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MEMORANDUM

Date:	June 24, 2015
To:	County and State Highway Agencies
From:	Tom Huber, Adam Wood, William Schultheiss, P.E.
Re:	Paved Shoulder and Rumble Strip Design Recommendations

Introduction

The practice of paving shoulders has grown in popularity among DOTs and counties over the past three decades after it became clear that paved shoulders have proven safety and maintenance benefits. An additional benefit of paving shoulders is that they better serve bicycling and walking than roads without paved shoulders. More and more agencies have recognized this benefit and have made modifications to their paved shoulder standards to better accommodate bicyclists and the occasional pedestrian.[1] During the past 20 years, adding rumble strips to paved shoulders has been supported as a proven crash reduction factor for motorists. However, the placement of these rumbles can have an effect on the usability of the shoulder for bicyclists and pedestrians. Agencies and the Federal Highway Administration are striving to find ways to ensure that the benefits of paved shoulders and rumble strips are maximized for overall motorist and bicyclist safety. This memo contains suggestions and recommendations on how that can occur through modest design standard changes.

This memo contains options and recommendations on how to prepare standards for paved shoulders and rumble strips, based on exemplary practices and research published by the Transportation Research Board as part of its National Cooperative Highway Research Program (NCHRP).

Rumble Strip Design Options

It is recommended that options be considered for the design of DOTs' rumble strips for roadways on which bicycle traffic is permitted. This includes primary and secondary rural two-lane roadways on which rumble strips are provided. Rumble strips are not provided on all roadways in all situations. Rather, in current practice, different DOTs' install rumble strips any time it provides a paved shoulder (through construction/reconstruction, 3R, or retrofitting) or where there is a demonstrated need for rumble strips (such as stretches of highway with disproportionate levels of Single-Vehicle-Run-Off-Road crashes). These recommendations are based on the findings of NCHRP Report 641 (see Attachment A).

Rumble Strip Depth

A depth of 0.375 inches should be considered for shoulder rumble strips on rural two-lane roadways. NCHRP Report 641 shows that this depth produces sound levels at least 10 dBA above ambient, which is more than sufficient to alert inattentive, distracted, drowsy, or fatigued drivers (see Table 88 in Attachment A).

Rumble Strip Width

Some studies state that 5-inch wide rumble strips are more bicycle-tolerable; others say 7-inch wide rumble strips are preferable. The wider option seems better for bicyclists due to the softer, more gradual transition from pavement surface to milled depth. In addition, 7-inch wide rumble strips produce greater sound levels, increasing their safety benefit, and are less expensive to mill.

[1] It is important to note that paved shoulders are not considered accessible by the Americans with Disabilities Act Accessibility Guidelines or the Public Right-of-Way Accessibility Guidelines.

Rumble Strip Length

Rumble strips that are 6-inches wide produce adequate sound levels at various speeds, according to the NCHRP report. By decreasing this length when the paved shoulder width is at a premium, up to another 6 inches of shoulder width usable by bicyclists can be claimed while retaining the safety benefit for motorists.

Recommendations and Options Summary

In summary, 7-inch wide, 0.375-inch deep rumble strips as long as just 6 inches provide adequate sound level increases over ambient levels to alert inattentive, distracted, drowsy, or fatigued drivers. Rumble strips designed in this way are also more tolerable by bicyclists and make easier the provision of bicycle accommodations on narrow pavement sections—without reducing the safety factor for motorists.

Paved Shoulder Width Recommendations for Two-Lane Rural Roadways

The following represents some general recommendations for improving conditions for bicyclists along rural roadways by increasing the application of paved shoulders on primary and secondary roadways. These recommendations are based on a review of state DOT paved shoulder practices and the BLOS analysis described briefly in **Attachment B.** AASHTO guidelines and paved shoulder standards from other states were also reviewed and considered.

The following recommendations apply to two-lane rural roadways. Multi-lane rural and urban-rural transition roadways can also be improved for bicyclists, but the ADT thresholds will differ. It is important to emphasis that every state and county have different conditions that could impact the implementation of these recommendations.

