

National Cooperative Highway Research Program

NCHRP Synthesis 191

**Use of Rumble Strips
to Enhance Safety**

A Synthesis of Highway Practice

**Transportation Research Board
National Research Council**

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National Cooperative Highway Research Program

Synthesis of Highway Practice 191

Use of Rumble Strips to Enhance Safety

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and Traffic Control

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Systematic, well-designed research provides the most effective approach to the solution of many problems facing highway administrators and engineers. Often, highway problems are of local interest and can best be studied by highway departments individually or in cooperation with their state universities and others. However, the accelerating growth of highway transportation develops increasingly complex problems of wide interest to highway authorities. These problems are best studied through a coordinated program of cooperative research.

In recognition of these needs, the highway administrators of the American Association of State Highway and Transportation Officials initiated in 1962 an objective national highway research program employing modern scientific techniques. This program is supported on a continuing basis by funds from participating member states of the Association and it receives the full cooperation and support of the Federal Highway Administration, United States Department of Transportation.

The Transportation Research Board of the National Research Council was requested by the Association to administer the research program because of the Board's recognized objectivity and understanding of modern research practices. The Board is uniquely suited for this purpose as: it maintains an extensive committee structure from which authorities on any highway transportation subject may be drawn; it possesses avenues of communications and cooperation with federal, state, and local governmental agencies, universities, and industry; its relationship to the National Research Council is an insurance of objectivity; it maintains a full-time research correlation staff of specialists in highway transportation matters to bring the findings of research directly to those who are in a position to use them.

The program is developed on the basis of research needs identified by chief administrators of the highway and transportation departments and by committees of AASHTO. Each year, specific areas of research needs to be included in the program are proposed to the National Research Council and the Board by the American Association of State Highway and Transportation Officials. Research projects to fulfill these needs are defined by the Board, and qualified research agencies are selected from those that have submitted proposals. Administration and surveillance of research contracts are the responsibilities of the National Research Council and the Transportation Research Board.

The needs for highway research are many, and the National Cooperative Highway Research Program can make significant contributions to the solution of highway transportation problems of mutual concern to many responsible groups. The program, however, is intended to complement rather than to substitute for or duplicate other highway research programs.

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The project that is the subject of this report was a part of the National Cooperative Highway Research Program conducted by the Transportation Research Board with the approval of the Governing Board of the National Research Council. Such approval reflects the Governing Board's judgment that the program concerned is of national importance and appropriate with respect to both the purposes and resources of the National Research Council.

The members of the technical committee selected to monitor this project and to review this report were chosen for recognized scholarly competence and with due consideration for the balance of disciplines appropriate to the project. The opinions and conclusions expressed or implied are those of the research agency that performed the research, and, while they have been accepted as appropriate by the technical committee, they are not necessarily those of the Transportation Research Board, the National Research Council, the American Association of State Highway and Transportation Officials, or the Federal Highway Administration of the U.S. Department of Transportation.

Each report is reviewed and accepted for publication by the technical committee according to procedures established and monitored by the Transportation Research Board Executive Committee and the Governing Board of the National Research Council.

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PREFACE

A vast storehouse of information exists on nearly every subject of concern to highway administrators and engineers. Much of this information has resulted from both research and the successful application of solutions to the problems faced by practitioners in their daily work. Because previously there has been no systematic means for compiling such useful information and making it available to the entire highway community, the American Association of State Highway and Transportation Officials has, through the mechanism of the National Cooperative Highway Research Program, authorized the Transportation Research Board to undertake a continuing project to search out and synthesize useful knowledge from all available sources and to prepare documented reports on current practices in the subject areas of concern.

This synthesis series reports on various practices, making specific recommendations where appropriate but without the detailed directions usually found in handbooks or design manuals. Nonetheless, these documents can serve similar purposes, for each is a compendium of the best knowledge available on those measures found to be the most successful in resolving specific problems. The extent to which these reports are useful will be tempered by the user's knowledge and experience in the particular problem area.

FOREWORD

*By Staff
Transportation
Research Board*

This synthesis will be of interest to traffic engineers, highway design engineers, highway maintenance personnel, those responsible for toll plaza design and operation, and others concerned with the operation, safety, and design of the roadway environment. Information is presented on the various applications of rumble strips on the traveled way and on highway shoulders.

Administrators, engineers, and researchers are continually faced with highway problems on which much information exists, either in the form of reports or in terms of undocumented experience and practice. Unfortunately, this information often is scattered and unevaluated and, as a consequence, is seeking solutions, full information on what has been learned about a problem frequently is not assembled. Costly research findings may go unused, valuable experience may be overlooked, and full consideration may not be given to available practices for solving or alleviating the problem. In an effort to correct this situation, a continuing NCHRP project, carried out by the Transportation Research Board as the research agency, has the objective of reporting on common highway problems and synthesizing available information. The synthesis reports from this endeavor constitute an NCHRP publication series in which various forms of relevant information are assembled into single, concise documents pertaining to specific highway problems or sets of closely related problems.

This synthesis describes the state of the practice with respect to placement, operational and safety effects, design, installation, and cost and service life of rumble strips. This report of the Transportation Research Board also discusses the effectiveness of rumble strips in preventing or reducing accidents. It provides infor-

mation on the potential adverse effects of rumble strips, such as noise, motorist use of opposing lanes to avoid rumble strips, maintenance problems, and concerns of special users such as senior citizens, cyclists, and truckers. The need for signing and public information support are also discussed. The synthesis presents several recommendations for future research.

To develop this synthesis in a comprehensive manner and to ensure inclusion of significant knowledge, the Board analyzed available information assembled from numerous sources, including a large number of state highway and transportation departments. A topic panel of experts in the subject area was established to guide the researcher in organizing and evaluating the collected data, and to review the final synthesis report.

