is one State that recommends that shoulder rumble strips on all non-controlled access highways include periodic gaps of 3.6m (12 in) in length. The gaps are placed at periodic intervals of spacing of 12.19m (40 in) or 18.29m (60 in). These gaps were provided as a solution to reduce the discomfort of bicyclists associated with crossing continuous shoulder rumble strips.

Several policies have been identified on the use of shoulder rumble strips to minimize the impact to bicyclists. In general, the guidelines do not recommend the use of rumble strips on routes where bicyclists are permitted, while other guidelines have suggested remedial measures to reduce the adverse effect of rumble strips on the bicyclists. These remedial measures include:

- Installing shoulder rumble strips as close to the pavement edge as the specifications can allow;
- Designing narrower rumble strips in order to provide the bicyclists adequate space to ride; and
- Installing rumble strips only on shoulders wide enough to provide sufficient space for the bicyclists to ride.

Based on this study the follow strategies have been identified as holding potential for accommodating bicycles and rumble strips:

1. Minimum shoulder width to accommodate rumble strips. Do not use rumble strips if the shoulder width is less than 8 feet.
2. Widen the shoulder to provide at least a 4 foot continuous riding surface (Florida).

3. Provide an offset of 1.2 m (4 feet) from edge of shoulder for bicycles and motorcycles (Hawaii).

4. Moving the rumble strip as close to the travel lane as possible (Minnesota)

5. Use of continuous rumble strips only on limited access facilities.

6. Use periodic gaps in the rumble strip on non-controlled access highways. Gaps of 12 in every 40 to 60 inches of rumble strips used in Arizona. Use of skip pattern on multilane rural highways with a speed limit greater than 50 mph (Georgia).

7. Not allowing bicycles on roadways where shoulder rumble strips are installed. (Connecticut)

8. Not allowing rumble strips on roadways used by bicyclists. (Maine)

9. Reducing the width of the rumble strip from 2 feet to 1 feet (Kentucky).

10. Requiring approval of the Pedestrian/Bicycle Coordinator if rumble strip is to be installed on a shoulder width less than 8 feet.

INTRODUCTION

BACKGROUND

Shoulder rumble strips (SRS) have been implemented by many highway agencies and State Departments of Transportation (DOTs) across the United States. Introduced in the early 1950s, shoulder rumble strips have been extensively used as a countermeasure to single-vehicle run-off-the-road (ROR) accidents on freeways caused by driver inattention. A survey performed in cooperation with the Federal Highway Administration reported showed that in 1993 41 States used shoulder rumble strips[1]. Five years later, in March 1998, the Federal Highway Administration's (FHWA) Office of Highway Safety conducted a second survey to identify State policies and guidelines for textured shoulders [2]. Although not all States responded to the survey, almost States responding stated they either had state guidelines in place or were in the process of developing guidelines for the design and placement of shoulder rumble strips.

Placed in the shoulder of a roadway, SRS provide motorists with both audible and tactile warning that the vehicle has left the roadway. Shoulder rumble strips have primarily been used on limited access roadways. The effectiveness of this treatment, however, has led to the consideration of using shoulder rumble strips for implementation on non-freeway roadways. There are concerns, however, that shoulder rumble strips may pose safety concerns to bicyclists using the shoulder as a bicycle path. Of concern is the potential for loss of control if the bicyclist strikes a rumble strip. Although rumble strips are installed in only about half of the paved shoulder width, the area between the rumble strip and the outside edge of the shoulder is often littered with debris making it unusable for bicyclists. As a result, there is concern that rumble strips encourage bicyclists to ride in the traveled way of a roadway. Some have claimed that shoulder rumble strips may pose maneuverability problems for bicyclists who claim discomfort and loss of control of the bicycle as a result of riding over the rumble strips. As a result, several research projects have been initiated to develop policies and configurations of rumble strips that can meet the requirements of the motorists without affecting bicyclists' safety.

PROBLEM STATEMENT

Little objective and reliable data exists to support the safety impacts of rumble strips on bicyclists. In addition, recommended policies and guidelines have not been developed for the design of SRS to make them compatible with the needs of bicyclists while maintaining the effectiveness of SRS to mitigate against run-off-the-road crashes. Existing research on shoulder rumble strip design and placement have provided results that are sometimes contradictory and in some cases difficult to implement. A comprehensive review of existing research on the safety impacts of rumble strips to bicycles may identify design and placement specifications allowing both SRS and bicycles to use the shoulder of a roadway.

OBJECTIVES

The objectives of the work performed under Task Order NCTIP-38, Project 2000-01, Shoulder Rumble Strips and Bicycles were to:

- To develop a comprehensive report covering the design, installation and costs of shoulder rumble strips, identifying the impacts of these rumble strips on bicyclists;
- To develop recommended policies and guidelines for implementing shoulder rumble strips so that they are compatible with bicyclists and beneficial to motorists as well; and
- To identify the most bicycle-friendly rumble configurations.

The tasks to be performed to achieve these objectives include:

Task 1. Perform a literature review.

Task 2. Survey the SRS policies and practices of State Departments of Transportation, including detailed descriptions of rumble strip designs, shoulder widths, the placement of the rumble strips within the shoulder, how rumble strips are installed, installation cost, installation location policies, and the experience and opinion of bike coordinators and local cyclists.

Task 3. Prepare an NCHRP first and second stage problem statement, a request for a pooled fund study and/or write a Request for Proposal (RFP) using Research's RFP format that is based upon Tasks 1 and 2.

ORGANIZATION

This report is organized into 6 sections: Introduction; Design and Placement of Shoulder Rumble Strips; Crash Analysis Studies; Bicycle Safety Issues; State Rumble Strip Designs; and Conclusions and Recommendations. The Introduction describes the problem statement and the objectives of the research. The Design and Placement of Shoulder Rumble Strip section provides a background on design and placement of shoulder rumble strips. The various types of shoulder rumble strips are described including a discussion on the noise and vibration levels of these rumble strip designs. The Crash Analysis Studies section provides a review of crash analyses performed to evaluate the effectiveness of shoulder rumble strips. A crash analysis of run-off-road accidents in New Jersey is also provided. The Bicycle Safety Issues section looks at bicycle safety issues. The State Rumble Strip Design section provides a review of surveys performed on State policies used in the design and placement of shoulder rumble strips. The section also presents the results of a review of State policies performed in this research. Finally,

the Conclusions and Recommendations describes the most bicycle-friendly rumble strips and provides recommendations on the use of shoulder rumble strips in New Jersey.

DESIGN AND PLACEMENT OF SHOULDER RUMBLE STRIPS

Rumble strips can be placed in several locations on the roadway including across the travel lane of the roadway, along the centerline and within the shoulder [3]. When placed in the traveled way of a roadway, rumble strips warn drivers of an upcoming condition such as an intersection, a horizontal curve, narrow bridge approaches, toll plaza, outside shoulders of lane drops, work zones, gore areas of freeway off-ramps, or paved highway medians. Rumble strips placed in the centerline of a roadway are intended to prevent crossovers resulting in head-on crashes.

The focus of this study is the placement of rumble strips within the shoulder of the roadway. When placed in the shoulder of a roadway, rumble strips alert drivers that they have left the traveled way of the roadway. In this location, shoulder rumble strips can be placed continuously within the shoulder of the roadway or can be spaced along the shoulder length intermittently.

TYPES OF RUMBLE STRIPS

There are four primary types of rumble strips: milled, rolled, formed or corrugated, and raised. These types of rumble strips differ in their installation methods, size, shape, spacing, and noise and vibration produced. Rounded or v-shaped grooves are typically used on asphalt shoulders and rectangular and corrugated shapes used on concrete shoulders [4].

The four types of shoulder rumble strips differ in their shapes, sizes, method of installation, vibration and the noise levels they produce. The following provides further details on the types of shoulder rumble strips in use including: milled, rolled, formed or corrugated, and raised.

In its review of designs of shoulder rumble strips, FHWA identified four types of rumble strip designs most often used[5]. These shoulder rumble strips included: milled-in, rolled-in, formed and raised rumble strips. Table 1 shows the design features for each type of rumble strip.

Table 1. FHWA Basic Rumble Strip Designs [2]

Type	Depth	Width[a]	Length[b]	Spacing	Offset
Milled-in	13 mm (1/2 in)	180 mm (7 in)	400 mm (16 in)	300 mm (12 in)	100-300 mm (4 - 12 in)
Rolled-in	25 mm (1 in)	50 - 64 mm (2 - 2.5 in)	450 - 900 mm (18 - 35 in)	200 mm (8 in)	150 - 300 mm (6 - 12 in)
Formed	25 mm (1 in)	50 - 64 mm (2 - 2.5 in)	400 - 900 mm (16 - 35 in)	15 m (50 ft)[c]	300 mm (12 in)
Raised[2]	12 – 13 mm[d]	50 - 100 mm	-	300 - 1500 mm	0 mm

[1] Source: Florida DOT Design Guide
http://safety.fhwa.dot.gov/roadway_dept/docs/dimensions.pdf

[2] Source: FHWA[(5)]

[a] Parallel to travel lane
[b] Perpendicular to the travel lane
[c] Generally in groups of five to seven depressions
[d] Height

Milled Rumble Strips

Milled rumble strips are currently the most commonly used type of rumble strip among various highway agencies. The strip is made by cutting or grinding the pavement surface using carbide teeth affixed to a rotating drum[(5)]. Milled rumble strips are typically 180 millimeters (7 in) wide in the direction of travel and 400 mm (15.5 in) long perpendicular to the direction of travel[(6)]. FHWA, in their review of state practices, found that in order to provide more clear area in the shoulder for use by bicycles, some states have installed milled-in shoulder rumble strips 300 mm (12 in) in the direction perpendicular to the travel lane instead of the usual 400 mm (16 in) [(5)]. This was considered the minimum width as any smaller width may allow the tires of vehicles, especially for large trucks, to bridge the indentation and reduce the vibration level of the rumble strip. Narrower strips were found only to be used on facilities with particularly narrow shoulders and a significant off-road crash history.

The depressions have concave circular shapes with minimum depths in the center at 13 mm (1/2 in) resulting in a tire drop of approximately 13 mm while passing over the milled rumble strip. These types of strips can easily be installed on new or existing asphalt shoulders. This rumble strip design is known to produce a considerable amount of noise and vibration.

Rolled Rumble Strips

Rolled rumble strips can be installed on constructed and reconstructed shoulder surfaces where they are of compacted nature. Grooves are formed into the hot asphalt shoulders by rollers. Rolled rumble strips have dimensions of 38 mm (1.5 in) wide and 31.9 mm (1.2 in) deep. The resulting tire drop is approximately 0.76 mm (0.03 in) which is about 1/26th the vertical tire drop of the milled rumble strip[6]. As a result, rolled rumble strips produce less noise and vibration than milled rumble strips. Milled rumble strips have been shown to be 12.6 times rougher and 3.4 times louder than that of rolled rumble strips. One problem associated with rolled rumble strips is that snow plows removing snow from the shoulder or adjacent roadway can remove some of the asphalt around the rumble strip, reducing the effectiveness of the rolled rumble strip.

Formed or Corrugated Rumble Strips

Formed, or corrugated rumble strips can be installed in Portland Cement Concrete (PCC) shoulders. This type of rumble strip is not used as often due to the more commonly used asphalt shoulders in this region. Grooves and indentations have to be formed into the concrete surface during finishing process. The indentations are approximately 25 mm (1 in) deep, 50 to 64 mm (2 - 2.5 in) wide parallel to the travel lane and 400 to 900 mm (16 - 35 in) long perpendicular to the travel lane [5]. Although the indentations may be continuous, they are generally grouped in groups of five to seven depressions spaced approximately 15 m (50 ft) apart and offset from the travel lane at about 300 mm (12 in).

Raised Rumble Strips

Raised rumble strips use different materials such as raised pavement markers or asphalt bars, which adhere to existing or new shoulder surfaces. The use of raised rumble strips is limited to warmer climates due to maintenance difficulties resulting from snow removal in cold climates. These strips can be placed continuously or can be spaced along the shoulder length intermittently. Some of the typical shapes used include rounded, rectangular, V-Shaped or tapered when placed on asphalt shoulders. Typically, along asphalt shoulders, rounded or V-shaped grooves are installed, but rectangular or tapered shapes may also be provided. Along PCC shoulders, rectangular and wave like or corrugated shapes are generally used. The height of the raised element may vary from 6 mm (1/4 in) to 13 mm (1/2 in) spacing and width across the shoulders vary widely.

NOISE LEVELS

Shoulder rumble strips not only differ in their design, but they also differ in the noise and vibration levels they provide. The noise and vibration produced by a rumble strip should be loud and strong enough to be heard inside the vehicle and felt by the driver. The literature found on studies of rumble strip noise level is summarized as follows:

1. The noise level produced by the rumble strip depends on the rumble strip design, including the spacing, and the type of vehicle used to measure the noise level.

    a. Higgins and Barbel[7]: increased the noise level by as much as 7 dB above the noise levels of traffic on normal pavement.
    b. Pigman and Barclay[8]: noise inside the vehicle was increased by 5 to 15 dB above ambient noise
    c. Perrillo[6]: noise inside of a passenger vehicle is approximately 60 decibels and 90 decibels for the cab of a large truck.
    d. Chen[9]: 2.5 dB for rolled rumble strips; 7.0 dB for corrugated rumble strips; and 10.87 dB for milled rumble strips.
    e. Garder[11]: found that normal peak noise level 20 m (66 ft) from the traveled way ranged from 72 dBA for a passenger car to 82 dBA for a heavy truck. The shoulder rumble strip increased the peak noise level by about 11 dB for a passenger car and by about 9 dBA to 91dBA for a full size truck.
    f. Noise levels inside an operating vehicle have been reported to be approximately 60 decibels for passenger vehicles and 90 decibels for large trucks.
    g. Noise levels were measured in the interior of a car by a Larson Davis Laboratories Model 710 Dosimeter from the front seat in a 1988 Toyota pickup and a 1994 Saturn SL. The noise levels recorded are shown in Table 2.

2. The noise level is also affected by the width of the grooves. Wider widths allow the tires to fall deeper into the grooves, thus producing greatest sound (Gupta[1]).

3. Round groove shapes provide the better sound effect than v-shaped groove (Chaudoin and Nelson[10]).

4. The noise levels have been one of the main causes for several states to avoid placing shoulder rumble strips in urban residential areas.

5. Noise barriers or moving the rumble strips farther way from the traveled lanes can possibly minimize noise disturbances in urban areas.

6. New York does not recommend rumble strips in built-up residential areas. However their use in such areas is warranted based on crash history.

Table 2. Interior Noise on Travel lanes and on Rumble Strip

Speed	Saturn		Toyota	
	Travel Lanes	Rumble Strip	Travel Lanes	Rumble Strip
15 mph (24 km/h)	64	73	64	74
20 mph (32 km/h)	66	78	65	76
30 mph (48 km/h)	67	85	67	83
40 mph (64 km/h)	71	87	70	84
50 mph (80 km/h)	71	91	72	81
55 mph (88 km/h)	73	93	74	85
65 mph (105 km/h)	75	95	77	89
75 mph (120 km/h)	78	98	80	92

Source: Garder[11]

CONTINUOUS SHOULDER RUMBLE STRIPS

In most cases, shoulder rumble strips are continuous for the length of the roadway and section where it is implemented. Placement of continuous shoulder rumble strips on locations such as across bridge decks and in areas with narrowing lateral clearances, such as approaches to bridges and acceleration/deceleration lanes, have been a subject of concern to authorities. New Jersey's policy on the installation and application of continuous shoulder rumble strips state that they should not be installed at bridge decks and 30.5 m in advance and beyond all intersections and driveways. New Hampshire and Connecticut refrain from using continuous shoulder rumble strips on bridge decks, acceleration and deceleration lanes, while Massachusetts, Maine and New York install them on acceleration and deceleration lanes. However, installations on proper ramps are avoided [6]. A few states place shoulder rumble strips along the freeway acceleration and deceleration lanes. Shoulder rumble strips are generally not placed on freeway ramps, although they have been used to alert drivers of an especially tight turn entering the exit ramp.