Design Year ADT of 3,000 or Greater

Provide paved shoulders that are at least 4 feet wide. Unless wider than 4 feet, the shoulders should be free of rumble strips, which should be applied on the full-depth pavement section between the shoulder and lane edgeline. If rumble strips are to be placed in the paved shoulder, the paved shoulder width should be (4 feet + width of the rumble strip).

Design Year ADT between 2,000 and 3,000

Provide 4' paved shoulders on rural roadways to design year ADT of 2,000 and ensure that at least 4' of paved shoulder is usable by bicyclists and pedestrians. If rumble strips are to be placed in the paved shoulder, the paved shoulder width should be (4 feet + width of the rumble strip). Essentially, this will mirror the current practice for providing paved shoulders on roads with design year ADT of 3,000 or greater (see above).

Design Year ADT between 1,000 and 2,000

Provide paved shoulders that are at least 3 feet wide and free of rumble strips. The recommendations of the placement of rumble strips included in this memo should be used to ensure 3 feet of unobstructed paved shoulder width. When paved shoulders less than 4 feet wide are provided, the rumble strip should be place all the way to the outside edge of the paved shoulder leaving 3 feet of a smooth section of paved shoulder to next to the travel lane. The following section in this memo provides options of how to incorporate rumble strips when paved shoulder width is limited.

NCHRP Report 641

The 2009 *NCHRP Report 641: Guidance for the Design and Application of Shoulder and Centerline Rumble Strips* explores the relationship between rumble strip design and placement and motor vehicle crash reduction. The research includes literature reviews, interviews with multiple state departments of transportation, and an analysis of the crash reduction impacts of rumble strip placement relative to the edgeline along nearly 900 miles of roadway in Minnesota, Missouri, and Pennsylvania.

The report makes clear that "installing rumble strips to reduce run-off-the-road or centerline crossover crashes, with no consideration of impacts to other users [bicyclists, pedestrians, mail carriers, school buses, and farm vehicles], may lead to unintended outcomes" (foreword).

Rumble Strip Benefits

According to the report, "shoulder rumble strips on rural two-lane roads are expected to reduce SVROR[2] crashes by 15 percent and SVROR FI[3] crashes by 29 percent" (143). Rumble strips are also effective at reducing these crash types on rural freeways. Rumble strips are known to be effective at reducing SVROR and SVROR FI crashes involving heavy vehicles on rural freeways. However, "on rural two-lane roads, there is no evidence that suggests shoulder rumble strips may result in a reduction of SVROR crashes involving heavy vehicles" (91).

Regarding the application of rumble strips on roadway types, the report confirms that rumble strips have crash reduction benefits on all types of rural roadways. However, it reports that many state departments of transportation have minimum ADT thresholds for applying rumble strips. These thresholds "range from 400 to 3,000 ADT, but in most cases fall between 1,500 and 3,000 ADT" (135).

Rumble Strip Stimulus Requirements

The report explains that it is the sound made by rumble strips that primarily alerts inattentive, distracted, drowsy, or fatigued drivers. Rumble strips also produce vibration, which drivers may sense through the steering wheels, pedals, floorboards, and seats of their vehicles. However, due to variations in vehicle suspensions, tire volumes, and other factors, there is great variability in the level of vibration that may be sensed. For example, the driver of a small hatchback will feel considerably greater levels of vibration than will the driver of a semi-trailer truck.

The report includes an extensive literature review to identify the necessary stimuli levels need to alert drivers. While "no conclusive evidence was found concerning the minimum stimuli levels needed" (118), it was determined that increases of 6 dBA[4] above ambient sound levels "would be clearly noticeable." The report cites multiple studies that conclude that increases of 9 to 10 dBA above ambient are sufficient to alert inattentive, distracted, drowsy, or fatigued drivers (116-117). Furthermore, one piece of research concludes that increases above 15 dBA could produce a "startle reaction," potentially causing the driver to over-correct (117).

Based on the literature review, the report makes the following recommendation for rumble strip stimuli parameters:

> On roadways where bicyclists are not expected, such as freeways, it is recommended that rumble strip patterns be designed to generate approximately 10 to 15 dBA above the ambient in-vehicle sound level,

[2] Single Vehicle Run-off-road (includes all crashes).