This synthesis is an immediately useful document that records practices that were acceptable within the limitations of the knowledge available at the time of its preparation. As the processes of advancement continue, new knowledge can be expected to be added to that now at hand.

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Director of Engineering for Highways, American Concrete Pavement Association; James Migletz, Vice President, Graham-Migletz Enterprises, Inc.; Burton W. Stephens, Chief, Traffic Performance Branch, Federal Highway Administration; Dean Testa, Chief of Construction and Maintenance, Kansas Department of Transportation; and Homer G. Wheeler, Regional Engineer, Strategic Highway Research Program.

Richard A. Cunard, Engineer of Traffic and Operations, Transportation Research Board, assisted the NCHRP Project 20-5 Staff and the Topic Panel.

Information on current practice was provided by many highway and transportation agencies. Their cooperation and assistance were most helpful.

USE OF RUMBLE STRIPS TO ENHANCE SAFETY

SUMMARY

Rumble strips are raised or grooved patterns placed on the pavement surface of a roadway or traveled way. Their purpose is to provide motorists with an audible and tactile warning that their vehicle is approaching a decision point of critical importance to safety or that their vehicle has partially or completely left the road. Rumble strips can be installed either in the traveled way of a roadway or on the roadway shoulder.

Rumble strips placed in the traveled way may consist of transverse raised bars or grooves. Exposed-aggregate rumble pads may also be used to create the same effect. Whatever their form, rumble strips in the traveled way are warning devices intended to alert drivers to the possible need to take some action. Rumble strips in the traveled way may be used:

- On approaches to intersections;
- On approaches to toll plazas;
- On approaches to horizontal curves;
- In the lane to be closed;
- On the approach to a mainline lane drop; and
- On approaches to or within work zones.

Signing may be used in conjunction with rumble strips to help the driver determine the appropriate action (e.g., STOP AHEAD sign, horizontal curve warning sign, speed limit sign). Locating rumble strips so that either the upcoming decision point or a sign identifying the action that may be required is clearly visible as the driver passes over the rumble strip and allowing time for drivers to take that action is essential.

The accident reduction effectiveness of rumble strips placed on intersection approaches has not been precisely quantified, but studies suggest that rumble strips can provide a reduction of at least 50 percent in the types of accidents most susceptible to correction. These include rear-end accidents and accidents involving running through a STOP sign or traffic signal. No similar accident reduction effectiveness estimates are available for other applications of rumble strips in the traveled way.

Traveled-way rumble strips should not be overused. If rumble strips are used at too many locations they may lose their ability to gain the motorists' attention. Rumble strips placed in the traveled way are most desirable at locations where there is a documented accident problem and where conventional treatments—such as signing—have been tried and found to be ineffective. At a few locations, it may be desirable to install rumble strips in the traveled way at a specific location, even

when there is no documented accident history, if accident problems have been encountered at similar locations.

Rumble strips are not generally effective as speed control devices. Their primary function is to draw the driver's attention to traffic control devices or potential hazards that unfamiliar drivers may fail to see. Where a substantial proportion of drivers fail to see speed limit signs or roadway features at which they would normally reduce speed, using rumble strips to call their attention to those signs or roadway features may result in a reduction in vehicle speeds. However, rumble strips should not be expected, in and of themselves, to reduce the speeds selected by drivers at locations where there is no apparent reason to slow down.

In residential areas, rumble strips placed in the traveled way may be objectionable to nearby residents because of the noise generated by vehicles continuously passing over the rumble strips.

Shoulder rumble strips may consist of continuous rumble strip grooves in the surface of an asphalt shoulder, rumble strip patterns at regular intervals on asphalt or portland cement concrete shoulders, or rumble strip patterns at critical locations along asphalt or portland cement concrete shoulders (such as at exit ramps, entrance ramps, or on narrow bridge approaches).

Shoulder rumble strips are warning devices intended to alert drivers that they are leaving (or have left) the traveled way and that a steering correction is needed to return to the traveled way.

Continuous rumble strips on asphalt shoulders or rumble strips installed at regular intervals along extended sections of asphalt or portland cement concrete shoulders have generally been shown to reduce the rate of run-off-road accidents by 20 percent or more. On highways with extremely monotonous driving conditions, such as freeways in desert regions of the West, reductions in run-off-road accident rates as high as 50 percent may be expected. Because of these substantial accident reduction benefits, shoulder rumble strips have been widely installed on freeways and other types of rural highways by some highway agencies. No similar accident reduction effectiveness estimates are available for shoulder rumble strips installed exclusively at critical locations such as exit ramps, entrance ramps, and narrow bridge approaches.

Specific concerns that affect the designs for rumble strips and the locations where rumble strip installation is appropriate include

- Noise created by rumble strip installations,
- Motorist use of opposing lanes to avoid rumble strips,
- Maintenance problems,
- Motorist concerns,
- Bicyclist concerns, and
- Motorcyclist concerns.

Each of these issues is addressed in this synthesis.

A public information program is recommended to educate motorists about the purposes of rumble strips, including installations on both the traveled way and on shoulders. It is most important that informational signs accompany the rumble strips so that the driver can take action.

Future research should include a well-designed safety evaluation to quantify the accident reduction effectiveness of rumble strips. Other potential research needs include an evaluation to distinguish between the safety effectiveness of shoulder rumble strips on the left and right sides of the traveled way, whether rumble strips create control problems for bicyclists and motorcyclists, use of alternative methods, (such as exposed aggregate) to create a rumble effect, methods to minimize noise effects on adjacent properties, and attitudes of older drivers toward rumble strips.