The Florida Department of Transportation recommends that rumbles strips be only used on curves, approaches to narrow bridges and other locations where there is a high potential for benefit. Raised rumble strips are restricted to approaches to narrow bridges[12]. Continuous shoulder rumble strips may not be appropriate for every location, but should be considered for use at certain locations such as on shoulders of approaches to narrow bridges, in gore areas, in advance of approaches, on shoulders adjacent to concrete median barrier, in areas with narrow clear zones and other critical locations.

INTERMITTENT SHOULDER RUMBLE STRIPS

Shoulder rumble strips have also been placed intermittently in the shoulder using a gap pattern. Arizona is one State that recommends that shoulder rumble strips on all non-controlled access highways include periodic gaps of 3.6m (12 in) in length. The gaps are placed at periodic intervals of spacing of 12.19m (40 in) or 18.29m (60 in). These gaps were provided as a solution to reduce the discomfort of bicyclists associated with crossing continuous shoulder rumble strips. The gaps are designed to be long enough to allow a typical bicyclists to cross the gap without entering the grooved rumble strip area, but not so long as to permit the tire of a vehicle leaving the travelway at a typical run-off-road angle to cross the gap without experiencing the noise and vibration of the rumble strip [13].

To determine the most appropriate gap spacing, tests were performed to determine the behavior of bicyclists traveling on a moderate downgrade roadway with intermittently spaced shoulder rumble strips at various spacings. A downgrade section of roadway was used to allow bicycle speeds to be between 37 - 45 km/h (23 - 28 mph). Twenty-eight bicyclists were tested varying in skill level from "basic" to "skilled" bicyclists. The gaps used for testing included gap spacings ranging from 6.1 m (20 ft) to 3.0 m (10 ft). The 3.7 m (12 ft) gap spacing was found to be the shortest spacing that could be cleared by test subjects most successfully.

The study also looked at the cycle length for use in constructing the gaps. The two cycle lengths used are shown in Table 3. Both the 18.3 m (60 ft) and the 12.2 m (40 ft) spacing were determined to be adequate for bicyclists' comfort and constructability [13].

The intermittent rumble strips were found to still be effective in alerting drivers who inadvertently left the travelway. Using a 3 degree angle of departure, which is a typical angle for a run-off-road accident, it would be impossible for a 200 mm (8 in) or 300 mm (12 in) rumble strip with a 3.7 m (12 ft) gap to be missed. If the width of the tire is considered, then a rumble strip as narrow as 125 mm (5 in) could still be used without being missed by a motor vehicle.

Table 3. Cycle Length for Intermittent Shoulder Rumble Strips

Cycle Length	Length	Gap Length	Percent Coverage of Shoulder	Gap Frequency[a]
18.3 m (60 ft)	14.6 m (48 ft)	3.7 m (12 ft)	80 percent	2.7 secs
12.2 m (40 ft)	8.5 m (28 ft)	3.7 m (12 ft)	70 percent	1.8 secs

[a] Assuming a bicycle speed of 24 km/h (15 mph)

Table 4. Minimum Shoulder Width and Offset Requirements

State	Offset from Travel Way		Minimum Shoulder Width	
	Right	Median	Right	Median
	Meters (in)	Meters (in)	Meters (ft)	Meters (ft)
New Jersey	0.10 (4)	0.10 (4)	2.44 (8.0)	1.52 (5.0)
Connecticut	0.31 (12)	0.15 (6)	0.92 (3.0)	0.92 (3.0)
Maine	0.10 (4)	0.10 (4)	3.06 (10.0)	1.22 (4.0)
Massachusetts	0.25 (10)	0.10 (4)	1.50 (5.0)	1.50 (5.0)
New Hampshire	0.76 (30)	0.76 (30)	1.83 (6.0)	1.83 (6.0)
New York (DOT)	0.25 (10)	0.10 (4)	1.22 (4.0)	0.92 (3.0)
New York (Thruway Authority)	0.41 (16)	0.31 (12)	None	None

Source: Perrillo[6]

TRAVELWAY OFFSET

Rumble strip placement varies from State to State. Perrillo [6] provides a review of six State policies with regard to the distance between the shoulder rumble strip and the edge of traveled way. The placement of the shoulder width was found to be dependent on the width of the shoulder. The minimum shoulder width and offset requirements for the six states surveyed are provided in Table 4

Of the states surveyed, New Jersey and Maine place the shoulder rumble strip the closest to the travel way at an offset from the travel way of 0.10 m (4 in). Maine, however, has a larger minimum shoulder width of 3.06 m (10 ft) for the right shoulder than New Jersey which has a minimum right shoulder width of 2.44 m (8 ft). Large shoulder widths provide time for an errant vehicle to recovery within the shoulder area. New Hampshire has the highest offset of the shoulder rumble strip from the travel way of 76 mm (3 ft) for a shoulder width of 1.83 mm (6 ft) or wider. For shoulders less than 1.83 m (6 ft), an offset of 153 mm (6 ft) is used. The placement of the shoulder rumble strip further from the travel way has been found to minimize the number of vehicles inadvertently hitting the rumble strip and thereby creating less noise. Also, this placement decreases the wear on the rumble strip caused by plows.

The FHWA study found that most states placed shoulder rumble strips near the edge line, but some states placed the strips near the edge of the shoulder[5]. When placed near the edge line, the rumble strip is offset from the travel lane by a distance of between 100 mm (4 in) to 300 mm (12 in). This distance was based on several considerations including: (1) it keeps the rumble strip away from the construction joint between the travel lane and the shoulder; (2) it helps reduce the number of inadvertent

hits from passing vehicles; (3) it allows for a substantial width of the paved shoulder to remain available for other users of the shoulder. This placement of the rumble strip was also determined to provide the largest recovery area for an errant vehicle and placed a warning device between errant vehicles and pedestrians or bicycles in the shoulder. The disadvantage of this approach, however, is that it may force the bicyclist to either ride in the travel lane or on the right side of the shoulder, which may contain debris.

Some states were found to offset the rumble strip an even greater distance from the travel lane by as much as 770 mm (30 in) from the travel lane. This offset, which was primary used in locations with wide shoulders, allowed maintenance vehicles and work zone vehicles to straddle the rumble strip when using the shoulder. The offset also allowed bicyclists to use the entire area between the travel lane and the shoulder. The disadvantage of this offset is that it reduces the amount of recovery area available for errant vehicles and may reduce the effectiveness of the rumble strip.

Table 5 summarizes the contrasting views of the placement of shoulder rumble strips and its advantages and disadvantages from the motorists' and bicyclists' perspective.

Table 5. Views on Shoulder Rumble Strip Placement

Perspectives	SRS Placement	
	Near Edgeline	**Near Edge of Shoulder**
Motor Vehicle Safety Advocates	1. Large recovery zone 2. Earliest warning for errant drivers	1. Eliminates the recovery zone 2.Diminished early warning for drivers
Bicyclists	1. Forces bicyclists to cross over the SRS 2. Places warning device between cars and bicycles	1. Allows bicycles to cross freely into travel way 2. Placing bicycle in sweep zone 3. Places bicycle closer to vehicles

Source: FHWA[(2)]

PLACEMENT CONSIDERATIONS

The placement of a rumble strip in the shoulder of a roadway is dependent on several factors. These factors include whether the location is rural or urban; the functional classification of the roadway**;** roadway geometry; width of the shoulder; noise level; and pavement condition. The following provides a discussion of these factors.

Area Type

The placement of shoulder rumble strips is a function of whether is roadway is located in rural, suburban or urban areas. Earlier installation practices of shoulder rumble strips have been to place shoulder rumble strips mainly in rural areas. Due to the higher speed limits on the rural roadways and relatively monotonous drives, drivers in these locations tend to grow inattentive and sleepy which ultimately leads to run-off-road accidents.

The State of Nebraska limits the use of shoulder rumble strips to rural roadways only. Washington, Utah, Maine and Oregon recommend the use of shoulder rumble strips at all rural highways and rural sections of the interstate roadways. Wyoming and Arizona install rumble strips on all rural locations subject to some minimum shoulder width requirement. Arizona has a policy of installing shoulder rumble strips on undivided and divided rural roadways subject to minimum shoulder width requirements. The New York State Throughway installs shoulder rumble strips on all rural full access control highways. All rural highways in New Mexico get rumble strips when they are improved, except for smaller projects, projects in mountainous terrain with many curves, or if shoulders are less than 2.4 meter (8 ft) wide.

Many of the current State practices have extended the installation of shoulder rumble strips to urban locations. Montana has a policy of installing shoulder rumble strips in urban locations subject to certain conditions. New York State Throughway allows the installation in all suburban/urban full access roadways. Neither Arizona nor Wyoming install rumble strips on roadways in urban areas. Some states install shoulder rumble strips on all the rural and urban areas of interstate roadways. Nebraska, Alabama, Massachusetts, Michigan, Montana, North Dakota, South Dakota, Tennessee and Virginia have a policy to install shoulder rumble strips on all interstate roadways.

Pavement Condition

The placement of shoulder rumble strips is also dependent on the condition of the pavement. Some states have a policy to install rumble strips only on new constructions or at the time of pavement reconstruction or resurfacing, whereas, some States have installed them on existing shoulders depending on the condition of the

pavement. Installation of milled rumble strips on older shoulder pavements with previous degradation and cracking, was shown to result in the rumble strip island being more likely to wear away more rapidly. The installation of rolled rumble strips was also shown to leave a pavement with higher air voids, which has the effect of leading the pavement to premature pavement degradation. Therefore, in New York, it was recommended that rolled rumble strips be installed on new or reconstructed pavements only. The types of specifications for installation differed by whether concrete or asphalt pavement was used. In New York, milled rumble strips were applied to previously deteriorated pavement and the rumble strips were noted to be in good condition, producing loud noises and strong vibrations. The pavement thickness should be thick enough to provide depth to mill out the rumble strips [(6)].

Colorado follows a policy to roll rumble strips into all bituminous overlays. Washington installs rumble strips only on those sections of the Interstate where shoulders are in good shape and will not be replaced or overlaid in the near future. Delaware recommends use of shoulder rumble strips where paved shoulders exist but no resurfacing is planned.

Georgia installs continuous shoulder rumble strips on all paved shoulders that are at least 1.2 meters (4 ft) wide. Cook County in Illinois has used continuous shoulder rumble strips for over 20 years on all resurfacing projects. In Kentucky, shoulder rumble strips have been added to resurfacing, rehabilitation, and new construction on all roads with wide and narrow paved shoulders since 1988. Arizona has a policy to install rumble strips on projects that involve new roadway construction, reconstruction, widening, and pavement preservation. The current practice in Connecticut is to install shoulder rumble strips on sections of freeways that have been resurfaced within the past 5 years and which satisfy the minimum shoulder width criteria. Tennessee South Dakota and Pennsylvania have a policy to install shoulder rumble strips on highway projects only when shoulder resurfacing or reconstruction is included as part of the project. Installation of shoulder rumble strips is a part of the all pavement constructions in Wyoming. Colorado installs rumble strips on all new highway constructions in Portland cement concrete.

Some states have a policy to install the shoulder rumble strips only if a particular pavement thickness is available and subject to some minimum shoulder width. Pavement surfaces less than one inch in depth has been found to cause de-bonding (New York State Department of Transportation, 1997). All roads in Missouri with PCC shoulders or bituminous lift at least 45 mm (1.75 inches) thick and at least 1.2 meters (4 ft) wide get continuous shoulder rumble strips as long as the shoulder is not expected to become a travel lane. All rehabilitation and overlay projects require rumble strips if the shoulder is 1.2 meter (4 ft) or wider in Nevada[(11)]. According to New York State policies, rumble strips should be installed on shoulders in a reasonable good condition and having a minimum thickness of 2 ½” (60 mm) of asphalt shoulders [(6)].

In colder regions, it has been found that the rumble strips too close to the travel lane pose a problem of snowplowing on the travel lanes. Also, in order to prevent the erosion of roadside embankment near the rumble strip area, the strips are not extended to the outside of the shoulder [3]. Illinois has experienced the problem of the shoulder rumble strips getting damaged at the time of snow plowing. Vermont does not use rumble strips at all due to severe weather conditions.

Bicycle Volumes

Inattentive driving of motorists is one of the primary causes for run-off-road accidents. These accidents pose a threat to the safety of the bicyclists using the shoulders of these roadways. This is the reason behind installation of shoulder rumble strips mainly on the right side of the shoulder, in spite of it being narrow as compared the left-hand side shoulder. On one hand, installation of shoulder rumble strips is a safety measure for the bicyclists against run-off-road accidents, while on the other hand, bicyclist community considers it unsafe to ride rumble strips as it is said to cause a loss of control. As a result, bicycle volume and safety of the bicyclist is a primary consideration for installation of shoulder rumble strips in some of the States. Several studies have been done to arrive at the width of the shoulder that should be adequate for the bicyclists to ride safely on the shoulders without the threat of the motorists.

In some states, the rumble strip pattern used is affected by bicycle volumes. Ohio and Arizona provide intermittent rumble strip patterns instead of continuous strips where heavy bicycle volumes are present. In California, continuous shoulder rumble strips are not used where bicyclists use the shoulder unless a minimum shoulder width requirement is met[11]. Arizona, Alabama, Florida, Washington, Wyoming, California, Colorado, Delaware, Hawaii, Iowa, Kentucky, New York, and Pennsylvania follows some minimum shoulder width requirement for placing rumble strips on shoulders where bicyclists are allowed.

In order to ensure bicyclists' safety, some of the states do not allow bicyclists on certain roadways. Alabama and Maine do not allow bicyclists on its interstate roadways. Connecticut does not allow bicyclists on any of the roadways where rumble strips are installed. Montana does not provide rumble strips on shoulders if there some amount of bicycle usage. However, the State does consider installation if the bicycle usage is little but the risk of run-off-road accidents is high.

Some states use rumble strips as a buffer between the travel lanes and the bicycle route. North Dakota, South Dakota and Maine attempt to position the rumble strips to allow bicycles to stay out of the traffic lanes where possible. South Dakota use

rumble strips to provide a separation between the bicycles and vehicles only on asphalt. It does not provide a provision for bicyclists on highways with other surface types.

Roadway Volume

Roadway volume and the proportion of heavy vehicles in the traffic are also considered as factors to justify the placement of shoulder rumble strips on roadways used by bicycles. New Jersey has guidelines on pavement width to accommodate bicycles. These guidelines may also be used in determining where shoulder rumble strip and bicycle interactions should be considered. New Jersey recommends roadways with very low volumes, having an average annual daily traffic (AADT) between 1,200 and 2,000, as roadways that are compatible for bicycle use. For a roadway with an AADT greater than 2000, it becomes more likely that that a vehicle overtaking a bicycle may also meet another coming vehicle on an undivided roadway. For this reason, more room on the edge of the roadway should be provided for bicyclists to ride safely [(14)].