[3] Single Vehicle Run-off-road Fatality and Injury (only includes crashes resulting in fatalities and/or injuries).

[4] A-weighting decibels.

but **for roadways where bicyclists may be expected, it is recommended that rumble strip patterns be designed to generate between 6 to 12 dBA above the ambient in-vehicle sound level.** Another way to consider this is that for roadways where bicyclists are not expected, relatively aggressive rumble strip patterns may be used, while for roadways where bicyclists are expected, more bicycle-tolerable rumble strip patterns should be used. (137)

Rumble Strip Design Parameters

The recommendation stated above acknowledges that rumble strips are uncomfortable for bicyclists, limit the effective width of a shoulder for bicycle use, and may pose potential safety hazards for bicyclists. It also supports designing less "aggressive" rumble strips that are less jarring to bicyclists yet still produce adequate levels of sound (at least 6 dBA above ambient). Three design parameters are relevant in designing "bicycle-tolerable" rumble strips. It should be made clear that even though the strips can be made more tolerable, in no way are they considered to be rideable by bicyclists. "Tolerable" used in this sense means helping avoid a crash if a bicyclist inadvertently steers over or crosses a rumble.

- **Depth** (dimension D in Figure 6, below) **–** Deeper rumble strips produce greater sound levels. However, the report states that rumble strips with the depths as little as 0.375 inches (10 mm) can be effective in generating at least 6 dBA above ambient (117).
- **Width** (dimension C in Figure 6, below) – Studies prepared for departments of transportation in Missouri and Pennsylvania recommend 5-inch wide rumble strips as preferable by bicyclists while producing adequate sound and vibration stimuli for drivers (117).
- **Length** (dimension B in Figure 6, below) – Longer rumble strips produce greater sound levels, probably because there is more contact with vehicle tires. However, the study found that 6-inch long rumble strips (5 inches wide and 0.375 inches deep) produce 10.9 to 13.3 dBA above ambient, depending on vehicle speed and departure angle (see Table 88 on the following page). This is well above the 6 dBA minimum.

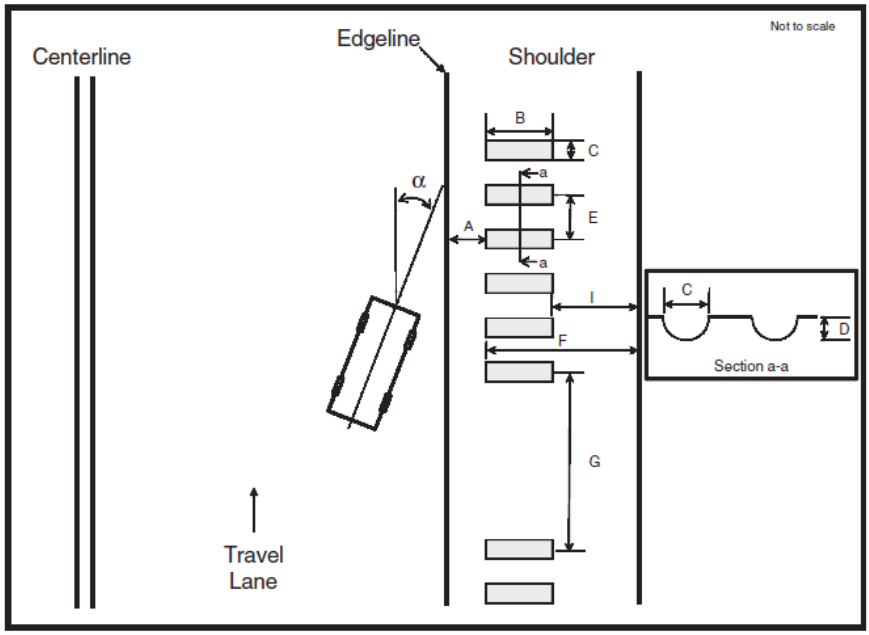

Figure 6. Design parameters associated with shoulder rumble strips.

Source: NCHRP Report 641, page 15.

Table 88. Rumble strip dimensions and parameters considered in example no. 2.