INTRODUCTION

DESCRIPTION OF RUMBLE STRIPS

A rumble strip is a raised or grooved pattern placed on the pavement surface of a roadway or shoulder. Rumble strips are intended to provide motorists with an audible and tactile warning that their vehicle is approaching a decision point of critical importance to safety or that the driver has partially or completely left the traveled way. An audible warning to drivers is provided by the noise generated by the vehicle tires passing over the rumble strip. A tactile warning to the driver is provided by the vibration induced in the vehicle by the rumble strip; the driver senses this vibration through contact with the steering wheel and the vehicle seat. Rumble strips have been applied on the approach to intersections where the driver may be required to stop and on highway shoulders where a driver may have inadvertently left the road. Rumble strips are intended to alert drivers to potential decision points or roadside hazards in their path in time for them to take appropriate corrective action.

While rumble strips warn drivers that some action may be necessary, they do not identify what action is appropriate. Depending on the rumble strip application, the action desired of the driver may be stopping, slowing, changing lanes, steer-

ing into a curve, or steering back onto the roadway. The rumble strip alerts the driver that some action may be necessary and the driver must use visual cues to decide what type of action is appropriate. Thus, rumble strips serve only to supplement, or call attention to, information that reaches the driver visually. Signing may be used in conjunction with rumble strips to communicate the desired action to the driver, especially at locations where an upcoming decision point (such as an intersection or horizontal curve) is not readily visible. Rumble strips may be used to call special attention to regulatory or warning signs of particular importance.

Only those devices placed on the roadway or shoulder surface that function primarily by creating an audible or tactile warning are considered to be rumble strips. The driver's attention is gained by hearing the sound of the vehicle tires passing over the rumble strip or by feeling the vibration induced by the vehicle tires passing over the rumble strip, or both. Other names for rumble strips that have been used by highway agencies include "chatter strips" and "jiggle bars."

Rumble strips are not generally intended as speed control devices, although they may be used to direct the driver's attention to signs concerning regulatory or advisory speed limits. In contrast, devices such as speed humps and speed

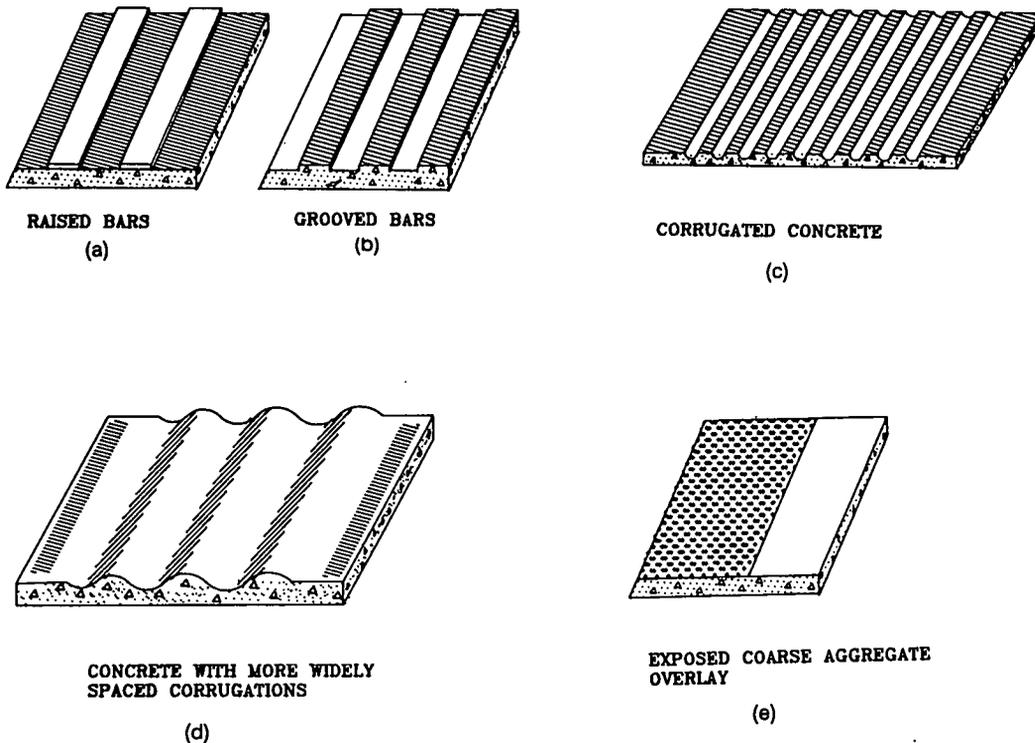


FIGURE 1 Types of rumble strips (1).

bumps that are intended to slow vehicles by creating a physical obstacle that can be comfortably traversed only at low speeds are not considered to be rumble strips. Speed humps and speed bumps are intended to be seen so that the driver can slow before reaching the hump or bump. Speed humps and speed bumps are generally 3 to 4 in. high, while rumble strips are typically less than 1 in. high. Speed humps typically have lengths of at least 12 ft, while speed bumps are shorter (1 to 3 ft long) with a more abrupt rise that is intended to force drivers to slow down. Since rumble strips operate by generating audible and tactile sensations, it is not necessary for a driver to see a rumble strip in order for the rumble strip to accomplish its purpose.

Figure 1 summarizes the common types of rumble strips in current use. These include: (a) raised bars; (b) grooved bars; (c) corrugated portland cement concrete; (d) concrete with more widely spaced corrugations; and (e) overlays with exposed coarse aggregate. Conventional rumble strips, like those shown in parts (a) through (d) of Figure 1, consist of a pattern or cluster of parallel bars or grooves spaced a short distance apart. Highway agencies are currently experimenting with rumble pads consisting of roadway or shoulder areas resurfaced with exposed-aggregate overlays (or chip-seal overlays), like that shown in part (e) of Figure 1. Rumble pads of exposed-aggregate overlays, typically about the size of a conventional rumble strip pattern, can be used to create a rumbling effect similar to a conventional pattern. In addition, rumble strips can be formed with raised pavement markers (buttons) or with strips of polycarbonate material glued to the pavement surface with an epoxy material. Each of these types of rumble strips is discussed in more detail later in the synthesis.

