ENHANCING HIGHWAY SAFETY WITH RUMBLE STRIPS

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Highway agencies have used rumble strips for many years to enhance the safety of vehicle operations. A 1993 survey (*1*) found that 89 percent of state highway agencies and 60 percent of toll road authorities have installed rumble strips in the roadway to warn drivers of upcoming decision points, most commonly on the approach to intersections and other junctions, but also on approaches to toll plazas, horizontal curves, and work zones.

The use of rumble strips on highway shoulders has increased in recent years. Eighty-five percent of state highway agencies and 60 percent of toll road authorities that responded to the survey have applied shoulder treatments of this type to avert run-off-road accidents. Every highway agency that has used them has installed them continuously or at regular intervals along the shoulders of some higher-volume highways. Several highway agencies have adopted a policy of installing shoulder rumble strips along all freeways or other high-volume highways. Other highway agencies use them only in areas with a history or likelihood of accidents caused by drivers leaving the roadway.

Local highway agencies have also used rumble strips, but local use is more limited than that by state agencies and toll road authorities because local agencies are less likely to operate freeways and other roads on which long-distance drivers become fatigued or inattentive. Furthermore the noise created by rumble strips may make them inappropriate on streets in residential areas.

Despite the widespread use of rumble strips, no comprehensive review of their application existed before 1993. Although many small studies have evaluated the use of rumble strips, this information was not collected and summarized until the publication of *NCHRP Synthesis of Highway Practice 191: Use of Rumble Strips To Enhance Safety* (*1*). Presented in this article are findings from that report.

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What Is a Rumble Strip?

A rumble strip is a raised or grooved pattern placed across the pavement surface of a roadway or shoulder to warn drivers that they are approaching a decision point of critical importance to safety or have partially or completely left the roadway. When a vehicle passes over a rumble strip, the noise provides an audible warning to the driver and the vibration provides a tactile warning. This alerts drivers that they must act, but drivers must use visual cues to decide on the appropriate action.

Objectives of Using Rumble Strips

Rumble strips are used on a roadway or shoulder to warn drivers of the need to stop, slow down, or change lanes; to warn them of changes in roadway alignment such as horizontal curves; to draw their attention to other potentially unexpected situations such as a recent change in traffic control devices; and to warn them that they are leaving or have left the roadway. All but the last of these objectives can be met by placing rumble strips in the roadway where drivers will encounter them when approaching a particular decision point. The final objective can be met by placing rumble strips on roadway shoulders.

Rumble Strips in the Roadway

Rumble strips are placed in the roadway at crucial decision points, including on approaches to intersections, toll plazas, or horizontal curves; in a lane about to close on the approach to a mainline lane drop; and on approaches to and within work zones. Roadway rumble strips have been used for many years at locations with traffic accident patterns that cannot be corrected effectively by other means. As shown in Figure 1, the strips may be used in conjunction with signs to help the driver determine an appropriate action. They should be placed in the roadway so that either the upcoming decision point or a sign identifying what action might be necessary is clearly visible as the driver passes over the treated surface. Rumble strips should be placed before decision points so that drivers have adequate time to take any required action.

Design and Placement

Roadway rumble strips typically consist of a pattern of raised bars or grooves on the pavement surface. Raised asphalt bars are placed on the pavement surface using wooden forms, or grooves are cut into the pavement by grinding or sawing. The maximum recommended bar height or groove depth is 1.2 mm (0.5 in.).

Rumble strips can also be created by placing lines of raised pavement markers across the roadway. When highway agencies use raised pavement markers to delineate roadway centerlines, lane lines, and edgelines, in effect they are providing a mechanism to warn drivers who wander out of their lanes.