Rumble strip dimensions				Speed (mph)	Departure angle (degrees)	Sound level difference (dBA)
Length (in.)	Width (in.)	Depth (in.)	Spacing (in.)			
16	5	0.375	12	45	1	15.7
16	5	0.375	12	45	5	14.6
16	5	0.375	12	45	10	13.3
16	5	0.375	12	55	1	16.0
16	5	0.375	12	55	5	14.9
16	5	0.375	12	55	10	13.6
12	5	0.375	12	45	1	14.6
12	5	0.375	12	45	5	13.6
12	5	0.375	12	45	10	12.2
12	5	0.375	12	55	1	14.9
12	5	0.375	12	55	5	13.8
12	5	0.375	12	55	10	12.5
6	5	0.375	12	45	1	13.0
6	5	0.375	12	45	5	11.9
6	5	0.375	12	45	10	10.6
6	5	0.375	12	55	1	13.3
6	5	0.375	12	55	5	12.2
6	5	0.375	12	55	10	10.9

Source: NCHRP Report 641, page 132.

Rumble Strip Longitudinal Placement

The longitudinal placement of rumble strips (dimension A in Figure 6 on the previous page) is often thought to have an effect on the crash reduction factor. The study concludes that this is true for rural multi-lane freeways. However, it also found that there is no relationship between longitudinal placement and crash reduction for rural two-lane roadways:

> ...for rural two-lane roads, the estimates of the safety effects of edgeline and non-edgeline rumble strips are so close (i.e., 39.2 percent reduction compared to a 41.9 percent reduction) that, for all practical purposes, the placement of shoulder rumble strips on rural two-lane roads has no impact on their safety effectiveness. (85)

The study compared rumble strips placed 0 to 8 inches, 9 to 20 inches, and 21+ inches from the edgeline and found little difference in the safety effectiveness between the three distances. In fact, the analysis showed that rumble strips placed 9 inches or farther from the edgeline were slightly more effective on rural two-lane roads. This led the authors to conclude that "installing the rumble strips further away [9+ inches] from the edgeline improves the safety effectiveness of the rumble strips, which is counterintuitive to some extent" (83).

The report indicates that no correlation was found between the width of the recovery area (dimension F in Figure 6 on the previous page) and crash reduction. This implies that rumble strips placed on the far outside edge of paved shoulders may be just as effective as edgeline rumble strips on rural two-lane roads.

ATTACHMENT B – PAVED SHOULDER WIDTH AND BICYCLE COMPATIBILITY

One of the most important safety improvements that can be made to a rural roadway is the provision of paved shoulders. From a safety standpoint, paved shoulders have been proven to be a factor in decreasing crashes. With respect to motorist safety, the benefit of paved shoulders decreases as the paved shoulder increases in width—the first foot of paved shoulder produces more benefit on a per-foot basis than each subsequent foot of width, with benefit greatly tapering off by the fourth or fifth foot. This is not to dismiss the other benefits of wider paved shoulders, including the usefulness for bicyclists and pedestrians, but to clarify the relationship with motorist safety. The width of paved shoulders—and by relationship the width of the entire roadway pavement surface—has an effect on safety and suitability for bicyclists and pedestrians. Rumble strips, while providing a significant safety benefit for motorists, reduce the effective width of paved shoulders, which is why this memo discusses rumble strips in detail. The shoulder widths discussed below are effective widths—that is, exclusive of rumble strips.

The recommendations for shoulder widths in this memo are based on two bicycle-level-of-service (BLOS) models. BLOS measures are intended to indicate the level of service that a bicyclist can expect to find on a given roadway. A BLOS model can measure many factors, which combine to affect bicycling conditions on roadways. The models can be put to use to help evaluate roadways for consideration of routes or as a means to recommend roadway improvements to reach certain levels of service. Currently there are a handful of methodologies for assessing conditions, but most of them are intended for and work better with urban and suburban roadways.

The most impactful factors for determining rural highway conditions for bicyclists are volume of traffic and width of the roadway (including the width of paved shoulders). Secondary criteria sometimes include volume or percent truck traffic, pavement conditions, vertical/horizontal curves, speeds, and grades. The two main methodologies that were considered for the purposes of making recommendations in this memo are the *Bicycle Level of Service* model from the Highway Capacity Manual and the *Wisconsin Bicycle Suitability* model.