SCOPE OF THIS SYNTHESIS

This synthesis describes the application of rumble strips to enhance highway safety. The scope of the synthesis is limited to rumble strips, as defined above, and does not include devices with other purposes, such as speed humps or speed bumps. Subsequent sections of this synthesis describe applications for which rumble strips have been used, operational and safety effectiveness of rumble strips, potential adverse effects of rumble strip usage, design and installation specifications for rumble strips, and their estimated cost and service life.

A survey of state and local highway agencies and toll road authorities was conducted during the preparation of this synthesis. The survey was conducted by means of a mail questionnaire sent to the 50 state highway agencies, 98 selected local agencies, and 15 selected toll road authorities. For state highway agencies, the questionnaire was sent to the headquarters office rather than to specific district or field offices. A total of 123 responses to the questionnaire were received for an overall response rate of 76 percent. Responses were received from 92 percent of the state highway agencies (46 out of 50), 63 percent of the local agencies (62 out of 98), and 100 percent of the toll road authorities (15 out of 15).

Appendix A of this synthesis presents the results of the survey described above. Appendix B presents a typical specification for installation of rumble strips in the traveled way. Appendices C and D present typical specifications for rumble strip installation on asphalt and portland cement concrete shoulders, respectively. Appendix E presents examples of typical rumble strip installations used in work zones.

RUMBLE STRIP APPLICATIONS

This chapter describes the applications of rumble strips used by highway agencies to enhance safety. The reasons for using rumble strips, the types of locations where rumble strips have been applied by highway agencies, and the applications for which rumble strips have been used in the traveled way and on shoulders are discussed.

REASONS FOR USING RUMBLE STRIPS

The six basic reasons for rumble strips are to:

- Warn drivers of the need to stop,
- Warn drivers of the need to slow down,
- Warn drivers of the need to change lanes,
- Warn drivers of changes in roadway alignment, such as horizontal curves,
- Warn drivers that they are leaving (or have left) the traveled way, and
- Warn drivers of other potentially unexpected situations, such as a recent change in traffic control devices.

Rumble strips have been used by highway agencies in the United States for each of these reasons since at least the 1950s. As documented in the user survey results presented in Appendix A, rumble strips have been used by 98 percent of state highway agencies, 87 percent of toll road authorities, and 24 percent of local agencies that responded to the survey. Examples of specific rumble strip applications are presented below.

LOCATIONS WHERE RUMBLE STRIPS ARE USED

This section presents the locations where rumble strips are used by highway agencies to enhance safety. The discussion includes comments on the number of highway agencies that have used each rumble strip application.

Rumble strip applications fall into two general categories, those that are placed in the traveled way, and those placed on roadway shoulders or other areas outside the traveled way.

Rumble strips placed in the traveled way are intended to warn drivers of a specific upcoming condition on the traveled way, such as an intersection, a horizontal curve, or a work zone. Rumble strips on roadway shoulders are used to alert drivers that they have left the traveled way and that a steering correction is necessary to return to the traveled way. Each of these applications is discussed below.

Rumble Strips Placed in the Traveled Way

Rumble strips may be placed in the traveled way to alert motorists approaching intersections, toll plazas, horizontal curves, lane drops, work zones, or any other location where

any unexpected condition is present. The survey results in Appendix A indicate that, of highway agencies that have used rumble strips, 91 percent of state agencies, 69 percent of toll roads, and 47 percent of local agencies have used rumble strips placed in the traveled way.

Since rumble strips in the traveled way alert drivers to decision points of critical importance but do not tell drivers what action to take, they must be placed so that either the upcoming decision point, or a sign identifying the action that may be required, is clearly visible as the driver passes over the rumble strip. Thus, traveled way rumble strips should never be used alone, but always in conjunction with traffic control devices or visual cues that help the driver to identify the potentially required action (e.g., stopping, slowing, or changing path). Rumble strip locations should be selected to provide adequate advance warning time for drivers to take the potentially required action.

Approaches to Intersections

Rumble strips have been used extensively on approaches to intersections and other junctions. The most common use of rumble strips is on intersection approaches controlled by a STOP sign, but they have also been employed on approaches to signalized intersections, especially for isolated signals on high-speed roadways where drivers may not expect the presence of a signal.

Rumble strips are most appropriate for installation on intersection approaches where, because of limited sight distance or the undeveloped nature of the environment, drivers may not expect to find an intersection. The use of a rumble strip may alert drivers of the need to stop at the intersection and may thus reduce right-angle accidents associated with running through the STOP sign or signal and rear-end accidents associated with collisions between an approaching vehicle and a vehicle stopped at the intersection. The survey in Appendix A indicates that, of highway agencies that have used rumble strips, 82 percent of state agencies and 47 percent of local agencies have used them in the traveled way on intersection approaches.

Figure 2 is a photograph of a typical rumble strip installation on an approach to a STOP-controlled intersection. This particular example shows only one pattern or cluster of rumble strips (raised bars, in this case) on the approach to the intersection, but a number of agencies use multiple rumble strip clusters on intersection approaches (see the section of this synthesis on rumble strip design and installation).

Approaches to Toll Plazas

Rumble strips have been used extensively on the approaches to toll plazas for bridges, tunnels, and toll roads. Figures 3



FIGURE 2 Typical raised rumble strip in the traveled way on an intersection approach.

and 4 are photographs of typical toll plaza approaches with rumble strips installed. Figure 3 illustrates a rumble strip that consists of a pattern of raised bars transverse to the direction of vehicle travel, while Figure 4 shows the use of raised pavement markers to create the same effect.

Rumble strips may be appropriate on the approach to any toll collection facility where drivers are required to stop. However, rumble strips are most needed at locations where motorists approach the toll plaza after long hours of monotonous driving under open road conditions and where the appearance of a toll plaza might be unexpected. For example, rumble strips may be more appropriate on the approach to toll plazas that extend across the main lanes of a toll road, as opposed to exit ramps where toll plazas are more likely to be expected by drivers.