At volumes greater than 10,000 AADT, vehicle traffic in the curb lane becomes almost continuous and bicyclists may require a separate right-of-way for comfortable riding. When the roadway volumes exceed 20,000 vehicles per days, or more than 5 percent of the traffic volume consists of trucks, New Jersey recommends that every effort should be made to provide a sufficient shoulder width for the benefit of bicyclist and to enhance the safety of motor vehicle movements.

Khan[(15)] provided an approach to estimate the expected accidents between motor vehicles on bicycles as a function of bicycle volumes and the AADT of the roadway. The expected accidents is determined by determining the probability of a motor vehicle and a bicycle occupying 0.5 km (0.3 mi) common space on the outside travel lane. According to the study, for a two-lane highway with an AADT of 8,000 or a multilane divided highway with an AADT of 16,000, if bicycle traffic per day amount to 50, the expected accident rate is 0.032/0.5 km per year.

CRASH ANALYSIS STUDIES

OVERVIEW OF CRASH ANALYSIS STUDIES

Many studies have been performed to identify the effect of shoulder rumble strips on run-off-road crashes. The results of some of these studies are summarized as follows:

1. Rumble strips, when placed in the roadway shoulder, are shown to reduce run-off-road accidents by 20 to 50 percent [3],[10],[16].

2. In Washington State where shoulder rumble strips were installed, an overall decrease in accidents of 18 percent was observed after the rumble strips were installed [3].

3. A study of 24 shoulder rumble strip installations in 11 states showed a 19.8 percent reduction in accidents compared to a 9.3 percent increase at control sites[16].

4. Studies performed on the installation of shoulder rumble strips on the Pennsylvania Turnpike, showed a 70 percent reduction in run-off-road crashes [4].

5. A study conducted by the Utah Department of Transportation showed overall crash rates experienced a 33.4 percent increase on control sections, without rumble strips, compared to the sections where rumble strips were installed [4].

6. Potential adverse effects to rumble strips include the overreaction of motorists to the warning provided by rumble strips and crash migration, or moving crashes from locations with shoulder rumble strips, to locations downstream without shoulder rumble strips [4].

DRIVER FATIGUE

In addition to the above studies on the effectiveness of rumble strips, many studies have also been performed on driver fatigue and how it should be accounted for in determining the need for installing shoulder rumble strips. An overview of fatal accidents in the U.S. showed that over 80 percent of all fatal accidents occurred on dry roads and in good weather conditions. In addition, 80 percent of rural fatal accidents took place away from junctions, and most of these on straight alignment and on level profile. These statistics suggest the likelihood of driver fatigue as a key factor contributing to the occurrence of a large number of these accidents.

A study conducted for the Maine DOT showed that 37% of the accidents were expected to occur due to driver falling asleep with most fatal sleep-related accidents were reported to occur in the daytime[11]. A review of police accident reports of sleep related accidents from 1989-1993 on one route in Maine showed that over half of the accidents occurred between 10 AM and 7 PM. The most common time was determined to be 2 and 3 PM.

Among 306 drivers responding to a survey in the same study, 29 percent had dozed off at least once while driving during the preceding twelve months. The average accident rate for these drivers was determined to be approximately once every 29,000 miles. Another study on the Maine Interstates showed that out of the 79 accidents on the Maine Interstates between 1989 and 1993, 37 percent of the accidents were caused by a driver definitely or very probably having fallen asleep.

NEW JERSEY RUN-OFF-ROAD ACCIDENT STUDY

An evaluation of run-off-road accidents in New Jersey was performed in this research to determine the locations and conditions under which these accidents occur. The objective of the study was to determine whether there is a need for shoulder rumble strips on roadways with bicycles. Accident data for the study were obtained from the State's accident database for 1997, 1998, 1999, and 2000. Single vehicle run-off-road accidents were identified by a process of first eliminating all records with more than one vehicle involved. Accidents involving a collision type with another vehicle were also eliminated. The collision types eliminated included rear-end, side-swipe, angle, head-on, left-turn and struck parked car. The final step was to then eliminate accident records where the sequence of events involved a collision with a non-fixed object.

As shown in Table 6, run-off-road crashes for the State represent about 9 percent of all motor vehicle crashes. Seventy-percent of all run-off-road crashes occur on Interstate roadways although these roadways are presently equipped with shoulder rumble strips. The next largest percentage of run-off-road crashes occurs on municipal roadways. These roadways account for 12 percent of all run-off-road crashes. To better understand the difference between run-off-road crashes and all other motor vehicle crashes, crash statistics were also gather for all motor vehicle crashes in Essex County. For all motor vehicle crashes in this county, crashes on municipal roadways account for six percent of all crashes. The comparison shows that run-off-road crashes occur on municipal roadways at a higher rate than for all motor vehicle crashes. The comparison may imply the need for addressing run-off-road crashes on municipal roadways.

Table 6. Run-Off-Road Crashes for 1997-2000 in New Jersey

Year	Motor Vehicle Crashes[a]	Vehicle Miles Traveled (x 10^6) [a]	Motor Vehicle Accident Rate (MVM) [a]	ROR Crashes	Percent of All Crashes
1997	-	-	-	30799	-
1998	248,930	64.51	3.86	23,668	9.5
1999	263,238	65.92	3.99	20,523	7.8
2000	286,700	67.17	4.27	28,145	9.8

[a] Source: NJDOT Reference Data, 2002.

Table 7. Light Conditions for ROR Crashes

Light Conditions	ROR	All
Unknown	1.9%	6.0%
Daylight	54.5%	64.2%
Dawn or Dusk	4.3%	4.3%
Dark (Street Lights On)	29.7%	23.1%
Dark (Street Lights Off)	1.6%	1.2%
Dark (No Street Lights)	8.0%	1.2%

Light Conditions

Table 7 shows the percent of run-off-road crashes by light condition. The table also shows the percent of crashes for all motor vehicle crashes in Essex County by light condition. As the table indicates, roughly half, or 55 percent, of all run-off-road crashes occur during daylight condition. This percentage, however, is significantly lower than the percent of all motor vehicle crashes occurring under daylight conditions. The table shows that a higher proportion of run-off-road crashes occur during "Dark" conditions. Thirty-nine percent of all run-off-road accidents in the State occurred under "Dark" conditions compared to 25 percent of all motor vehicle crashes.

Weather Conditions

Weather and roadway surface condition is a contributing factor in many of the run-off-road accidents. There is a higher proportion of run-off-road crashes during rain and snow conditions than all motor vehicle crashes during these weather conditions. Twenty-eight percent of run-off-road crashes occurred during rain or snow conditions, compared to about 17 percent for all motor vehicle crashes. In these conditions, shoulder rumble strips would not be effective in eliminating or reducing run-off-road crashes.

Road Character

Almost half of run-off-road crashes occur on straight and level roadway sections. A higher percentage of all motor vehicle crashes, about 73 percent, however, occur on straight and level roadway sections. The difference suggests that more run-off-road crashes occur on roadway sections that are not straight and level. About 30 percent of all run-off-road crashes occur on curve roadway sections.

BICYCLE SAFETY ISSUES

INTRODUCTION

In 2000, there were 690 pedalcyclists killed in traffic crashes in the U.S. and 13 pedalcyclists killed in New Jersey. These fatalities represent 2 percent of all traffic fatalities. Most of these fatalities occurred in urban areas which accounts for 63 percent of fatal bicycle crashes. About 34 percent of bicycle deaths in 2000 occurred at intersections.

BICYCLE/RUMBLE STRIP IMPACTS

A 1995 survey of State DOT determined the policies for the use of bicycles on shoulders of roadways[15]. In all states surveyed, with the exception of Arizona, bicyclists were not permitted on Interstate or limited-access roadways.

Rumble strips are installed as a safety device, which alerts the motorists in case of a potential ROR crash by producing noise and vibrations. But, it has caused concern to the bicyclists. In the presence of paved shoulders riders generally avoid using the travel lanes and the outer ends of the shoulder which are generally covered with litter. As a result, the bicyclists may be forced to use the width of the shoulder containing the rumble strip. It remains a question as to whether rumble strips cause bicyclists to lose control if they are forced to travel over the rumble strip[17]. The rumble strips, however, have been known to cause bicyclists to experience some level of discomfort while riding over the rumble strips. Garder[11] carried out tests using two different configurations of milled rumble strips using different riders and several types of bicycles. He found that none of the bicyclists reported any loss of control. It was agreed that riding the rumble strips was annoying. Garder concluded that bicyclists are not faced with dangerous conditions if they mistakenly enter into a rumble strip area. Garder recommended the use of narrower rumble strips compared to the 40 cm (16 in) strip would be preferable.

Young[18] studied the effect of different bicycle speeds on the maneuverability. He found that the riders found it dangerous to ride on the rumble strips at speeds greater than 5 mph. On the contrary view, Garder and Alexander[11] found that rumble strips were essential to ensure bicyclists' safety, as they tend to alert the motorist before they infringe onto the vehicle part of the shoulder. If the shoulder is not well maintained and bicyclists cannot ride on the shoulder for long distances, then most bicyclists will choose to travel in the travel way rather than ride on the rumble strip. When the rumble strip is put into the only usable 60 cm (2 ft) of shoulder, the rider will move to the left of the rumble strip which will represent a dangerous situation. However, if the usable shoulder is 90 cm (3 ft) or more, and a 40 cm (16 in) rumble strip is used, the remaining 50 cm (20 in) is adequate for bicyclists as long as this area is free of debris. Garder

recommends that a narrower rumble strip than the 40 cm (16 in) rumble strip would be a preferable design. Also, rolled-in rumble strips do not create problems for bicyclists since they are much shallower than the milled-in types tested in this study.

The most comprehensive study, which also included two-lane roadways, was conducted on 24 sites of 11 states concluded that rumble strips can be used for creating a buffer separating bicycles from other traffic[16]. In some later studies which included telephone information from Cook County, Illinois, as well as discussions with expert cyclists suggest that shoulder rumble strips are a conflict to bicycling [3].

Garder found that paved shoulders, although effective for reducing ROR, head-on, and sideswipe crashes, did not necessarily make pavements any safer for the bicyclists. The study indicated a separating device such as shoulder rumble strip is necessary if bicycles were permitted on Interstates. The study also suggested that further research was required to find an effective narrow design of strips that infringes less than 18 inches into the “bicyclists” area and still remain efficient in alarming a dozing motorist.

NCHRP Report 254, *Shoulder Geometrics and Use Guidelines*[19] states that if bicycling is allowed on the shoulder, the “bike lane” should be a minimum of 4 feet wide, separated from the remainder of the roadway by a 2 feet buffer. The report recommends the select use of shoulder rumble strips at locations with high run-off-road crashes.

BICYCLE FRIENDLY RUMBLE STRIP DESIGNS

Penn State Study

A study was conducted by Pennsylvania State University to develop new rumble strip configurations that could both alert motorists and be comfortably traversed by bicyclists [4]. In designing the "bicycle-friendly" rumble strip, a simulation model was developed to simulate the interactions between a bicycle, its rider and the pavement surface. The simulation model used a commercial software package Dynamic Analysis and Design System (DADS) to determine the vertical acceleration and pitch angular acceleration of the bicycle and riding system as a bicycle was ridden over a rumble strip of a particular configuration. The depth of groove was fixed at 0.5 inches (13 mm) as a depth less than 0.25 inches (6 mm) was believed to not generate enough noise and vibration to alert an inattentive/drowsy motorist.

A total of 26 configurations were simulated, varying the width and spacing of the grooves. The width of the grooves varied from 4 to 8 inches (102 to 203 mm), and the spacing between the grooves was varied from 2 to 9 inches (51 to 229 mm). The root-mean-square (RMS) of the bicycle vertical acceleration and pitch angular acceleration, which measures the vibration of the rider/bicycle system, was then determined for the 26 configurations. The simulation showed that the groove width impacted the dynamics of the bicycle/rider system more significantly than groove spacing. Therefore, configurations with narrower grooves were identified as being more bicycle-friendly.

The configurations identified as bicycle-friendly designs were then installed and tested. The configurations were limited to designs that could be installed with the machinery available and also based on recommendations from a reviewing task force. Table 8 shows the rumble strip configurations that were installed and tested.

Table 8. PTI Tested Rumble Strip Configurations

Test Pattern	Groove Width Inches/(mm)	Flat Portion between Cuts Inches/(mm)	Depth Inches/(mm)
1	7 in (178 mm)	5 in (127 mm)	0.5 in (13 mm)
2	5 in (127 mm)	7 in (178 mm)	0.5 in (13 mm)
3	5 in (127 mm)	7 in (178 mm)	0.375 in (10 mm)
4	5 in (127 mm)	6 in (152 mm)	0.5 in (13 mm)
5	5 in (127 mm)	6 in (152 mm)	0.375 in (10 mm)
6	5 in (127 mm)	7 in (178 mm)	0.25 in (6.3 mm)

Testing of the configurations involved collecting vibration and perception data from volunteer participants bicycling over the various rumble strip configurations. Four types of bicycles ranging in type and sizes were used, low to high speeds were tested, three approach angles, and both intermediate and advanced bicyclists were used. Both objective and subjective measures of comfort and control were also measured in the test. Objective measures included vertical and pitch angular acceleration. In addition, test subjects were asked to ride along an 8 inch (203 mm) white line with and without the rumble strip. The amount of time the test subject spent off the while line was recorded and compared with and without this rumble strip. This provided another objective measure of controllability. Subjective measures of comfort and control were also determined by ratings provided by the test subjects on the comfort level of different body parts and control while traversing the rumble strip configurations. From the bicyclist's perspective, the test patterns were ranked from the highest to the lowest as test pattern 6, 3, 2, 5, 4, and 1.

A second component of the testing involved gathering vibration and noise data from a motor vehicle traversing the rumble strip configurations. Data were gathered for speeds of 45 and 55 mph (72 and 88 km/h) and a departure angle of approximately 3 to

5°. The rumble strip test patterns with the greatest noise at 45 mph, and therefore the most effectiveness, was test pattern 4, followed by test pattern 2, which is the current PennDOT rumble strip configuration. Test pattern 6, which was ranked by bicyclists as the best configuration, had the lowest noise level. At 55 mph, the test pattern with the greatest noise level was test pattern 1.

The study concludes that although test pattern 6 was ranked by bicyclists as the best rumble strip configuration, the low level of noise generated from the rumble strip made this configuration unacceptable. Test pattern 3, which was ranked second most "bicycle-friendly" configuration by bicyclists and ranked second in terms of greatest noise, this pattern was recommended for implementation along non-freeway facilities with higher operating speeds. Test pattern 5, which was ranked fourth for most "bicycle-friendly" configuration by bicyclists and ranked third in terms of greatest noise was recommended for non-freeway facilities with lower operating speeds.