Traffic Operational and Safety Effects

Most traffic operational and safety evaluations of roadway rumble strips have addressed their use on intersection approaches. The accident-reduction effectiveness of this practice has not been precisely quantified, but studies suggest that it can reduce by at least 50 percent the most correctable types of accidents. These include rear-end accidents and those involving running through a stop sign or traffic signal. This finding is based on the results of 10 safety studies previously reported in the literature on the topic. These studies vary greatly in quality and completeness, with weaknesses that include limited sample sizes, lack of exposure data (e.g., traffic volumes before and after rumble strip installation), lack of control sites, and the absence of conclusions based on formal statistical analyses. These weaknesses should be evaluated so that the accident-reduction effectiveness of this treatment can be quantified more reliably. Virtually no evaluation has attempted to quantify the accident-reduction effectiveness of roadway rumble strips at locations other than intersection approaches. Such evaluations are necessary to assist highway agencies in determining whether and where the strips should be used.

Rumble strips are not generally effective as speed control devices. Their primary function is to draw attention to traffic-control devices or potential hazards that drivers may fail to see. At a site where a substantial proportion of drivers fail to see speed limit signs or roadway features that would normally cause them to slow, rumble strips can call attention to those signs or features and result in a reduction of speeds. However this pavement treatment should not be expected to reduce the speeds selected by drivers at locations where there is no apparent reason to slow down.

Traffic operational research has found that rumble strips can cause drivers on an intersection approach to begin slowing down earlier than they otherwise might. Vehicle speeds at distances of 90 to 150 m (300 to 500 ft) from a stop sign or traffic signal at treated sites are typically 3.2 to 6.4 km/hr (2 to 4 mph) lower than before installation. The percentage of drivers who come to a full stop at stop signs is also greater at these sites. Although rumble strips have been found to increase the speed variance on intersection approaches, there is no indication that this has any adverse effect on safety. Some highway agencies have experimented with decreasing the spacing between successive rumble strip patterns in the roadway to give drivers the impression that they are speeding up and thus encourage them to slow down.

Application of roadway rumble strips at too many locations may reduce their ability to gain the driver's attention. The factor of surprise may be vital to the effectiveness of this treatment; it works because it creates an unusual sensation for drivers. Rumble strips placed in the roadway are most desirable at locations where an accident problem has been documented and where conventional treatments such as signs have been found ineffective. At a few locations it may be desirable to install rumble strips in a roadway if accident problems have been encountered at similar locations, even if there is no documented accident history at that specific site.

Potential Adverse Effects

Several potential adverse effects of this device are of concern to highway agencies. First, the noise generated by vehicles passing over a rumble strip can be objectionable to nearby residents. A number of highway agencies have consequently adopted policies that restrict the use of rumble strips in residential areas.

HARWOOD

FIGURE 1 Typical raised rumble strip in roadway on intersection approach.

There is also concern that the grooved or ridged surface of a rumble pattern in the roadway may pose a hazard to bicyclists or motorcyclists who might strike it and lose control of their vehicles. Some highway agencies have restricted the use of roadway rumble strips to locations with minimal bicycle traffic in the roadway or where a separate bicycle lane is provided. Because there are no reliable data on whether these concerns are valid, further research on this issue is warranted.

Finally there is particular concern that pavement treatments that are too high or too deep may create a jarring action and that drivers may fear the possibility of damage to their vehicle. It has been observed that this may lead some drivers into undesirable behavior such as avoiding the treated area by moving onto the shoulder or into the opposing traffic lanes. For this reason a number of highway agencies have concluded that rumble strips should be limited to a maximum height or depth of 1.2 mm (0.5 in.) to minimize the jarring effect on vehicles while still generating an unmistakable warning.

The noise created by vehicles passing over rumble strips limits their use in residential areas. With the exception of bicy-

clist and motorist concerns, which are not well documented at present, the other potential adverse effects of rumble strips appear to be manageable problems that should not prevent their use where increased safety is desired.

Cost and Service Life

Because rumble strip installation is not often treated as a separate payment item in highway construction contracts, cost data for this activity are limited. Costs are typically quoted as a cost per linear foot or as a lump sum per intersection approach. One highway agency has estimated that raised rumble strips in the roadway cost $4.59 per meter ($1.40 per linear foot). Reported costs for grooved rumble strips range from $2.92 to $7.31 per meter ($0.89 to $2.23 per linear foot). One highway agency reported lump-sum costs of $400 per intersection approach for grooved strips and $500 per intersection approach for raised strips. The Kansas Department of Transportation has reported that its paving costs have not risen since it began including rumble strips in its payment items for paving.