Appendix A indicates that 27 percent of state highway agencies and 54 percent of toll road authorities have used rumble strips in the traveled way on the approaches to toll plazas.

Approaches to Horizontal Curves

Rumble strips in the traveled way have been used by a few agencies on the approaches to sharp horizontal curves, particularly curves with advisory speed limits and curves at the



FIGURE 3 Raised rumble strip on the approach to a toll plaza.



FIGURE 4 Raised pavement markers used as rumble strips on the approach to a toll plaza.

end of long tangent sections. Rumble strip usage on the approach to a horizontal curve is intended to reduce skidding or run-off-road accidents involving drivers who do not see the curve or who enter the curve at too high a speed. The Appendix A survey indicated that, of highway agencies that have used rumble strips, 22 percent of state agencies, and 33 percent of local agencies have used them in the traveled way on horizontal curve approaches.

Approaches to Lane Drops

A limited number of highway agencies have used rumble strips in advance of locations where the right or left lane is dropped on a mainline freeway. Rumble strips are placed in the lane that will be dropped to alert drivers to the need to vacate the lane. Two state highway agencies and two local highway agencies reported using rumble strips for this application.

Rumble strips are not well-suited for use in lanes that are dropped at a freeway exit, because the warning conveyed by the rumble strip is appropriate for only a portion of the drivers in that lane. A rumble strip could be effective in alerting drivers of through vehicles of the need to change lanes, however, the rumble strip would provide an unnecessary (and, possibly, even a misleading) message to exiting drivers who do not need to change lanes. Thus, rumble strips are potentially appropriate for use in advance of mainline lane drops, but not in advance of lane drops at freeway exits.

Approaches to and Within Work Zones

Rumble strips in the traveled way have been used on approaches to and within work zones to warn drivers of lane closures or restrictions, width reductions, sharp detour transitions, or other conditions that might require drivers to change their path or substantially reduce speed (1). Rumble strips may be employed, as appropriate, on the approach to the work zone or within the work zone on the approach to a specific restriction or detour. Seventeen highway agencies,

including 11 state agencies, one local agency, and five toll road authorities indicated that they have used rumble strips in the traveled way within work zones.

Other Traveled Way Locations

Rumble strip usage in the traveled way may also be appropriate at other locations. Two highway agencies have reported using rumble strips in the traveled way at the end of a freeway where all of the mainline traffic is routed back onto a conventional highway. One highway agency has reported using rumble strips in the traveled way in advance of school crossings on high-volume roads. The user survey in Appendix A indicates that rumble strips are not currently being used by highway agencies in the traveled way on approaches to railroad-highway grade crossings and narrow bridges. However, published literature indicates that rumble strips have been used in the past at railroad-highway grade crossings in at least four states (2,3) and rumble strips are being used on shoulders on approaches to narrow bridges.

Rumble strips may be effective in calling attention to recent changes in traffic control devices. For example, one state highway agency is currently using rumble strips in the traveled way, in conjunction with speed limit signing, at each location where the 65-mph rural freeway speed limit is reduced to 55 mph upon entering an urban area. Temporary installation of rumble strips may also be appropriate on intersection approaches where a STOP sign or traffic signal has been installed for the first time.

A unique application of rumble strips by one highway agency is the placement of rumble strips along the centerline of two-lane two-way rural highways for the specific purpose of alerting drivers when they inadvertently cross the roadway centerline. Another highway agency has reported the use of rumble strips to delineate center two-way left-turn lanes on arterial streets and exclusive turn lanes at intersections.

Highway agencies that routinely use raised pavement markers for traffic control markings are, in effect, providing rumble strips. For example, some highway agencies routinely use raised pavement markers to delineate highway centerlines, lane lines, and edge lines. Raised pavement markers used for such applications serve as rumble strips to alert motorists who inadvertently cross these lines. However, raised pavement markers are used extensively only in areas with little or no snowfall, because snowplows tend to dislodge the markers.

Rumble Strips Placed on Highway Shoulders

The use of rumble strips on highway shoulders to warn the drivers of errant vehicles that they are leaving (or have left) the traveled way is becoming increasingly common. This practice started with limited usage of corrugated areas of concrete pavement or "chatter strips" in critical spots such as at the gore areas of freeway off-ramps and in shoulder areas beyond the end of lane drops. Some state highway agencies have, for a number of years, used rumble strips on highway shoulders on approaches to narrow bridges. Today, rumble strips are being used by some highway agencies intermittently or continuously along extended sections of rural and urban freeways and other major highways. These practices are described below.

Shoulder Rumble Strips Along Extended Highway Sections

Most rumble strip installations are at specific locations of critical importance to the driving task. However, a number of state highway agencies have recently begun the practice of providing rumble strips continuously or at specified intervals along extended sections of major highways, particularly freeways. Intermittent rumble strip patterns may be formed into portland cement concrete shoulders during finishing and continuous rumble strips may be placed into asphalt shoulders with a special roller during compaction. Grooved rumble strips may also be cut into existing shoulders by grinding or sawing. Figure 5 shows a continuous application of rumble strips that have been rolled into the surface of an asphalt shoulder. In Figure 6, rumble strip patterns placed at regular intervals on the portland cement concrete shoulder of a freeway are shown. Figure 7 shows similar rumble strip installations in the portland cement concrete shoulders of freeway ramps.

While most rumble strip installations on shoulders use grooves formed or cut into the pavement, a few highway agencies have used raised pavement markers on the shoulder. This type of rumble strip installation is illustrated in Figure 8.