Colorado Study

Colorado Department of Transportation conducted a similar study to the Penn State to design a shoulder rumble strip that is less disruptive to bicyclists than the standard rumble strip, but still providing a safety factor to help prevent accidents caused by motorists running off the road [20]. The study compared three types of rumble strips: (1) Colorado's standard asphalt rumble strip; (2) Colorado's standard concrete rolled-in rumble strip; and (3) a new 2 inch (5 mm) groove rumble strip ground into asphalt. The standard type rumble strip used in Colorado are 12 inches (30 mm) wide, with grooves 3/8 inch (1 mm) deep, 5 inches across, a 7-inch flat between grooves ground on 12-inch centers. Strips were placed with a 12-foot gap every 60 feet. For the study, five different depths of the standard rumble strip were ground with grooves 3/4, 1/2, 3/8, 1/4 and 1/8 inches deep. The standard concrete rolled-in rumble strip is 18 inches wide, with grooves 1/2 to 1 inch deep. 2-3/8 inches across, and 1-5/8 inch flat between grooves. These rumble strips are to be continuous.

A two-inch groove rumble strip with roughly rectangular cross-section was also tested in the study. The rumble strip is 12 inches wide with grooves two inches wide and 1/2 inch deep. Bicycle tires in this configuration do not drop down into the groove when a bicycle crosses it, therefore creating less vertical movement for the bicyclists. Seven types of this design were tested with different spacing: twelve inches on center, seven inches on center, and five inches on center. Both continuous and interrupted patterns were tested, where the interrupted pattern had twelve feet of rumble strip followed by a six-foot gap.

Testing of the rumble strip configurations was done similar to the Penn State study using both bicyclist's ratings of comfort and controllability, as well as motor vehicle

measurements of sound and vibration. Twenty-nine bicyclists, most members of the bicycle club Bicycle Colorado, tested the comfort and controllability of the rumble strips. Fifteen of the bicyclists rated themselves as very experienced, twelve as intermediate, and two as inexperienced. Bicyclists were asked to ride directly on the rumble strips and each rider rated the controllability and comfort of the section. Measurements of vibrations were also taken to provide an objective rating of the rumble strip configurations. Noise and vibration was also measures from the interior of four motor vehicles while they traveled on the rumble strip sections. The vehicles traveled at 55 and 65 mph and the types of vehicles included a: (1) 1994 Oldsmobile Cutlass station wagon; (2) 1999 Dodge full-sized pickup truck; (3) 2000 GMC minivan; and (4) unloaded tandem axle dump truck.

Like the Penn State study, the test showed that the motor vehicle test rankings were almost opposite to the bicyclist's rankings. The study recommended the use of a standard style rumble strip with grooves ground to a depth of 3/8 inch (± 1/8 inch) on 12-inch centers in a gap pattern of 48 feet of rumble strip followed by 12 feet of gap.

STATE BICYCLE POLICIES

The above studies has lead to the development of several policies by Departments of Transportation and highway agencies, on where shoulder rumble strips should be used so as to not impact bicyclists. In general, the guidelines do not recommend the use of rumble strips on routes where bicyclists are permitted, while other guidelines have suggested remedial measures to reduce the adverse effect of rumble strips on the bicyclists. These remedial measures include[3]:

- Installing shoulder rumble strips as close to the pavement edge as the specifications can allow;
- Designing narrower rumble strips in order to provide the bicyclists adequate space to ride; and
- Installing rumble strips only on shoulders wide enough to provide sufficient space for the bicyclists to ride.

Garder[11] survey states to identify the policies used for using shoulder rumble strips on roadways other than limited access highways. Of the thirty-five (35) states surveyed, only fifteen (15) had policies for the use of shoulder rumble strips on roads other than limited access highways. The following summarizes the policies of these states:

- Arizona – Used on shoulders of rural undivided and divided roadways with a pavement width including shoulder exceeds 10.4 m (34 ft).

- California – Shoulder rumble strips are not used where bicyclists use the shoulder unless there is a 1.5 m (5ft) clear shoulder on outer edge.

- Colorado – Roll rumble strips used in all bituminous overlays as well as in new construction of all Portland cement concrete highways.

- Georgia – Shoulder rumble strips used on all paved shoulders that are at least 1.2 m (4ft) wide.

- Idaho – Considered on primary highways with a history of run-off-road accidents.

- Cook County, Illinois – Used on all resurfacing projects. Noise pollution and opposition from bicyclists have slowed the continued use of rumble strips.

- Kansas – Used on two-lane roadway where shoulders are wider than 1.8 m (6 ft).

- Kentucky – Used on resurfacing, rehabilitation, and new construction projects with wide paved shoulders.

- Missouri – Used on all roadways with Portland concrete cement shoulders or bituminous lift of at least 45 mm (1.75 in) thick and at least 1.2 m (4 ft) wide.

- Nevada – Used on all rehabilitation and overlay projects where the shoulder is 1.2 m (4 ft) or wide more.

- New Mexico – Used on all rural highway projects except for smaller projects, projects in mountainous terrain with many curves, or is shoulders are less than 2.4 m (8 ft) wide or used by many bicyclists.

- Pennsylvania – Shoulder rumble strips are used on roadways where there are many run-off-road accidents and the shoulder is at least 2.4 m (8 ft) wide.

- Utah – Used on roadways with safety problems or design speed more than 50 mph and at least 1.2 m (4 ft) shoulders.

- West Virginia – Shoulder rumble strips used on all US and State routes with bituminous pavement if the shoulders are at least 2.4 m (8 ft) wide.

STATE RUMBLE STRIP SURVEY AND DESIGN

INTRODUCTION

Several surveys have been performed to determine the design and placement guidelines of rumble strips by various agencies. Surveys have been performed by the Minnesota Department of Transportation, FHWA, Ohio Department of Transportation, and Harwood[3]. In this research, a survey was also conducted of State Departments of Transportation to obtain information on current design practices and bicycle policies related to the placement of shoulder rumble strips. The following provides a summary of these surveys including a discussion of each State's shoulder rumble strip design.

RUMBLE STRIP SURVEYS

Project Survey

A survey of State Departments of Transportation was conducted in this research to determine current design practices and bicycle policies related to the placement of shoulder rumble strips. The survey was administered through email, with follow-up telephone calls made to agencies not responding to the email messages. Responses were received from 40 States. A total of seven questions were asked including the following:

- What types of shoulder rumble strips does your State use?
- What are the specifications for these rumble strips?
- What is your state's policy on the placement of shoulder rumble strips?
- On what types of roadways and shoulders are they used?
- What is the offset of the rumble strip from the travel lane?
- What guidelines does your State follow to mitigate the impact of shoulder rumble strips on bicyclists?
- Are special designs of the shoulder rumble strip used?

The results obtained from this survey, along with results from previous surveys, are summarized in Appendix I. Some general conclusions were drawn from the State policies regarding the design and installation of the rumble strips[1]. Various State departments of Transportation suggest that northern states, where snow removal causes maintenance problems prefer the use of grooved-rumble-strips instead of raised strips. In all other states, raised strips are preferred only for temporary installations as they are easier to place and remove. Straight edge grooves are more common than tapered-edge grooves. Tapered-edge strips are more expensive and are not found to make any significant difference in effectiveness. Generally, a rumble strip of 4 inches width and ½ inches depth is suitable for installation. Three to four pads of rumble strips seem to have significant effect as opposed to five or more pads. Rumble strips are

found to have a positive impact in percentage reduction of vehicles over a speed of 55 mph. They are also effective in reducing mean speeds by approximately 3 mph. The first grooved-rumble-strip is known to have a significant impact on mean speed as compared to subsequent strips.

Other Surveys

Minnesota Department of Transportation Survey

The Minnesota Department of Transportation conducted a survey in February 2000, on the use of continuous milled shoulder rumble strips[2]. In the survey, six questions were asked about their use, including where the strips are used, restrictions on where the strips were used, experience with the bicycling community, and the design of the strips used. From the thirty-nine responses were received, 70 percent of the agencies used milled shoulder rumble strips. Fifty-four percent of respondents restrict the placement of rumble strips based on shoulder width and thirty-six percent restrict rumble strips based on bicycle history.

FHWA Surveys

Two surveys were conducted by FHWA in the Spring of 2000 and in September 2000 to identify proposed shoulder rumble strip research/effectiveness studies and to complete a synthesis on practices and policies of shoulder rumble strips. In the first survey, 21 responses were received from either FHWA Division offices or State Departments of Transportation on research/evaluation studies that were either completed, on-going or proposed. In the second survey, forty-two responses were received on issues related to bicyclists' rights to travel on Interstates, controlled access highways, and non-access controlled roadways. The survey found that bicycle travel on rural Interstates is primarily allowed in Western States. The respondents were also asked to provide information on the policy and standards used by the State in their design and placement of shoulder rumble strips.

Ohio Department of Transportation Survey

In 1993, the Ohio Department of Transportation surveyed State DOTs to obtain information on their design, placement, and effectiveness of rumble strips [1]. A total of forty-one State DOTs and the District of Columbia responded to the questionnaire. Responses to the questionnaire showed that most states have general guidelines for installation of rumble strips and most use both grooved and raised rumble strips. Raised rumble strips were primarily used for temporary installations, such as at work zone areas. To better accommodate bicycle and motorcycle traffic, a few states used 38 to 46 mm (15 to 18 in) offsets.

NCHRP Survey

Harwood[3] conducted a survey of State and local highway agencies and toll road authorities to gather information on shoulder rumble strip design and practices. A total of 123 responses were received. The survey found that 98 percent of State highway agencies, 24 percent of local agencies, and 87 percent of toll roads used rumble strips, both shoulder rumble strips and other rumble strip applications. Of the highway agencies using shoulder rumble strips, 16 percent used strips on Portland cement concrete shoulders only, 33 percent on asphalt concrete shoulders only, and 51 percent on both types of shoulders. A majority of the agencies responded did not use shoulder rumble strips on low-speed urban roadways. Seventy-six percent of agencies using shoulder rumble strips used them on freeways or other highways with full access control, 39 percent on multilane divided non-freeways, 35 percent on two-lane highways, 22 percent on multilane undivided non-freeways, and 2 percent on urban streets.

CONCLUSIONS AND RECOMMENDATIONS

INTRODUCTION

In December, 2001, FHWA issued a technical advisory for use in the design and installation of shoulder rumble strips [2]. The advisory is intended to provide guidelines for use of shoulder rumble strips on appropriate rural segments of the National Highway System (NHS). The following provides a description of the recommendations for the design and placement of shoulder rumble strips, and the warrants that should be considered in installing the strips.

DESIGN AND PLACEMENT RECOMMENDATIONS

The advisory recommends the use of continuous, milled shoulder rumble strip on rural freeways and expressways on the National Highway System. When used on roadways with a 3 m (10 ft) shoulder, the strip should be installed as close to the edge line as possible, leaving at least 2.4 m (8 ft) of clear shoulder width remaining available after installation.

If an engineering study or crash analysis indicates that the number of crashes would be reduced by installing shoulder rumble strips, then shoulder rumble strips can also be used on non-freeway facilities, such as rural multilane and two-lane roadways. Additional countermeasures may be implemented instead of or in addition to shoulder rumble strips. These countermeasures may include improved roadway geometry, additional signing and markings, or increased pavement skid resistance.

FHWA also recommends that shoulder rumble strips be coupled with continuing driver behavior safety programs to educate the driving public on the dangers of drowsy and inattentive driving and to alert bicyclists on the increased use of shoulder rumble strips. Cooperation should be sought between agencies and bicycle group in the development of policies, standards and implementation techniques.

FHWA INSTALLATION WARRANTS

FHWA provides guidelines that should be considered when installing shoulder rumble strips. The guidelines are based on the review of policies and practices of shoulder rumble strips for 41 jurisdictions in the United States.

Shoulder Width

The width of the shoulder should be considered in determining whether a shoulder rumble strip should be included on a roadway. The suggested minimum shoulder width before installation should range from 610 mm (2 ft) to 2438 mm (8 ft).

Crash Experience

One of the primary warrants for shoulder rumble strips is crash experience at the location. Although many of the policies reviewed in the FHWA study mentioned installing shoulder rumble strips at high run-off-road crash locations, only one State provided a threshold of what that crash experience should be to warrant a shoulder rumble strip. Ohio uses a threshold of 0.25 crashes per million vehicle-miles traveled in determining whether a location has a high run-off-road crash experience.

Length of Roadway

Shoulder rumble strips are intended for installation at longer roadway segments with infrequent interruption. The State of Oklahoma has as one of its criteria for the placement of shoulder rumble strips that the minimum length of uninterrupted roadway needed is determined as follows:

$$L = \frac{1}{30} V_D$$

where: L = uninterrupted roadway length (miles); and
V_D = design speed (mph).

Bicycle Volumes

Many agencies use the volume of bicycles on a roadway in determining whether a shoulder rumble strip is appropriate for the roadway. No State, however, provided threshold bicycle volumes above a shoulder rumble strip would not be appropriate.

Speed Limit

As many States only implement shoulder rumble strips on freeway roadways, the minimum speed limit recommended for the installation of shoulder rumble strip is 50 mph. This speed limit, however, does not appear to be based on accident or severity data, but on where shoulder rumble strips are currently being implemented.

Roadway Access

Shoulder rumble strips are recommended on fully controlled roadways or roads where bicycles are prohibited.

Roadway Location

Shoulder rumble strips are not recommended in urban or suburban areas. In an FHWA study, many states were found to only install shoulder rumble strips on rural roadways.

BICYCLE CONSIDERATIONS

The FHWA has supported the American Association of State Highway and Transportation Officials (AASHTO) guidelines for the development of bicycle facilities. Those guidelines state that rumble strips or raised pavement markers are not recommended where shoulders are used by bicyclists unless there is a minimum clear path of 0.3m (1 foot) from the rumble strip to the traveled way, 1.2m (4 feet) from the rumble strip to the outside edge of paved shoulder, or 1.5m (5 feet) to adjacent guardrail, curb or other obstacle.

Rumble strips should only be installed when an adequate unobstructed width of pavement remains available for travel by bicyclists. To aid a bicyclists movement to the left of a shoulder rumble strip when needed to avoid debris, make turns or avoid other shoulder users, some states provide periodic gaps of 3.0m (10 ft) to 3.2m (12 ft) between groups of the milled-in elements throughout the length of the shoulder rumble strip. A study by one State recommends a gap of 3.2m (12 ft) between milled-in elements of 12.2m (40 ft) to 18.3m (60 ft) in length. Other states have specified 3.0m (10 ft) gaps between 3.0m (10 ft) milled-in elements.

To aid the travel of bicyclists, the agency responsible for maintaining the roadway should periodically sweep shoulders along major bicycle routes and other routes of high bicycle usage, so the bicyclists will have a clear area beyond the rumble strip in which to ride.

Research has recently been concluded in California and Colorado in an attempt to identify a more bicycle-tolerable rumble strip. Both studies concluded that the reduced-depth, milled rumble strips is the most reasonable compromise between maximum warning to errant motorists and tolerable discomfort to cyclists.

Strategies for Accommodating Bicycles and Shoulder Rumble Strips

Based on this study the follow strategies have been identified as holding potential for accommodating bicycles and rumble strips:

1. Minimum shoulder width to accommodate rumble strips. Do not use rumble strips if the shoulder width is less than 8 feet.

2. Widen the shoulder to provide at least a 4 foot continuous riding surface (Florida).

3. Provide an offset of 1.2 m (4 feet) from edge of shoulder for bicycles and motorcycles (Hawaii).

4. Moving the rumble strip as close to the travel lane as possible (Minnesota)

5. Use of continuous rumble strips only on limited access facilities.

6. Use periodic gaps in the rumble strip on non-controlled access highways. Gaps of 12 in every 40 to 60 inches of rumble strips used in Arizona. Use of skip pattern on multilane rural highways with a speed limit greater than 50 mph (Georgia).