One vendor has reported that temporary rumble strips for use in work zones can be purchased for $4 per strip. These strips are 0.6 m (2 ft) wide, so that six at a total cost of $24 must be used side by side to extend for the entire width of a 3.6-m (12-ft) lane. All cost data in this article were supplied by highway agencies and vendors during 1991. These costs have probably risen moderately in the intervening years.

Most highway agencies have reported that the service life of rumble strips should be the same as the service life of the pavement itself: 7 to 8 years between resurfacing for asphalt pavements and 25 years or more for portland cement concrete pavements. One toll road authority reported a service life of 5 years for rumble strips installed on asphalt pavement in the roadway on toll plaza approaches; this is equivalent to the normal interval between resurfacing for such a high-wear location. One highway agency has observed that grooves in an asphalt pavement surface with an initial depth of 1.2 mm (0.5 in.) were worn by the continual passage of traffic to about half their initial depth within 2 years. Comparable grooves in a portland cement concrete roadway surface took 5 years to wear to half their initial depth.

Rumble Strips on Roadway Shoulders

Rumble strips on roadway shoulders warn fatigued or inattentive drivers that their vehicles are leaving or have left the roadway and that a steering correction is needed to return to the road. A continuous shoulder treatment along a roadway section and a rumble strip installed at a narrow bridge approach on a horizontal curve where drivers may leave the road unintentionally are shown in Figures 2 and 3.

The earliest experiments with the shoulder treatments first known as "singing shoulders" were conducted on the Garden State Parkway in New Jersey in 1955. Other early tests were conducted in Arizona, Florida, and Illinois. Despite these early trials, the application has only recently come into widespread use along extended sections of highway.

Design and Placement

Shoulder rumble strips may consist of a continuous sequence of grooves placed in the surface of an asphalt shoulder, patterns installed at regular intervals on a portland cement concrete shoulder, or patterns installed at critical locations—such as exit ramps, entrance ramps, or narrow bridge approaches—along either type of shoulder.

Continuous grooves as shown in Figure 2 can be placed on an asphalt shoulder with a special roller while the asphalt is still hot during the paving operation (Figure 4). Intermittent patterns on portland

FIGURE 2 Continuous rumble strips on asphalt shoulder.

FIGURE 3 Shoulder rumble strips on narrow bridge approach.

cement concrete shoulders consist of grooves formed at the time of construction during the finishing of the concrete surface. As in the case of roadway grooves, shoulder grooves have a recommended maximum depth of 1.2 mm (0.5 in.).

Raised pavement markers can also be placed on roadway shoulders, as shown in Figure 5. This approach allows the markers to be removed if it becomes desirable to use the shoulder temporarily as a travel lane during rehabilitation or reconstruction of the roadway.

Traffic Operational and Safety Effects

Two major studies of the safety effectiveness of continuous shoulder rumble strips have been performed. A 1985 evaluation by the California Department of Transportation (Caltrans) reported that installing this treatment on long, monotonous stretches of freeway through desert areas of California reduced run-off-road accidents by 49 percent (2). Thus this application appears to be effective in reducing accidents caused by driver inattentiveness, with one caveat—the issue of accident migration—which is discussed later. All of the shoulder treatments evaluated by Caltrans were composed of a continuous sequence of grooves on asphalt shoulders, similar to those shown in Figure 2.

Another 1985 study for the Federal Highway Administration evaluated the accident-reduction effectiveness of shoulder rumble strips installed at 10 freeway sites in 5 states: Arizona, California, Mississippi, Nevada, and North Carolina (3). Sites with both asphalt and portland cement concrete shoulders were included in the evaluation. The three sites in California were among those included in the Caltrans study previously described. It was reported in this study that the installation reduced run-off-road accidents by 20 percent (and only 6 percent at the sites located outside the California desert areas, which is substantially less than the effectiveness estimate reported in the Caltrans study. It is likely that the greater effectiveness was found at the California sites because these desert freeways may have a more serious run-off-road accident problem than other less monotonous sites.