Rumble strips on roadway shoulders are used to alert motorists that they are leaving (or have left) the traveled way. The audible and tactile sensation created by the rumble strip

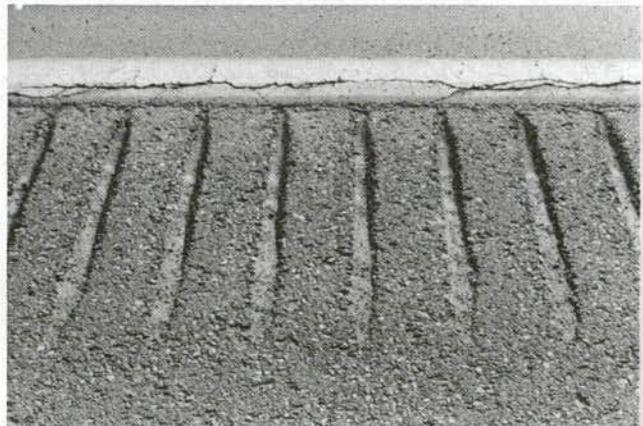


FIGURE 5 Continuous rumble strips on an asphalt shoulder.

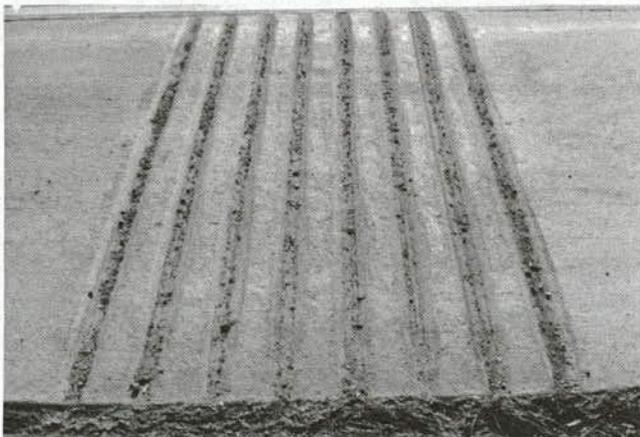


FIGURE 6 Rumble strips placed at regular intervals on portland cement concrete shoulder.

is intended to alert the driver that an unusual or unexpected condition has occurred. The encounter with the rumble strip is expected to help the errant driver realize that one or more of the vehicle's tires has left the roadway and that a steering correction must be made to return to the roadway.

The survey results presented in Appendix A indicate that 35 state highway agencies and nine toll road authorities have provided rumble strips at intervals or continuously along extended sections of highway. The survey responses indicate that six state agencies have used shoulder rumble strips on portland cement concrete shoulders only, 10 states have used shoulder rumble strips on asphalt shoulders only, and 23 states have used rumble strips on both portland cement concrete and asphalt shoulders. Of the highway agencies that have used shoulder rumble strips, 82 percent report using them in new construction or major reconstruction projects, while 35 percent report providing them in retrofitting projects on existing highways. A few highway agencies have adopted a policy of incorporating intermittent rumble strips in all new portland cement concrete shoulders on freeways or providing continuous rumble strips in all asphalt shoulders on freeways whenever the shoulder is resurfaced.

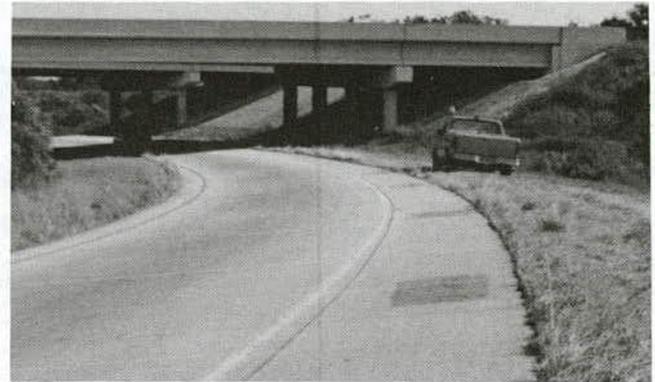


FIGURE 7 Rumble strips placed at regular intervals on portland cement concrete shoulders of freeway ramps.

Many miles of highway now have been built or resurfaced with continuous or intermittent rumble strips on the shoulders. In addition to use on freeways, a substantial number of highway agencies have also used shoulder rumble strips on multilane divided nonfreeways, multilane undivided nonfreeways, and two-lane highways (see highway agency responses in Appendix A).

A few highway agencies have used shoulder rumble strips exclusively on the right or outside shoulders of divided highways, while most have placed rumble strips on both the right (outside) and left (median) shoulders on divided highways. Only one highway agency reported using shoulder rumble strips exclusively on the left (median) shoulder of divided highways.

Shoulder Rumble Strips on Narrow Bridge Approaches

Seven state highway agencies have reported using shoulder rumble strips specifically on the approaches to narrow bridges. Shoulder rumble strips at narrow bridge sites are similar in purpose to the intermittent and continuous shoulder rumble strips described above. The rationale for using shoulder rumble strips just at narrow bridge approaches is that alerting errant drivers is much more critical at locations where a fixed

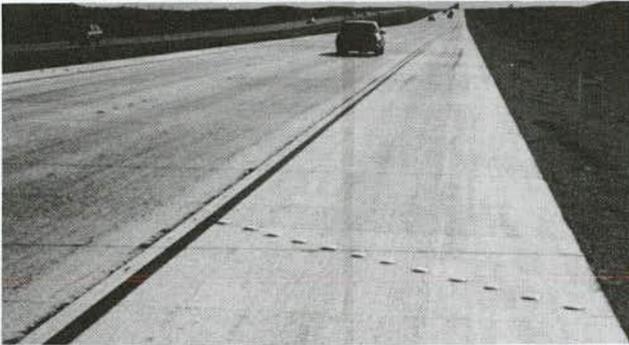
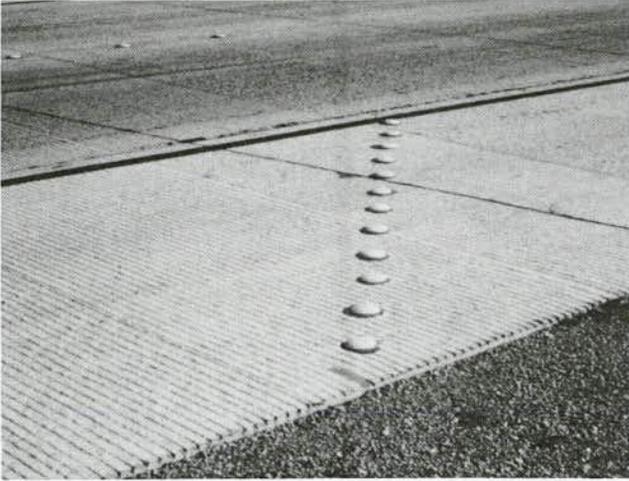