7. Not allowing bicycles on roadways where shoulder rumble strips are installed. (Connecticut)

8. Not allowing rumble strips on roadways used by bicyclists. (Maine)

9. Reducing the width of the rumble strip from 2 feet to 1 feet (Kentucky).

10. Requiring approval of the Pedestrian/Bicycle Coordinator if rumble strip is to be installed on a shoulder width less than 8 feet.

APPENDIX I. State Shoulder Rumble Strip Designs

Alabama

Alabama DOT uses raised rumble strips at 2-way and 4-way stop, signalized intersections, horizontal and vertical curves. Grooved strips are used on shoulders of Interstate highways. The height and the width of the raised strips are 2mm (5/6") and 20mm (8") respectively. The number of pads is 4-5 with 5 strips per pad spaced at 25 mm (10") clear. Warning beacons and signs are used in conjunction with rumble strips[(1)].

The ALDOT has an unwritten policy to allow the use of scored shoulders or surface treatment on new freeways over overlays. The treatment is selected the State Division in a geographical area. Bicycles are not allowed in the Interstate roadways. The State DOT suggests that shoulder pavements should be extended wider where there is potential for bicycle usage [(2)].

The State uses indentations on the roadway shoulders, which are called "scoring of the shoulders". These indentations are used on control access and limited access freeways and on Interstate roadways and rural highways. The indentations start from the edge of the travel lane and extend 0.6 m-0.76 m (2- 2 ½ in) into the shoulders. Indentations are generally provided on roadways with shoulders 2.4 m – 3 m (8'-10') wide so bicyclists have enough shoulder space available to ride. The State does not use rumble strips on two-lane highways, since the shoulder is not wide enough and also, the speeds of motorists are low on these roadways. But for such roadways, there is an attempt to pave the shoulders. The scoring is machine cut with indentations about 30mm to 41mm (12-16 in) long. The indentations are 1.3mm (½") grooves on asphalt shoulders only on large volume and high-speed roads[(21)].

Alaska

Alaska has a limited experience of using grooved rumble strips on shoulders. The Alaska Department of Transportation (ADOT) does not have a statewide policy governing the use of rumble ships. Each ADOT region has its own policy for the location of and specifications of rumble strips. In the Northern region, the installation of rumble strips is prohibited at locations where the shoulder is less than four feet wide. The Central region requires that the shoulder be at least six feet wide before a rumble strip is used. The Southeast Region currently does not use rumble strips. One proposal for a statewide specification for rumble strips is the use of 30 mm (12 in) wide (46 mm(18 in) maximum) rumble strips, placed as close to the fog line as possible. Where the shoulder width is less than 300 mm (12 in), shoulder rumble strips should not

be installed as bicyclists would then be restricted to a usable shoulder with unacceptable width dimension [22].

Arizona

Arizona DOT recommends use of milled rumble strips, however it does not prohibit the use of other types of rumble strips. The specification consists of milled rounded grooves 13mm (0.5 in) in depth and 178mm (7 in) wide with a center to center spacing of 305mm (12 in). The dimensions perpendicular to the travel lane vary from 127 to 305mm (5 in to 12 in) which varies with the type of the roadway and the area. The offset from the edge line is 0 to 305 mm (0 in to 12 in), depending upon the type of roadway. Recent studies conducted by Arizona DOT resulted in recommendations that all non-controlled access highways include periodic gaps of 3.6m (12 in) in length, and all gaps should be placed at periodic intervals of spacing of 12.19m (40 in) or 18.29m (60 in). The policy directs the Districts to evaluate when and where shoulder rumble strips should be installed[23].

The Arizona Department of Transportation (ADOT) recommends the use of ground-in rumble strips. The main advantage of ground-in rumble strips is that they can be installed an anytime and on almost any type of pavement surface. These rumble strips are applied to projects that involve new roadway construction, reconstruction, widening, and pavement preservation. The criteria used for applying the rumble strips are a function of the location of the roadway in rural, urban or suburban locations. In rural locations, shoulder rumble strips are applied on undivided highways with shoulder widths of four feet or greater. At undivided four-lane highways and highways with narrower shoulders, the implementation of rumble strips will be on a case by case basis. On divided highways in rural locations, shoulder rumble strips will be applied on the right shoulder with a width of four feet or more and on the left shoulder with a width of two feet or more. Where narrower shoulders are founded, the implementation of shoulder rumble strips will be evaluated on a case by case basis.

Within developed urban areas, ADOT does not recommend the implementation of shoulder rumble strips. This recommendation is based on the level of noise produced by the rumble strips. Shoulder rumble strips can be considered in urban areas if there are no other reasonable alternatives and/or the rumble strips are being installed to mitigate a specific problem. In suburban areas, rumble strips are applied using the guidelines for rural locations and evaluating specific factors affecting the installation of shoulder rumble strips. The factors include: existing and future development; number and spacing of driveways of existing and future driveways; posted speed limits (where roadways with speed limits less than 45 mph should generally not include rumble strips); operating speed; future widening or shoulders designated as future traffic lanes; close spacing of traffic signals; heavy bicycle traffic,

location of tied objects and steep cross slopes; and run-off-road type/collision with fixed object accident history[23].

Arkansas

Arkansas uses both grooved and raised pavement marker rumble strips mostly on road shoulders or at hidden horizontal and vertical curves. The strips are 1 mm (3/8”) deep, 2 mm (¾”) high and 10mm (4”) wide. There are 3 pads, each of 1.5 m (5’) length with 6 strips per pad spaced at 1.8m (6”) clear. The grooves were found to be more effective than raised strips in attracting driver’s attention. The local residents also raised complaints regarding the noise created by the use of rumble strips[1].

Shoulder rumble strips are placed approximately 10mm (4") from and parallel to the lane edge line. They are 41mm (16") wide transverse to traffic, by 18mm (7") long (plus or minus 1/2") in direction of traffic, by 1.3mm to 2.0 mm (1/2" to 5/8") deep. Since bicycles are prohibited on freeways, rumble strips cause no impacts to bicyclists. Prior to commencement of the work, the specifications require that the contractor demonstrates tat the rumble strips will not damage the existing pavement[24].

Arkansas currently uses rumble strips on the inside and outside shoulders of freeways only on both asphalt and concrete shoulders. The rumble strips are installed on existing asphalt shoulders as shown on the plans or as designated by the Engineer. On Portland Cement Concrete Shoulders, there is an option of cutting or forming the rumble strips according to the design specifications.

California

California uses continuous shoulder rumble strips that are 19mm or less in height if raised or 25 mm or less in depth if indented. State DOT considers bicycle usage as a factor in considering shoulder rumble strips along State highways. The DOT suggests that where bicycles are permitted, shoulder rumble strips should not be used unless approximate width for bicycle use is available between rumble strips and the outer edge of the shoulder. Shoulder rumble strips have a maximum width of 900 mm (3 ft) and should not be permitted unless approximately 1.5 m (5 ft) of clear shoulder width for bicycle use is available between the rumble strip and the outer edge of the shoulder[25].

Colorado

Colorado permits the installation of milled, rolled or formed rumble strips on concrete shoulders and only milled strips on asphalt shoulders. The recommended dimensions of milled rumble strips are 15mm to 20mm (6” to 8”) grooved width, 30.5mm

(12”) spacing, and 13mm to 19mm (0.5” to 0.75”) depth, a width of 40.6mm (16”) which can be reduced to 30.5mm (12”) for shoulders less than 1.83m (6’) wide. Offset from the edge line is a maximum of 15.2mm (6”).

The State highway system should be evaluated to accommodate rumble strips for which, input from bicycle community should also be considered. As opposed to the installation only on shoulders at least 1.8m (6’), rumble strips may be installed on shoulders 1.2m (4’) or less wide if there is a history of ROR crashes. The typical pattern width of 30.5mm (12”) can be changed to 40.6mm (16”) to provide an additional smooth shoulder width of 10.2mm (4”) to the bicyclists [(1)].

Connecticut

Connecticut DOT recommends the use of milled rumble strips along shoulder with a finished dimensions of 18mm ± 1.2mm (7”± 0.5”) in width, 30mm ± 1.2mm (12”± 0.5”) spacing**,** 1.2mm (0.5”) depth and 41mm (16”) spacing. The offset from the edge line is approximately 15mm (6”) from left shoulder and 30mm (12”) from the right shoulder. The Connecticut DOT has made no consideration for bicyclists [(1)].

The current practice in Connecticut is to install shoulder rumble strips on sections of freeways that have been resurfaced within the past 5 years and where the shoulder width is at least 91.5mm (3’) wide. Bicycles are not allowed on the roadways where rumble strips are installed [(2)].

The State of Connecticut began installation of shoulder rumble strips in the fall of 1996 on limited-access highways. Rumble strips are placed in both the left and right shoulders. Currently, less than half of the limited-access highways in Connecticut have shoulder rumble strips. Connecticut does not have any rumble strip installation guidelines with respect to bicyclists because rumble strips are only installed on limited-access highways where bicycles are not permitted[(26)].

Delaware

DelDOT has developed a draft policy (with FHWA recommendation and assistance) on use of shoulder rumble strips which covers both new pavements and the installation of shoulder rumble strips as separate projects where paved shoulder exist but no resurfacing is planned. The policy covers both limited access highways, and has provision for considering bicycles and horse-and-buggies. The draft policy has not yet been considered by DelDOT’s policy Committee[(2)].

The State of Delaware has not done any studies regarding rumble strips. The only places where shoulder rumble strips are installed are Interstate roadways where bicyclists are not allowed. Certain county roads where intersections are notorious for accidents have transverse rumble strips only, which do not affect the bike lanes. The complaints from bicyclists about county roads are often about tar and chips and that shoulders are poorly maintained. There are no specific guidelines for any kind of rumble strips and no studies have been done by the State to determine if the rumbles strips that have been implemented have been effective[27].

Florida

Florida only uses raised types of strips using asphalt concrete method for installation. The strips are being used at 2-way, 4-way, signalized intersections, off-ramps, road shoulders and railroad crossings. The stripes used are 1.3mm (½") high and 5mm (2") wide. The stripes per pad are 6, which are spaced at 25mm (10") clear 38mm (15") clear is kept for bicyclists. Reflectorized pavement stripes replaced the raised strips, which became rounded and flattened [1].

The Florida Department of Transportation uses ground-in or milled rumble strips in two patterns: the skip array and the continuous array. The skip array is the standard pattern used on both inside and outside shoulders on divided highway sections. The continuous array is used in advance of bridge ends or at the gore recovery area for mainline interchange bridges. The width of the strip is 180mm (71") in the direction of travel, 400mm (157") length and 400 mm (157") offset from the travel lane. In the skip array pattern, 8 cuts covering an area of 2.1 m (7') is followed by a 1.5 m (5') skip (Florida, Design Geometrics and Criteria, January 1998).

The Florida Department of Transportation recommends that rumbles strips be only used on curves, approaches to narrow bridges and other locations where there is a high potential for benefit. Raised rumble strips are restricted to approaches to narrow bridges. The use of continuous rumble strips is used only on limited access facilities. For restricted areas where shoulder rumble strips are applied, the shoulder should be widened to provide at least a 1.2m (4') riding surface. The rumble strip pattern is designed to not create instability to bicyclists.

Continuous ground-in rumble strips have been suggested for use on busy two-lane roadways. This shoulder-rumble strip type was tested in Florida using a 7" x 12" by 3/8" (175 mm x 300 mm x 10 mm) ground-in rumble strips adjacent to the edge line on an existing 1.2m (4 foot) paved shoulder. Using this width of 1 foot, the space taken by the shoulder rumble strip covered only the area needed for the handle bars overhang and therefore the bicyclist's space was not infringed on. A 6 mile (10 km) test section

was installed on a two-lane highway, SR 44, that has bicycle traffic. There have been no complaints to date. The 3/8" (10 mm) depth was used because the asphalt on the shoulders is only 1" (25 mm) thick per the plans. Initial evaluations suggest these strips are safe for bicyclists [12].

The Florida Department of Transportation's use of rumble strips is limited to limited-access roadways, the approaches to narrow bridges and rural intersections. Raised rumble strips are also used on the approaches to some rural intersections. While the same issue of handling occurs at these locations, they are extremely rare and not often mentioned as a problem. Occasionally, the 46mm (18") clearance to the edge of the striped lane has not been provided. Ground-in rumble strips are used for limited access highways. As bicyclists are not allowed on freeways in Florida, bicyclist safety on freeways has not been an issue. On the approaches to bridges, raised rumble strips are used but a minimum of 46mm (18") clearance is required at the edge of the shoulder for cyclists. Cyclists have posed a resistance against this treatment as the edge of the shoulder frequently collects debris or have encroachment from vegetation. The raised rumble strips are found to be aggressive and can cause handling problems for some cyclists [12].

Georgia

Raised strips are used at 2-way and 4-way stop and signalized intersections. Grooved strips are preferred on road shoulders. The depth of the groove is a minimum of 1.3mm (½") and a maximum of 2mm (¾"). The strips are placed on 3 pads of 65.6m (20') length at a spacing of 20mm (8") c/c. Georgia uses rumble strips as the last resort and does not prefer the use of rumble strips in general [1].

Georgia currently installs rumble strips on its rural roadway shoulders 1.8m to 2.4m (6' to 8') in width. The rumble strips used are rolled strips with indentations 0.6m to 0.9m (2' to 3') in depth. The purpose of installation has primarily been to move the bicyclists from edge of the travel lane to back of shoulder. The latest recommendation include use of exclusively milled rumble strips 41mm (16") width, 18mm (7") length, 1.3mm (½") depth, spaced at 13mm (5") and placed 0mm to 8mm (0-3") from the edge of the pavement.

After a study to determine the optimum gap for the rumble strips, the pattern to be used should be skip pattern, i.e. 8.5m (28') of continuous strip with 3.6m (12') gap in between. It has been recommended that continuous strips should be used on Interstate roadways. Skip pattern is recommended for multilane rural highways with a speed limit greater than 50 mph. On two lane roadways, skip pattern should be provided on roadways with speeds greater than 50 mph, roadways with shoulder width of 1.2m (4') and an AADT greater than 400 vehicles. Skip pattern is also to be installed in the case

where the shoulder width is greater than 1.2m (4'). No rumble strip is to be provided on shoulder widths of 0.6m (2') or less. Also, a shoulder width of 2m (6.5') in lieu of 1.8m or 2.4m (6' or 8') has been recommended[28].

Hawaii

Only raised pavement markers are being used which are mostly located on off-ramps, road shoulders and for channelizing on highways. The strips are located on 3 pads of length 7.6m (25') spaced at 22.8 m (75') minimum. The strips are spaced at 3'center to center. An offset of 1.2 m (4') is maintained from edge of shoulder for bicycles and motorcycles. A sign of "Rumble Strips Ahead" is used at every installation [1].

Illinois

Raised strip are preferred, though grooved strips may also be used. Rumble strips are installed temporarily in construction areas. The pads are 7.6m (25') in length, which are placed 83.8m (275') from STOP. The grooved strips are 1m (3/16") deep and 1.2m (4') wide, whereas the raised strips are 8" wide. The problem encountered on both type of installations are that the raised strips get damaged while snow plowing and grooves on asphalt surfaces get filled up due to erosion. Residential areas in Illinois have complained against the noise produced due to rumble strips [1].