Since the publication of *NCHRP Synthesis 191,* concern has been raised that the observed benefits from shoulder rumble strips could be partially offset by the phenomenon known as accident migration. For example, suppose that a fatigued driver inadvertently runs onto the shoulder of a treated section, is alerted by passing over a grooved or raised surface, and returns safely to the road without having an accident. Further down the road, the same fatigued driver may run onto the shoulder at an untreated location, continue onto the roadside, and either roll over on a side slope or collide with a fixed object. Thus the installation of shoulder rumble strips could result in an apparent migration of accidents from treated to untreated locations.

The Caltrans and FHWA studies reported increases in accidents of 20 percent and 9 percent, respectively, on roadways used as control sections, many of which were adjacent to the treated sections. This could indicate that the accident-reduction benefits of shoulder rumble strips on the treated sites are being partially offset by a spillover effect related to accident migration from the treated sections to the control sections. A more complete investigation of this issue is needed, with emphasis on both accident-reduction benefits at the treated sites and possible accident-migration effects on adjacent untreated sites.

The results reported here indicate that installation of shoulder rumble strips can be a highly cost-effective accident countermeasure, particularly given their extremely low installation costs, described below. However the possibility of accident migration suggests that continuous installations over extended highway sections may be necessary to get the most benefit from them as an accident countermeasure. In contrast to rumble strips placed in the roadway, there is little concern that shoulder rumble strips may be overused, because drivers only encounter them by leaving the roadway.

Potential Adverse Effects

There are few potential adverse effects of shoulder rumble strips that would create any potential restriction on their use, particularly on freeways. Noise is not a major concern because vehicle encounters with shoulder rumble strips are relatively infrequent. Shoulder rumble strips may create some problems in plowing snow on roadways and shoulders and in creating erosion caused by runoff where rumble strips extend to the outside edge of the shoulder. These problems can generally be remedied through adjustments in rumble strip design and location.

Use of shoulder rumble strips, either continuously or at regular intervals, over extended highway sections should be

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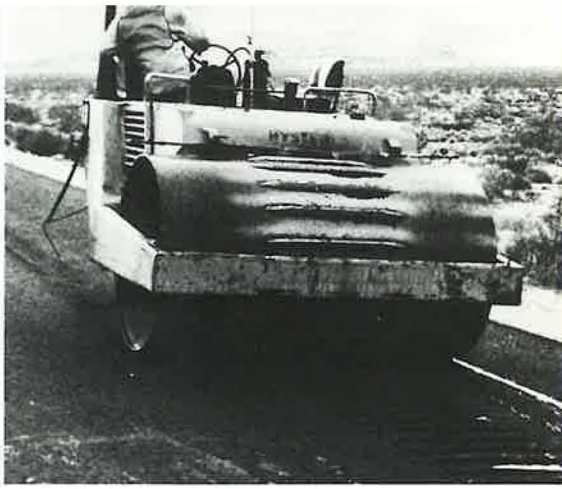

FIGURE 4 Roller being used to place rumble strips on asphalt shoulder.

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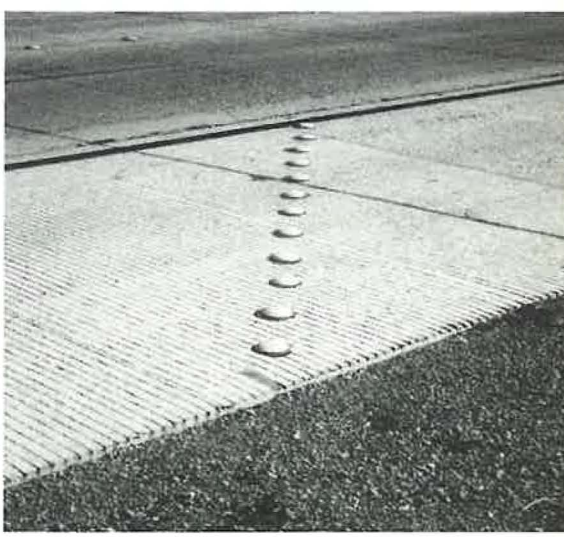