FIGURE 8 Typical installation of raised pavement markers to provide shoulder rumble strips.

object, such as a bridge rail, is present on the roadside than at other locations. Thus, narrow bridge approaches are logically assigned a high priority for the application of shoulder rumble strips. At least one highway agency has adopted a policy of providing shoulder rumble strips on the approach

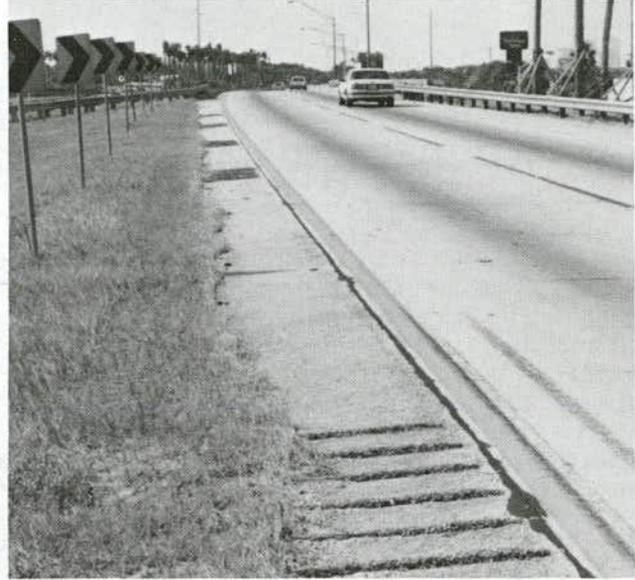


FIGURE 9 Shoulder rumble strips installed on narrow bridge approaches.

to all freeway bridges where the bridge shoulder is narrower than the approach shoulder. Figure 9 shows typical rumble strip applications on narrow bridge approaches.

Other Applications of Shoulder Rumble Strips

Other locations at which some highway agencies have applied shoulder rumble strips include work zones, gore areas of freeway off-ramps, paved highway medians (especially narrow medians), and outside shoulders of lane drops.

OPERATIONAL AND SAFETY EFFECTS OF RUMBLE STRIPS

This chapter summarizes the known information on the operational and safety effects of rumble strips, including rumble strips placed in the traveled way and rumble strips installed on roadway shoulders. The discussion addresses the effects of rumble strips on traffic accident experience, vehicle speeds, and driver compliance with traffic control devices. Work zone applications of rumble strips are discussed separately from other applications.

EFFECT OF RUMBLE STRIPS ON TRAFFIC ACCIDENT EXPERIENCE

The following discussion summarizes the results of research concerning the effect on accident experience of rumble strips placed in the traveled way (primarily on intersection approaches) and rumble strips installed continuously or at regular intervals along roadway shoulders. The accident reduction effectiveness of other rumble strip applications—including rumble strips in the traveled way on approaches to toll plazas and lane drops and shoulder rumble strips at point locations such as entrance ramps, exit ramps, and narrow bridge approaches has not been evaluated. Rumble strips in the traveled way on horizontal curve approaches have been evaluated in one British study, but have not been evaluated in the United States.

Safety Effects of Rumble Strips in the Traveled Way

Operational experience of highway agencies shows that rumble strips placed in the traveled way can be very effective in reducing accidents. Most of the available accident studies concern rumble strips placed on STOP-controlled approaches to T-intersections and to four-way intersections with STOP-control on two approaches.

Safety evaluations in the literature generally show that the installation of rumble strips is effective in reducing accidents on intersection approaches (5–14). Table 1 summarizes the results of these studies which show that the accident reduction effectiveness of rumble strip installation in the traveled way can range from 14 to 100 percent, for a variety of safety measures of effectiveness. However, the studies that document these results are generally small and vary greatly in quality and completeness. Only two of the studies summarized in Table 1 found a statistically significant accident reduction from rumble strip installation. In both cases, these results were statistically significant at the 95 percent confidence level.

All of the accident studies in Table 1 used the before/after evaluation design. These studies were based on accident data for periods of time both before and after rumble strip instal-

lation. However, several of these studies involved only a very few rumble strip installations. Six of the 10 studies from Table 1 drew no conclusion about the statistical significance of the evaluation results. Most of the remaining studies did not incorporate features in the before/after evaluation design to guard against the common threats to the validity of accident studies (4). For example, only a few of the studies used control sites, where no rumble strips were installed, for comparative purposes. Control sites are used in the design of an experiment to guard against mistaking a general time trend in accident experience for an effect of an accident countermeasure, such as rumble strip installation. Only two of the evaluations in Table 1 took the elementary precaution of determining the traffic volumes both before and after rumble strip installation and basing the evaluation on accident rates (per million vehicles traversing the rumble strips), rather than just on accident counts. Several studies asserted that the traffic volumes in the before and after periods were comparable, but did not document this assertion.

The greatest problem in assessing the validity of the accident studies in the literature is the lack of any detailed discussion of why the particular study sites were selected. If these sites were selected because of high short-term accident rates, this could potentially bias the evaluation. If an improvement is made at a location whose accident experience is high during the before study period solely due to random variation, then lower accident experience would be expected in the after study period, whether or not an improvement was made. This phenomenon, known as “regression to the mean,” is a potential threat to the validity of many of the studies cited in the literature.