Illinois currently uses rolled in rumble strip on bituminous shoulders. The installation pattern is typically continuous, but shoulder rumble strips are also placed intermittently at some locations. For bituminous shoulders, the contractor has the option of using a continuous or intermittent pattern unless otherwise specified. Continuous patterns are specified at high-accident locations and at locations with high number of run-off-the-road accidents.

Continuous rumble strips are 2mm (¾") in depth and 6mm (2 ½") wide on 20mm (8") centers. They are placed 30mm (12") from the edge of pavement and are 91mm (36") in width. Rumble strips in concrete shoulders are placed intermittently on 18m to 30.5m (60' to 100') centers. Each set of corrugations is 1.8m (6') long with corrugations 6mm (2 ½") wide, 2.5mm (1") deep, on 11mm (4 ½") centers. Placed 30mm (12") from the edge of pavement and extending to the edge of the shoulder. For PCC shoulders, 18m (59') spacing is specified 180m (590') in advance of structures and horizontal curves that have operating speeds greater than 15 km/h less than the design speed of the highway. The State is currently reviewing the rolled in rumble strips and may go to a milled in rumble strip.

Illinois considers following policies for placement of rumble strips:

1. Provide rumble strips along all Interstate roadways and other freeways built to Interstate criteria.
2. Include rumble strips along major highways that have high-accident locations as identified in the Division of Traffic Safety's high-accident location maps and at locations with known run-off-the-road accidents.
3. Do not specify rumble strips where bicyclists are present unless it is a high-accident location.
4. Rumble strips may be provided at other locations as deemed appropriate.

Since the use of rumble strips is limited, by policy, to primarily Interstate roadways, and Illinois does not permit bicycles on Interstate roadways, there is little effect on bicyclists. Illinois does not currently use rumble strips on State marked highway except as noted in the above policy[29].

Indiana

The State uses milled shoulder corrugations on asphalt and concrete shoulders. For National State Highway (NHS) routes, except those in urban areas, milled shoulder corrugations shall be included on all shoulders greater than 1 m in width ([30]).

Iowa

Iowa DOT uses only grooved strips at 2-way, 4-way signalized intersections, off-ramps and shoulders. The number of pads per installation is 3, which are 7m (24') in length, and the distance of the last pad from the STOP sign is kept 61m (200'). The number of strips per pad are 25 which are at a spacing of 30mm (12") c/c. Depth of the grooved strips are 1 m (3/8"). A 46mm (18") left clear from edge of pavement is maintained for bicycles and motorcycles. A "Stop Ahead" sign is posted in advance of rumble strips pad. Iowa DOT does not install rumble strips in residential areas to avoid noise complaint [(1)].

Iowa has used rumble strips on some of its Interstate roadways, as a number of them do not have paved shoulders. None of the two-lane roadways have rumble strips installations since the shoulders for these roadways are not paved. The bicyclists have not been criteria for the placement of rumble strips yet, but research and surveys to coordinate the rumble strip and bicyclists issue are in progress. The type of strips mostly used is rolled in which are placed at the edge or 0.6m to 0.9m (2'-3') away from the travel lane depending on the type of the project[31].

Kansas

According to the State policy on rumble strips, shoulder rumble strips shall be used on rural highways having full width (2.4m (8') to 3.0m (10')) paved shoulders. Rumble strips may be placed on highway sections having narrow shoulders to provide continuity between locations with full-width shoulders. An engineering study may determine other locations where their use is appropriate or locations where it is not desirable to use shoulder rumble strips. Shoulder rumble strips are to be used on all reconstruction and new construction projects where full-width shoulders are to be constructed. Rumble strips are also used when full-width shoulders are overlaid with a minimum of 25mm (10") of asphalt. It has been decided to eliminate shoulder rumble strips from all asphalt projects plans to be let to construction contract. Rumble strips for concrete pavements will continue to be part of project plans, because they can be "formed-in" the fresh concrete if they replicate the configuration of the milled-in rumble strip[32].

Kentucky

Raised strips are only used as temporary installations in construction zones. Grooved strips are used as permanent installations at 2-way and 4-way stop and signalized intersections, tollbooths, off-ramps and road shoulders. The height of the raised strips is ¼" to 3/6" for approach speeds less than 45 mph and 0.9 mm to 1.3 mm (3/8" to ½") for speeds greater than 45 mph. Spacing of the raised strips is 30 mm (12") clear for speeds less than 45 mph while 61 mm (24") clear for speeds more than 45 mph. The raised strips are 20 mm (8") wide and are 10 in number per pad. The number of grooved strips per pad is 6. They are 1.3 mm (½") deep, 10 mm (4") wide and are spaced at 30 mm (12") c/c/ The Kentucky DOT uses an accident reduction factor pf 25% for rumble strips and uses warning signs in conjunction with rumble strips [1].

Kentucky suggests installation of bituminous indented rumble strips on all mainline shoulders, including both outside and median shoulders, except for flushing medians on divided highways and for two-lane roads when called for by pavement design. While Kentucky does not have a stated policy, it does provide room for bicycles in all identified bicycle routes[2].

Kentucky has a policy to install rumble strips on all the new and resurfaces roadways. A task force has been formed in order to modify the prevailing design standards to accommodate bicyclist safety issue. One of the recommendations under discussion is reducing the width of the 0.6m (2') wide rumble strips to 0.3m (1') wide strips and to use the rumble strips on all the roads. The offset of rumble strips from the roadway depends on the availability of the shoulder width. Generally, it is offset by

2.5mm (1”) from the edge line. Attempts have been made to provide 3m (10’) of paved shoulders on all new and resurfaced roads[33].

Louisiana

The State uses three types of rumble strips. The first type of shoulder rumble strip used is cast into a concrete shoulder. This type of rumble strip is installed only on new construction and is used primarily on Interstate roadway shoulders. The second type of rumble strips used is ground into an asphalt shoulder. It is applicable for new or existing construction and is primarily used on interstate shoulders and four lane divided highways. The third type is rumble strips made from raised pavement markers on a concrete shoulder. This type is applicable for new or existing construction and is primarily used on urban interstate shoulders and bridge shoulders. As vehicles use the shoulder during construction, the installation cannot be of cast in type[34].

Maine

Maine's practice is to install shoulder rumble strips on all RURAL-4R interstate projects as well as on 3R Interstate projects. Rumble strips are not installed as part of any other special programs. The State uses a 400 mm (157”) rumble strip, offset 100 mm (39”) from the edge of the travel lane. Since rumble strips are only used on rural Interstate roadways, bicycle traffic is not a consideration. MDOT allows milled rumble strips on its asphalt shoulders. Part of a MDOT sponsored research project was to look at benefit/cost ratio of the installation of rumble strips [2]. At present, Maine only installs rumble strips on the Interstate Highway System on which bicyclists are forbidden. As a result, there are no bicyclist/rumble strip conflicts in the State[35].

Maryland

The Maryland State Highway Administration (SHA) and the Maryland Transportation Authority (MDTA) typically use milled rumble strips on the shoulders of rural expressways (full-access controlled highways). Following their installation along most rural expressways on the State system as a blanket program, shoulder rumble strips are to be installed on newly constructed, reconstructed, and resurfaced shoulders along SHA highways. Rumble strips are also to be installed on other SHA highways where engineering/safety studies document their benefit. Rumble strips are not installed on any structures or on local roads.

Rumble strips are installed on both the inside and outside shoulders and are nominally 41mm (16") long (laterally) and 18mm (7") wide (longitudinally). Placed 30mm (12") on center, rumble strips have 30mm (12”) radii and are about one-half inch deep. They may be placed up to 30mm (12") off the roadway. For the most part, shoulder

rumble strips have been installed on highways where bicycle travel is prohibited. However, guidelines specify that the designer must consider other shoulder uses, such as use by bicycles, in deciding on the use of rumble strips. Where bicycles are allowed, the designer must consult with the agency's bicycle coordinator. To date, no modification of the typical rumble strip design has been made in such instances[36].

Massachusetts

The State installs both raised and grooved strips on locations like on and off-ramps, road shoulders and gores on Interstate highways. The height of the raised strips and depth of the grooved strips is 1.3 mm (1/2"). The State doesn't have any other set criteria for rumble strip design. The sign "Rumble Strips Ahead" is used in advance of rumble strip locations. Grooves are cut by saw method [1].

Shoulder rumble strips are installed on all Interstate and National Highway System limited access roadways where the shoulder width is at least 610 mm (240'). These rumble strips are also installed on other roadways with a speed limit of 65 km/hr or greater with the following exceptions: in areas where the shoulder is used as a travel lane during certain hours; on bridge decks; and where the paved shoulder is less than 610 mm (240')[2].

Michigan

Grooved type strips are mostly used on interstate highways and freeway shoulders, some of the 2-way and 4-way stop intersections. Raised strips were also constructed on 2-way stop intersections on experimental basis. Michigan DOT has different specifications for different locations of installation. For intersection, the grooves of width 8.9 mm or 10 mm (3-1/2" or 4") and depth 0.9 mm to 1.3 mm (3/8" to ½") spaced at 25 mm (10") center to center. For bituminous roadway shoulders, the grooves are of width 6 mm (2-1/2"), depth 2.5 mm (1") and are spaced at 2.5 mm (1") center to center. For concrete roadway shoulders, the corrugations are of width 11 mm (4-1/2"), depth 1.3 mm (½") with the corrugated pads of 15 mm (5'-9 ¾") length. The bituminous shoulders are cut using roller method and for intersections, grooves are cut by saw [1].

The rumble strips used by Michigan DOT are machine cut ground in rumble strips. Shoulder rumble strips are used only on the limited access freeways most of the times with very few exceptions. The rumble strips being used currently are very narrow providing sufficient space for bicyclists to use the shoulder. The offset is generally 0.3m (1') from the edge of the traveled lane. Rumble strips are generally used on limited access freeways only. Corrugations shall be in bituminous and concrete shoulders paved 1.2m – 1.8m (4'-6') or wider or where the shoulder lies between the pavement and valley gutter or curb and gutter. In rare occasions where rumble strips might be

used on non-freeway applications, the width of the rumbles are only 41mm (1'-4") and would in most cases allow room for a bicyclist to operate beside them. Corrugations are not used on ramp shoulders or where shoulders are separated from pavement by curb or gutter. Corrugations are not to be placed over a transverse shoulder joint. Since rumble strips are only placed on roadways, which do not have a bicycle population, the safety issues of bicyclists are not criteria in placement[37].

Minnesota

The State uses milled rumble strips, which are placed in an intermittent pattern to accommodate bicycles. They have minimum shoulder width criteria for the placement of shoulder rumble strips and have tried to move the rumble strips as close to the travel lane as possible in order to provide sufficient shoulder width for the bicyclists. The State installs shoulder rumble strips on its rural highways and some other locations with a history of ROR accidents. Rumble strips are not installed on urban roadways. Bicyclists are not allowed on Interstate roadways and some controlled access highways[38].

Mississippi

Shoulder rumble strips are ground in 0.15m to 0.6m (½' to 2') and 3.6m (12') long on asphalt shoulders of four-lane roadways[39].

Missouri

The State uses raised strips only and the typical locations for installation are 4-way intersection, off-ramp and T-intersections. Height of the strips is 1 mm (3/8"). Each installation has 3 pads, each of length 5.8 m (19') and having a clear spacing of pads 76 m (250'). Each pad has 18 strips spaced at 18 mm (5"). Distance of the 1st and last pad from STOP sign is 317 m (1040') and 152 m (500'). A STOP Ahead sign is posted or barricades with flashing lights and warning signs are placed with rumble strips [1].

Bicycles have not been a consideration for the placement of shoulder rumble strips to date, but the State is in the process of updating its policies. The bicyclists' population is not very high in the State and bicycle paths are provided on some of the locations [2].

Montana

The Montana DOT recommends continuous corrugated pattern of 30mm to 41 mm (12" to 16") width, center spacing of 11 mm (4-1/2"), 2.5 mm (1") radius, and 2.5 mm (1") depth on new concrete shoulders. For asphalt shoulder, milled rumble strips 30

mm to 41 mm (12” to 16”) wide, 1.3 mm to 2 mm (½” to ¾”) deep are recommended. The offset from the inside shoulder edge should be 41 mm (6”). Rumble strips should be installed on shoulders 1.2 to 1.8 m (4’ to 6’) wide unless accident history or bicycle usage prohibits it. For shoulder widths less than 1.2 m (4’), rumble strips should not be provided unless there are incidents of ROR crashes and there is little or no bicycle usage [(1)].

Shoulder rumble strips are recommended on the right and left shoulder of all Interstate roadways. For National Highway or Primary routes within designated city or urban limits, engineering judgment should be used on a case-by-case basis to determine if rumble strip installation is appropriate. Shoulder rumble strips are recommended for placement in shoulders with a width greater than 4 feet. At locations which meet this requirement, the decision to not install shoulder rumble strips should be based on factors including corridor continuity, approach density, bicycle usage and accident history. Shoulder rumble strips should generally not be provided where shoulder widths are less than 4 feet. If however, there is little or no bicycle use and the incidence of run-off-the-road accidents is high, rumble strips should be considered [(40)]

Montana revised its policy for the use of rumble strips on roadways in 1996, which reflected inputs from the bicycle community and others on the rumble strips installed on State highways. Montana uses formed in rumble strips in a corrugated pattern 30 mm (12”) wide on new concrete shoulders. The corrugations shall be on 11.4 mm (4 ½**”** centers, with a 2.5mm (1”) radius, and 2.5mm (1”) depth. The rumble strips are placed 15.0mm (6”) outside the shoulder stripe. On existing concrete shoulders, the installation method is determined on a case-by-case method. In case of asphalt shoulders, 30.0mm (12”) wide and 1.3mm to 1.9mm (1/2 to ¾”) deep milled in rumble strips are installed. The rumble strips are placed on 30.0 mm (12”) centers, and 15.0mm (6”) outside the shoulder stripe.

The placement policy states that shoulder rumble strips should be provided on the right and left shoulders of all interstate new constructions, re-construction and overlay projects unless there is a specific reason not to do so (Documented in scope of Work Report). Installation of rumble strips should be done on the right shoulder on an 18.3m (60’) cycle pattern consisting of a 14.7m (48’) rumble strip and a 3.6m (12.8’) gap. The gaps are eliminated on the left shoulder. Rumble strips are ended at the exit ramps 30m (98’) upstream of the ramp taper, and begun again at the gore nose left off-ramp shoulder stripe. At entry ramps, rumble strips are again ended at the gore nose, and begun again at the ramp taper. Rumble strips are discontinued on outside shoulders less than 1.8m(6’) wide if guardrail exists or is proposed.

On segments of National Highway, Primary, or Secondary routes within designated city or urban limits, use of engineering judgment is made on a case-by-case basis to determine if rumble strips installation is appropriate. Rumble strips are discontinued across full width of all public and private (residential and commercial) road approaches.

Rumble strip are to be provided on the shoulders of all National highway, Primary, and Secondary new construction, reconstruction, and overlay projects, subject to the restrictions within urban and city limits. Rumble strips are not generally provided on shoulders less than 1.2 m (4') wide. In cases where there is little or no bicycle use and the incidence of run-off-the-road accidents is high, rumble strips are to be considered. Where significant bicycle use is documented, consider a 100mm (39") offset from shoulder strip where shoulder width is 1.2 m (4') or less is considered. Also a transverse width of rumble strips of 200mm (79") is considered where the shoulder width is 1.2m (4') or less [41].