FIGURE 5 Typical installation of raised pavement markers to provide shoulder rumble strips.

carefully considered on bicycle routes. Bicycle considerations are primarily a concern on nonfreeway facilities, because bicycles are normally prohibited on freeways. Although the treated surface often extends across only part of the shoulder width, the area between it and the outside of the shoulder is often covered with debris. Installation may not be desirable if it results in a substantial number of bicyclists riding in the roadway instead of on the shoulder. It may be desirable to move the rumble strip farther from the travel lanes so that bicyclists can ride between it and the roadway, although this moves bicyclists closer to motor vehicle traffic and decreases the recovery area available to inattentive drivers.

Cost and Service Life

The cost of rumble strip installation on an asphalt shoulder is essentially equivalent to the cost of installation in the roadway if the shoulder surface is treated by grinding or sawing. When rumble strips are rolled into an asphalt shoulder during resurfacing, reported costs vary from $93 to $361 per km ($150 to $580 per mi) for a continuous 0.6- to 1.5-m (2- to 5-ft) wide strip along one shoulder. This is equivalent to a cost of $372 to $1,442 per km ($600 to $2,320 per mi) to treat all four shoulders of a divided freeway. Limited cost data are available for rumble strips on portland cement concrete shoulders, but one agency reported that rumble strips had been added to a construction contract by change order for $0.04 per square meter ($0.05 per square yard) of the rumble strip pattern. There are no data on the service life of rumble strips placed on roadway shoulders, but it should generally be as long as the service life of the shoulder itself because the strips should be subjected to little traffic wear.

Findings

Rumble strips placed in the roadway provide safety benefits when used at a limited number of locations with safety problems that cannot be corrected in any other way. They can direct driver attention to traffic control devices, but should not be expected by themselves to be effective speed control devices. Roadway rumble strips should not be overused or they may lose their effectiveness at the locations where they are most needed.

Shoulder rumble strips are inexpensive to install and appear to provide a reduction in run-off-road accidents caused by driver inattentiveness, although the magnitude of the reduction has not been well quantified. Their safety benefits and minimal cost may make them appropriate for widespread use, particularly on freeways and other roadways where bicycle traffic is not permitted or where bicycle volumes are minimal.

Public Information Programs

A public information program is recommended to educate drivers about the purposes of this pavement treatment, including both roadway and shoulder installations, particularly in and near areas being treated for the first time. Some motorists have been seen to stop and check their tires after encountering a treated surface; other drivers have called highway agencies to complain about imperfections in the pavement. Clearly such motorists do not understand rumble strips and need additional information.

Future Research Needs

Future research is needed on several issues related to rumble strips:

- A well-designed evaluation is needed to determine the safety effectiveness of rumble strips placed in the roadway. The studies available in the published literature are not adequate for this purpose.
- A well-designed evaluation is also needed to more precisely quantify the accident-reduction effectiveness and cost-effectiveness of shoulder rumble strips in reducing run-off-road accidents. This evaluation should be structured to investigate the issue of accident migration.
- Current designs should be evaluated to determine whether they create control problems for bicyclists and motorcyclists. If control problems are found, alternative designs that do not create problems should be developed.
- Innovative methods of creating rumble effects without raised or grooved strips should be evaluated. For example, exposed aggregate pads merit further investigation to determine their effectiveness and service life for use on both roadways and shoulders.
- Further noise studies are needed to determine whether designs can be developed to minimize noise that is disturbing to nearby residents. Guidelines that specify the minimum distance from rumble strips to the nearest residence are needed.
- It should be determined whether the noise and vibration created by rumble strips are more objectionable to older drivers than to younger drivers and whether any problems experienced by older drivers can be minimized by alternative designs.

References

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