Nebraska

Grooved strips are used at shoulders of Interstate highways and rural roads. All the Interstate roadways in the State are being outfitted with rumble strips (Gupta, 2000). Bicycles are permitted to use the roadway when a 0.6 m (2') rumble strips are in place. This is true for all roadways except for Interstate roadways [15].

The Nebraska Department of Roads currently uses only ground-in rumble strips on multi-lane roadways, however studies are being done on their use on high volume two-lane two-way roadways. The current specifications call for a 1.3mm (1/2") depth strip, (18mm (7") wide (direction of travel), by 41mm (16") long. The strips are to be placed 15mm (6") from the edge of the driving lane with 13mm (5") between strips. Because of the narrow width of the strips, 1.9m (6'-2") of 2.4m (8') paved shoulder behind the rumble strips are retained for use by bicyclists. No complaints have been received regarding the current design of rumble strips [42].

New Hampshire

The State uses rumble strips only at shoulders and medians. The State does not have any design specifications. Granite logs are used as rumble strips [1].

The only rumble strips placed in the State of New Hampshire have been placed on the Interstate roadways. The bicyclist population has not been a criterion for placement policies of rumble strips or for freshly laid projects and roadways [43].

New Jersey

The State DOT recommends that rumble strips are to be constructed on the inside shoulders that are 1.52m or greater and outside shoulders that are 2.44m or greater in width along the mainline on all interstate highways, freeways and other limited access highways. They may also be constructed along the land serving highway locations where accident data indicates a nighttime run-off-road accident problem and the shoulder approaching a bridge overpass or underpass is reduced or eliminated. The rumble strips should be provided at a minimum distance of 500' in advance of the bridge. The minimum length of rumble strips measured longitudinally along the shoulder shall be 30.5m for its effectiveness. Rumble strips shall not be constructed across the bridge decks and 30.5m in advance and beyond intersections and driveways [(2)].

New Mexico

Only experimental raised strips had been installed at 2 construction sites. No definite evidence that rumble strips are effective in speed reduction [(1)].

New York

Grooved rumble strips have been used in advance of toll barriers. Raised strips have been used at several locations. No formal studies have been carried out to fid out the effectiveness of rumble strips. There has been no reduction in accidents. Complaints about the noise produced have come to notice. They have been found to be effective in getting driver's attention, but they are rendered ineffective within a year. Raised strips have led to an increase in rear-end accidents[(1)].

The DOT recommends the use of SAFE-STRIPS on new, reconstructed and resurfaced shoulders of all rural full access-control highways, including rural full access-control parkways, regardless of accident history, on sections of any highway with a history of inattention/sleep/fatigue drift-off road crashes. The SAFE-STRIPS are considered for installation of new reconstructed and resurfaced shoulders of suburban/urban full access-control multi-lane highways, including suburban/urban full access-control and rural partial access-control multilane parkways. On the highways which qualify for installation, SAFE-STRIPS are to be installed either in conjunction with a construction project, or as a retrofit on existing shoulders via a separate contract exclusively for this purpose. On highways having substantial volumes of bicycle traffic, SAFE-STRIPS shoulder generally not be installed in the right shoulder , unless the shoulder is wide enough to accommodate the rumble strips and still provide a width of 3" for bicyclists. Gaps in installation should be provided in advance of intersections where bicyclists are likely to make left turns, to permit bicyclists to merge with cross-

traffic. According to NYSDOT's experience, rolled-in strips are inefficient in providing adequate audibility [3].

North Carolina

Solid pads have been installed at 38 locations and grooved strips at 2 locations. The installations were mostly done at 2-way STOP or T-intersections. Height of the solid pad is a maximum of 1.3 m (½"). Pads are 23mm to 30 mm (9" to 12") wide and 7.6 m (25') long. The number of pads is 11 and the distance of last pad from STOP is 46 m (150'). Raised, solid pads get eroded after some time. Complaints of noise and vibrations have been received from residential areas [1].

The State guidelines for the installation of shoulder rumble strips in North Carolina specify that surface treatment should be used on the median shoulder and right shoulder at locations where surface treatments are desired. The shoulder rumble strip installation should be considered for paved shoulders having widths less than or equal to four feet. This guideline is based on the fact that less time is available for inattentive drivers to recover on narrower paved shoulders. Surface treatments, which reduce the amount of concrete covering steel reinforcement, are not recommended for shoulders on structures. Rumble strips are typically not required on urban sections that have good ambient lighting and where high levels of driver attention are required to operate vehicles.

Shoulder surface treatments are recommended on Interstate roadways and rural freeways on medians and outside shoulders. In addition, major arterials in rural areas with low-density roadside development should be considered for shoulder surface treatment. The rumble strips are used on interstate throughway routes, rural freeway segments and expressway segments that are located in sparsely developed rural areas. Rumble strips are not used on urban freeways and loop projects around urban areas and non-freeways with the exceptions.

North Carolina uses formed rumble strips on concrete shoulders and milled rumble strips on asphalt shoulders. Formed rumble strips are used on the concrete portion of the shoulders that have a combination of concrete and asphalt pavements. The rumble strips should be 41mm (16") in length, 18mm (7") wide, 1.3mm (½") deep, and are placed continuously along the paved shoulder. The State also recommends use of thermoplastic rumble strips in addition to the milled rumble strips in order to enhance visibility in many areas where nighttime visibility is a problem. Some other surface treatments have also been approved by North Carolina to provide sensory warning treatment for paved shoulders [44]. These treatments include:

1. Ground, or cut grooves which are primarily used on narrow median shoulders. This is the most expensive and effective method available.
2. Rolled-in grooves, which is the easiest treatment to construct and the least expensive, however it is also the least effective method.
3. Thermoplastic pavement marking strips, which provide the advantage of, improved visibility on the roadway shoulder during inclement weather. They are moderately effective.
4. Profile treatment-marking edgelines, which are used as a substitute for normal edge line and are relatively low in cost. They may pose a maintenance problem in areas where snow plowing is required.

North Dakota

Grooved strips are installed on 2-way intersections and shoulders of Interstate highways using saw method. On Interstate highways, pavements grooves are formed in the plastic concrete. On PCC shoulders, corrugations have a depth and width of 1" and 12' respectively. For saw slot installations, grooves have a depth and width of 3/8" and 4" respectively. Length of each pad is 15'-4". the grooves per pad are 16 and spacing of grooves are 8" clear. For bicyclists and motorcyclists, a clear margin of 4' is left on Interstate highway shoulders, but no such provision is considered on two lane rural roads. Grooves have been found to erode and get filled up due to which, they have to re-sawed[(1)].

Rumble strips are to be installed on the outside shoulder of Interstate construction and 3R paving projects. Rumble strips are not routinely provided on the median shoulder. Where practical, they are also installed on interstate maintenance projects. When a concrete outside shoulder is used a 4' wide by 6' long cast in place rumble strip shape offset 3' from the edge of the travel lane and positioned on 60' centers is used. The rumble strip peaks are 12" centers an the max. depth is 1". When bituminous outside shoulder is used, two options exist. The rolled in option is an 18" wide shape offset about 14" from the edge of the travel lane and rolled in continuously on an 8"-12" spacing with a nominal length of 2" and depth of ¾". The milled in option is an 18" wide shape offset 6" from the edge of the travel lane. The shape has a nominal depth of ¾" and length of 7' and is on 12" centers and is milled in continuously. NDDOT designers do attempt to position the rumble strips to allow bicycles to stay out of the traffic lanes where possible [(2)].

Ohio

Ohio State DOT permits the use of milled, rolled and formed type of rumble strips out of which milled rumble strips are mostly preferred because of it's efficiency in producing desired audible and vibratory effects. The typical dimension specifications followed are 18 mm (7") grooved width, 30 mm (12") spacing, 1.3 mm (0.5") depth, and

41 mm (16”) pattern width. The offsets from left and right edges are 6” to 6’ and 15 mm to 25 mm (6” to 10”) respectively, depending upon the shoulder width. Ohio DOT recommends the use of shoulder rumble strips only on the shoulders which are wide enough to provide a minimum clear path of 4’ from the rumble strip to the outside edge of the paved shoulder or 5’ to adjacent guardrail, curb or other obstacle. It also recommends the use of intermittent ruble strips instead of continuous ones, with an alternate gap pattern, 10’ in length [(1)].

Ohio DOT has used shoulder rumble strips since 1996. Three types of rumble strips are being used, the first type is rolled into new asphalt, the second type is milled in new or existing concrete or asphalt, and the third type formed into new concrete. Type 2 is the most effective as it is found to produce a noticeable vibratory and auditory warning to the drivers. It is a preferred treatment on most of the rural roads. Types 1 and 3 are recommended in urban and residential areas to minimize noise levels.

The DOT also intends to install them on both shoulders of fully access-controlled rural highways and sections of highways with a history of run off the road accidents due to driver inattention. The bicycle issues are addressed by either not installing the strips if the shoulder is narrow, or using an intermittent pattern to allow cyclists to cross the shoulder. Rumble strip installation is recommended on both right and left shoulders of divided roadways but individual circumstances may limit their use to any one shoulder as well. Rumble strips should only be installed on existing paved shoulders that are in good condition and have a minimum width of shoulder for a type of rumble strip. The minimum width of shoulder for Type 1 rumble strip is 1 m (3.5 ft) and 0.7 m (2.5 ft) for Types 2 and 3.

Rumble strips generally should not be used on the shoulder of roadways designated as bicycle routes or having substantial volume of bicycle traffic, unless the shoulder is wide enough to accommodate the rumble strip and still provide a minimum clear path of 1.2m (4’) from the rumble strip to the outer edge of the paved shoulder or 1.5m (5’) to adjacent guard rail, curb or other obstacle. Rumble strips placed in residential areas may be placed further from the edge of the traveled lane to reduce the frequency of contact while still providing some degree of warning to the drifting drivers. The distance of the edge of the traveled lane to the rumble strip pattern should not exceed 0.6m (2’) on the outer shoulder. Also, type 1 and 3 rumble strips are preferable in these areas as compared to type 2. The rumble strip pattern should not be continuous but should consist of an alternative pattern of gaps and strips each 3m (10’) in length). Also, gaps should be provided in pattern ahead of intersection, cross walk, driveway openings or other locations where bicyclists are expected to cross the shoulder [(45)].

Oklahoma

Mostly raised strips and a few grooved strips have been used at locations such as two-way stop and signalized intersections, road shoulders and toll booths. Depth of the grooves is 1.6 mm to 2 mm (5/8" to 7/8") while width of the grooves is 9 mm to 11 mm (3-1/2" to 4-1/2"). Asphalt concrete method is used for raised strips and roller method for grooved strips. Raised trips have some problem due to snow plowing [(1)].

The State uses continuous milled in rumble strips 46mm (18") wide and one foot off from the shoulder. The State normally provides a full width of paved shoulders, which are about 2.4m to 3m (8'-10') wide. The bicyclist population is not very high and the bicyclists normally prefer to ride on travel lanes. There has been no inquiry by the bicyclist community above current policies and practice. The use of rumble strips is currently restricted only to the rural high-speed type of roadways. Rumble strips are not installed on urban roadways [(46)].

Oregon

The Oregon DOT permits the use of milled rumble strips on rural Interstate roadways, and on non-Interstate roadways only if the data suggests it necessary for safety purpose. The specifications for milled rumble strips are 18 mm $\pm$ 1mm (7"$\pm$0.5") grooved width, 30 mm (12") spacing, 1.3 mm to 1.9 mm (0.5" to 0.625") depth, and 41 mm (16") pattern width. The offsets from the left and right edge lines should be 30 mm (12") and 0 to 15 mm (0" to 6") for rural Interstate roadways and non-interstate roadways respectively. No specific consideration for bicyclists has been made in the policy [(1)].

The Oregon Department of Transportation recommends the use of milled shoulder rumble strips. Rumble strips are not recommended for non-interstate roadways unless accident data show a problem and shoulder rumble strips can correct the problem area. Centerline rumble strips are also considered on roadways with a high incidence of median crossover crashes. These rumble strips require a minimum median width of 1.2 m (4'). Where the median width is less than 1.2 m (4'), the rumble strip can be placed in the center of the median. Where the median width is greater than 1.2 m (4'), the rumble strip should be placed 300 mm (118") inside of each median strip (Statewide Rumble Strip Decisions, 1999).

Oregon installs shoulder rumble strips on rural Interstate roadways with an offset of 0.3m (0.9') on right and left shoulders. Shoulder rumble strips are not installed in snow zones, climbing areas, or in rolling, mountainous or curvy terrain except where the data indicates a significant single vehicle ROR problem, at locations where guardrails or

barriers leave shoulders of 1.2m (4') or less and on bridge decks. Milled shoulder rumble strips are not installed in the area between points 100m (328') before the exit ramp and 100m (328') after the last entrance as measured from the point where the fog stripe departs and rejoins the mainline. As stated in the Oregon Design Manual, the continuous rumble strip is not necessary when the right shoulder is less than 1.8m (6') wide.

No rumble strips are placed on non-Interstate roadways unless data indicates a safety problem that is correctable by use of milled-in rumble strips. Rumble strips on non-Interstate roadways require a traffic investigation and approval of the Region Traffic Engineer. Rumble strips are not deleted from the standard design unless there is a clear and documented problem, the process for deleting a rumble strip from a standard design requires that the statewide rumble strip policy team be informed of decisions to delete existing rumble strip installations. If shoulder rumble strips are considered, design teams should then discuss whether these should be milled or durable line profiles. Raised profile pavement markings are considered when rumble strips are not allowed because of narrow shoulders or for centerline applications. The intent is to place rumble strips only where a benefit is expected and only on shoulders of 1.2m or greater in width. In lieu of milled in rumble strips, a marking line made of durable striping materials with raised bumps could be used [47].

Pennsylvania

The State DOT requires that milled rumble strips on each right and left shoulder be included on all limited access highway projects when shoulder resurfacing or reconstruction is included as part of the project. It considers milled shoulder rumble strip installation on a project-by-project basis, for rural restoration (3R & reconstruction) projects where single vehicle run-off-road accidents are a defined problem and shoulder rumble strips will help reduce the problem. Milled shoulder rumble strips do not have to be a part of a construction or restoration project. They can be installed via projects initiated exclusively for this purpose.

It is desirable to have a minimum paved shoulder width of 8' when installing milled right shoulder rumble strips. If it is required to install milled right shoulder rumble strips on paved shoulders that are 6-8' wide, the review an approval of the Central Office of Pedestrian/Bicycle Coordinator is required to ensure that bicyclist needs are net. Shoulder rumble strips are not to be milled on right paved shoulders that are less than 6'wide. The designer has flexibility to adjust the offset of the milled shoulder rumble strips to better adjust the special needs of bicyclists[2].

Rhode Island

No rumble strips have been used [1]. No rumble strips being used any where in the entire State [48].

South Carolina

Mostly raised and some grooved strips have been used at 2-way and 4-way stop and signalized intersections, road shoulders and railroad crossings. Solid pads are installed by chip or seal method, whereas, grooved strip by saw method. Height of the raised strips is 1.3 mm (½"). Depth of rolled grooves is 2 mm (3/4") and depth of molded grooves is 2.5 mm (1"). Number of pads is 12 and length of each pad 1.2 m (4'). Distance of 1st and last pad from STOP sign is 242 m (794') and 8 m (26') respectively. Solid pads and raised strips have been found to become flat and require maintenance. Rumble strips are used to supplement warning signs such as "STOP AHEAD", "SIGNAL AHEAD", "RAILROAD ADVANCE" [1].

South Carolina DOT uses milled in shoulder rumble strips. These are only used on Interstate highways. Since bicycles are prohibited from using the Interstate no special accommodation is needed [49].

South Dakota

All the installations have been of raised type at locations like 2-way and 4-way stop and T-intersections. Height of raised strips is 1.3 m (½"), length of each pad is 7 m (24'-6") and the number of pads is 2. Strips per pad are 17 and spacing of the strips is 46 mm (18") c/c. Spacing of the pads is 312 m (1025'). The distances of 1st pad and last pad from STOP are 510 m (1675') and 198 m (650') respectively. A "STOP AHEAD" sign is used in conjunction with rumble strips [1].

SDDOT is in the process of developing a written policy on when rumble strips will be used. The draft policy indicates that rumble strips will be installed on both shoulder of the Interstate System and 4 land divided arterials when they are reconstructed or overlaid. For projects where the mainline is constructed out of concrete and the shoulders are asphalt, the rumble strips on the outside shoulder will be installed in the outside 1.5 m (5') of the 8 m (26') wide concrete pavement. On the median side, the rumble strips will be rolled into the asphalt shoulder. The SDDOT does make exceptions to this rule in urban areas where noise is a problem or in case where the outside shoulder is being constructed wide enough that it can be turned in to n additional lane in the future. On 2-lane asphalt highways with ADTs under 2500 rumble strips are not installed. If the ADT is over 25000 rumble strips are rolled into asphalt overlays and new mats. On 2 lane concrete highways with ADTs over 550 rumbles trips will be installed in

the outside .45 m (1.5') of the 8.5 m (28') wide mainline concrete pavement. Rumble strips have not been installed into any highways that were not being reconstructed or overlaid. By placing the rumble strip next to the edge line in concrete mainline pavements with asphalt shoulder the rumble strips provide a separation between the bicycles and vehicles. No special provision for bicycles is made on highways with other surface types [2].

The South Dakota Design Manual states that rumble strips shall be placed 12m (40') center to center on PCC shoulders. Rumble strips are recommended on all asphalt concrete shoulders by milling continuous indents in the asphalt concrete. The strips should be placed 30mm (12") center to center with and a width of 41mm (16") min, 15mm to 30mm (6" to 12") from the edge of the asphalt concrete shoulder. Rumble strips are not installed in urban locations due to the noise produced [50].

Tennessee

A scored shoulder shall be specified on all new construction and resurfacing projects in the Interstate System and the NHS. According to DOT, on multi-lane roadways scored shoulders will be used on all main-line shoulders, including both outside and inside shoulders and median shoulders in divided highways [2].

The State uses shoulder rumble strip on all the Interstate roadways, freeways, and other roadways, like parkways, which can be identified as freeways. Rumble strips are installed on the shoulders of all the rural and urban Interstate roadways. The type of rumble strips used is rolled-in rumble strips. The State does not have a policy to specifically accommodate bicycle safety issue [51].

Texas

Most of the rumble strips are installed on the shoulders and very few within travel lanes of highways. No standards have been followed by this state. Only jiggle bars shoulder strips have guidelines [1].

Texas policy states that a minimum shoulder width of 2.4 m (8') is required for the outside shoulder to be provided with milled rumble strips. A minimum shoulder width of 4 feet is required for the inside shoulder to be milled. Milled-in texturing produces sufficient stimuli to alert inattentive drivers but does not affect the maneuverability capabilities of vehicles. Considerations in evaluating rolled-in texturing include state that placement must be in coordination with other asphalt concrete pavement construction.

Rumble strips are installed as part of new asphalt concrete shoulder construction, reconstruction, and overlay projects on rural four-lane or more controlled- and partially controlled-access highways with asphalt concrete shoulders. Rumble strips are also installed as part of new Portland cement shoulder construction and reconstruction projects. If the concrete shoulder will be used in the near future as a permanent travel lane or a travel lane in a work zone, rumble strips are not installed. Rumble strip installation is not recommended for asphalt concrete or Portland cement shoulders except in special cases where a significant number of accidents, by frequency and percentage of total accidents, are run-off-the-road accidents and the installation of rumble strips is determined to be cost beneficial.

The accident history along with consideration of shoulder use by traffic, mail carriers, bicyclists, and/or farm equipment should be evaluated. Rumble strip installation is not considered for urban facilities. When installing shoulder rumble strips, appropriate riding space for bicyclist is a consideration. The standard details for rumble strip installation provides appropriate riding space for bicyclists. During rumble strips installation, continuity across district boundaries should be achieved where possible.

Shoulder rumble strips are not placed across exit or entrance ramps, acceleration and deceleration lanes, crossovers, gore areas, bridge decks, or intersections with other roadways. The State also recommends that while installing the rumble strips, it is important to educate the public on fatigued or drowsy driver issues and how the installations has shown to be an effective roadside treatment in reducing run-off-the-road accidents [52].

Utah

Only grooved strips have been used and have been laid down by roller method or placed in fresh concrete paving. They have been installed on reconstructed or new interstate highways and on shoulders. Depth and width of corrugations are 2 m (¾”) and 11 mm (4-1/2”) respectively. Width of the corrugated pad is 1.8 m (6’) and the grooves have a minimum spacing of 2.4 m (8’) c/c and a maximum spacing of 23 mm (9”) c/c. UDOT is trying to limit the use of rumble strips to rural highways only [1].

The rumble strips being used in the State are milled in rumble strips and are used in a pattern that allows gaps in between the strips. There are 48 inches of rumble strip and then a 30mm (12”) inch gap. The offset depends on the available shoulder width. The width of the rumble strip is varied depending on the shoulder width available. The rumble strip has a range from a maximum of 30mm (12”) to a minimum of 13mm (5”). The depth varies from 41mm to 48mm (16” to 19”). Rumble strips are covered with a layer of chips In order to avoid the snow from reducing their effect. Rumble strips are placed on all the Interstate, non-Interstate roadways and secondary roadways where

the placement depends on the history of run-off-road accidents. The use of rumble strips on the non Interstate roadways and secondary roads is optional and depends on the recommendations of the regional committee which can recommend the use of rumble strips taking into account other factors, such as available shoulder width and history of ROR accidents [53].

Vermont

No rumble strips have been used in the State due to severe winter conditions [1].

The State DOT has just completed the milling in of rumble strips on its entire Interstate system, (320+ miles) and a few other limited access four-lane highways. It does not plan to use them on any other highways currently. As bicycles are not allowed on the Interstate roadways, the issue of bicycles has not been considered [54].

Virginia

Raised strips have been used at 2-way stop and intersections using asphalt concrete method. Grooved strips have been used at tollbooths and on interstate road shoulders. The strips are 1.3 mm (½") high, 15 mm to 20 mm (6" to 18") wide and have a clear spacing of 3 m (10'). There are 4 pads of length ¾ secs. of continuous rumble. Distance of the last pad from STOP should be greater than SSD.

The design specifications are the guidelines by Virginia Highway and Transportation Research Council and not standard design criteria. It was found that three rumble strip pads probably produce optimum results and a half-inch height or depth of rumble strips is most effective [1].

Virginia has established the policy to install rumble strips on all of its rural Interstate highways since 1993. About 150 miles of shoulder length currently has milled rumble strip installations. Virginia has started the testing of a variety of Intelligent Transportation Systems technologies on Department of Transportation's Smart Road near Blacksburg. VDOT has installed almost four miles of magnetic tape in two strips on the Smart Road.

Washington

Rumble strips are being used in conjunction with other traffic control devices. Solid pads of size 30 mm x 10 mm (12" x 4") and 0.45 m (1'-1/2") indented rumble strips at 20 mm (8") c/c have been used. No significant reduction in the number of accidents

after the installation of rumble strips has been noticed. Rumble strips have been found to present a hazard to bicyclists and have limited use although a clear margin is left on shoulders for bicyclists [(1)].

Rumble strips are to be placed on shoulders of all new rural, limited access highways where shoulders are to be resurfaced or replaced. Rumble strips shall be cut into mainline shoulders to have a concave circular shape with a minimum 13mm to 16mm (5" to 6") maximum depth at the center and have 175 mm (69") width across the cit. They shall be offset 150 mm (59") from the edge of the pavement and be 400mm long and be spaced at 300mm centers. The depressed area of the rumble strip shall be coated with asphalt material CRS-1,2,1h or CSS-1h.

Rumble strips shall be placed on non-limited access shoulders where studies indicate there may be a significant number of run-off-road incidents. The rumble strip installation is being done on a statewide basis at this time for those sections of Interstate where shoulders are in good shape and will not be replaced or overlaid in the near future. Where bicycles are allowed, rumble strips will only be used where the min. width of paved outside shoulder is 2.4 m (8') or wider [(2)].

As stated in the Design Manual of Washington State DOT, the continuous rumble strip is not necessary when the right shoulder is less than 1.8m (6') wide. The requirement on shoulder width is in consideration of bicyclists. In addition, the State is looking into incorporating the rumble strip design used in Pennsylvania which is considered to be more "bicyclist friendly".

Washington, D.C.

Humps are used here instead of rumble strips.

West Virginia

Grooved rumble strips are used at 2-way stop intersections. The grooves have a maximum depth of 2 mm (¾"), a width of 10 mm (4") and spacing of 20 mm (8") c/c. The number of grooves on a pad of 3.5 m (11'-4") is 12. Total number of pads are 10 spacing between which depends on speed. Distance of the last pad from the STOP sign is 76 m (250') . Some maintenance problems have been encountered [(1)].

According to recommendations of WVDOH, rumble strips are not placed in narrow shoulders such as truck climbing lanes or in the transitions from a full shoulder

to narrow bridge shoulder. The only type of rumble strips being used in the State are rolled-in rumble strips [2].

The State uses rumble strips only on the Interstate roadways and corridors that are controlled access and high-speed roadways. Bicycles are not allowed on any of these roadways. The typically used type of rumble strips is rolled-in rumble strip [55].

Wisconsin

Grooved rumble strips are used at 2-way stop, road shoulders and hidden horizontal and vertical curves. The strips are 0.9 mm – 1.3 mm (3/8”-1/2”) deep and, 3”-5” wide and are spaced at 30 mm (12”) c/c. The number of pads is 3, which have a length of 6 m – 7.6 m (20’-25)’ each. The distance of last pad from STOP sign is 91.4 m (300’). “STOP AHEAD” sign is used in conjunction with rumble strips and installation of rumble strips have been considered to be viable safety improvement project [1].

Shoulder rumble strips are placed on the shoulders just beyond the traveled way to warn drivers when they are entering a part of the roadway not intended for routine traffic use.

A comparison of rolled-in rumble strips and milled-in continuous shoulder rumble strips (CSRS) has determined that CSRS, although more expensive, are more cost effective. CSRS are the standard design. Rumble strips may be used when an analysis indicates a problem with run-off-the-road accidents due to inattentive or fatigued drivers. CSRS are considered on both the left and right shoulders of rural divided highways. CSRS are required on both the right and left shoulders of rural Interstate highways. Lack of required CSRS is a design exception (DE) under any one of the following conditions:

- When another project scheduled within two years of the proposed project will overlay or reconstruct the shoulders or will use the shoulders for detours;
- When a pavement analysis determines that installing CSRS will result in inadequate shoulder strength.
- When shoulders will be less than 1.2m (4’) wide on the left and 1.8m (6’) wide on the right;
- When CSRS are used, they are discontinued where no edge strip is present such as at intersections and where curb and gutter are present.

Wyoming

On asphalt shoulders, WYDOT recommends each strip measuring 18 mm (7") wide and 41 mm (16") long to be ground ½" into the pavement. Milled or formed intermittent rumble strips are to be installed on concrete shoulders while continuous pattern on interstate highways. On rural Interstate highways, rumble strips should be milled into both inside and outside shoulders, while within urban limits, the strips should be installed on the inside shoulder only. Rumble strips should not be installed on non-interstate roads within urban areas, in developed suburban areas, where posted speed limits are 45 mph or less, where curbs and gutter is in place, or along rural highways which have a shoulder width of 0.6 m (2') or less. In an intermittent pattern of installation, 3 m (10') series of strips followed by 3 m (10') of pavement with no strips. Shoulder width is recommended to be a minimum of 1.8 m (6') at designated bicycle routes [(1)].

Wyoming does not have a written policy. They have in the past installed rolled-in rumbles trips on asphalt shoulder as part of the pavement construction. In 1996, WY installed milled rumble strips as a retrofit project on various routed throughout the State on asphalt shoulders. Concrete pavements with concrete shoulders have had rumble strips included in the standard plans. Currently however, Wyoming placed a one year moratorium on the use of rumble strips mainly due to concerns of the bicycling community [(2)].

Wyoming places rumble strips on all bituminous shoulders in accordance with project plans. Rumble strips are normally not placed on city streets and other urban shoulders adjacent to curb and gutter unless specifically noted in the plans. Rumble strips may be continuous through all minor approaches and shall be omitted across principal intersecting roadways. Rumble strips shall be placed with respect to the applicable shoulder condition and width. It is intended that rumble strips should be placed as close to the edge of traveled way as possible. For wide shoulder conditions, the rumble strip is offset a little greater distance as shown to accommodate snow-plowing operations on shoulders. The width between the rumble strip and the edge of shoulder should be a maximum within specified distance constraints to accommodate bicycle traffic.

International Experience

The experience of other countries with regard to their use of shoulder rumble strips and the impacts of these rumble strips on bicyclists was also investigated in this research. The following provides a general overview of countries and their policies:

Canada

Bicycle traffic is permitted on highway shoulders in Canada, with certain exceptions. The provinces of Alberta, British Columbia, and Manitoba have comprehensive policies and designs regarding the use of shoulders for bicycling. Alberta provides paved shoulders and allows bicycling on designated routes. A minimum width of 1.1 m (3.6 ft) is provided to the right of the shoulder rumble strip for bicycles. These strips are used on shoulders with a minimum width of 2 m (6.5 ft). Indented bars used for the rumble strips are offset 150 mm (6 in) from the edge of the travel way and are 750 mm (29 in) in length.

In British Columbia, bicycles are allowed on shoulders except for Trans Canada Highway and other major highways. The travel lanes adjacent to the shoulder are a minimum of 3.6m (12 ft) wide with a minimum shoulder width of 2.5 m (8 ft) where the highway design speed exceeds 80 km/h (50 mph) and the SADT exceeds 10,000.

In Manitoba, a bike path is not considered unless there are a minimum of 50+ bicycles per day using the facility. Separate bike lanes are provided for multilane highways with posted speed limits greater than 80 km/h (50 mph) and for two-lane highways with SADT exceeding 3000.

New Zealand

New Zealand uses thick pads of thermoplastic as rumble strips on roads in an attempt to wake drivers up to dangerous situations. The rubber have been observed to create noise and vibration when a vehicle crosses them, alerting drivers and causing them to look for visual warning signs. Studies collected by Transit New Zealand show rumble strips can lead to a 20% to 40% reduction in crashes. Rumble strips have been installed in Auckland and Wellington. However, rumble strips have been found to create nuisance noise and to have some adverse effects on driver behavior. Drivers regularly using a road where a rumble strip has been laid have tended to avoid the pads by driving on the shoulder of the road or even in the opposing lane. Noise from the strips have also annoyed nearby residents.

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