On the other hand, if the study sites represent locations with high long-term accident experience consisting of accident types—such as rear-end and ran-STOP-sign accidents—that are susceptible to correction by rumble strips, then rumble strips would be expected to be particularly effective at such locations. However, the evaluation results would then be appropriate for estimating rumble strip effectiveness at other locations with high long-term accident experience of types that are susceptible to correction. The results would not, however, be applicable to estimating rumble strip effectiveness at locations in general.

Despite the lack of rigor in their accident evaluation designs, the study results in the literature generally indicate that rumble strip installation in the traveled way can be effective in reducing accidents. However, the study results are not reliable enough to quantify the expected accident reduction effectiveness. The available studies suggest that rumble strips in the traveled way may be effective in reducing accident types that are susceptible to correction by over 50 percent. Therefore, rumble strip installation in the traveled way should be considered at locations where rear-end accidents and ran-STOP-sign accidents, involving an apparent lack of driver

TABLE 1
ACCIDENT REDUCTION EFFECTS OF RUMBLE STRIPS PLACED IN THE TRAVELED WAY

Study and Date	Reference Number	Location	Number of Sites	Type of Sites	Safety Measures	Percent Change in Safety Measure	Statistically Significant ?
Kermit & Hein (1962)	(5)	California	4	Intersection approaches	Total accidents	-59 to -100	Not stated
Kermit (1968)	(6)	California	1	Intersection approaches	Ran-STOP-sign accidents	-50	Not stated
Owens (1967)	(7)	Minnesota	2	Intersection approaches	Total accidents	-50	No
Illinois (1970)	(8)	Illinois	5	Intersection approaches	Total accidents Ran-STOP-sign accidents	+5 -50	Not stated Not stated
TRRL (1977)	(9)	U.K.	10	Intersection approaches Roundabouts Horizontal curves Small towns	Total accidents Related accidents	-39 -50	No Yes
Virginia (1981)	(10)	Virginia	9	Intersection approaches	Total accidents Fatal accidents Injury accidents PDO accidents Total accident rate Related accident rate	-37 -93 -37 -25 -44 -89	Not stated Not stated Not stated Not stated Not stated Not stated
Carstens (1982)	(11)	Iowa	21	Primary hwy intersection approaches Secondary hwy intersection approaches	Total accident rate Ran-STOP-sign accidents Total accident rate Ran-STOP-sign accidents	-51 -38 -1 +3	Yes No No No
Zaidel, Hakkert, & Barkan (1986)	(12)	Israel	1	Intersection approaches	Right-angle accidents	-50 to -67	No
Moore (1987)	(13)	Louisiana	24	Intersection approaches	Total accidents Fatal and injury accidents Daytime accidents Nighttime accidents	-29 -14 -14 -50	Not stated Not stated Not stated Not stated
Penn DOT (1991)	(14)	Pennsylvania	8	Intersection approaches	Total accidents Ran-STOP-sign accidents	-40 -59	Not stated Not stated

attention, are prevalent. Care should be taken not to overuse rumble strips by placing them in too many locations in the traveled way. It may be the very unusual nature of passing over a rumble strip that makes it effective in alerting inattentive motorists.

Several highway agencies have indicated their concern that the effectiveness of rumble strips deteriorates over time. In other words, a portion of the accident reduction effectiveness of a rumble strip may be due to its novelty when first installed. However, one study conducted in California (see the Contra Costa County study, discussed below), found the opposite effect; this study found, for one site, greater effectiveness in the fourth and fifth years following rumble strip installation than in the first. Overall, none of the data reported in the literature are sufficiently reliable to make a valid determination of whether the accident reduction effectiveness of rumble strips changes over time.

Several of the research reports on rumble strips, and several of the highway agencies that use them, have cautioned that overuse of rumble strips in the traveled way could diminish their effectiveness. Normally, placement of the rumble strips in the traveled way should be considered only where a documented accident problem exists and only after more conventional treatments—such as signing—have been tried and been found to be ineffective. Rumble strips may be effective in reducing or eliminating accident patterns—such as accidents involving vehicles running a STOP sign—that are not easy to eliminate by any other means.

The published accident evaluations each addressed slightly different rumble strip designs. There is no reliable basis for concluding from the data that any one particular design performs better than any other. The range of rumble strip design currently in use by highway agencies in the United States is documented in Chapter Five.

Each of the studies that has evaluated rumble strips placed in the traveled way is discussed below.

Contra Costa County study: A 1962 study by Kermit and Hein (5) evaluated rumble strip pads installed on the approaches to four STOP-controlled intersections in Contra Costa County, California. These installations involved 8 to 11 rumble strip pads, each 25- to 30-ft long, spaced at 50- to 100-ft intervals, installed on each intersection approach. These rumble strip installations reduced accidents per year by 59, 76, 84, and 100 percent, respectively, at the four intersections. These results were based on very small accident sample sizes—an average of only three accidents per intersection per year during the before study period and one accident per intersection per year during the after study period. Only accidents classified by the authors as susceptible to correction by rumble strips were included in the study. Kermit and Hein drew no conclusions concerning the statistical significance of their findings.

A later study by Kermit (6) in 1968 found that the frequency of accidents that involved running through the STOP sign on the STOP-controlled approach to a T-intersection in California was reduced by 50 percent from before to after rumble strip installation. Furthermore, after the rumble strips had been in place for just over 3 years, the intersection experienced an 18-month period with no accidents involving running the STOP sign. This led Kermit to conclude that rumble strips were effective in reducing accidents, and that their effective-

ness increased over time. Again, no conclusions were drawn concerning the statistical significance of the observed findings.

Minnesota study: A Minnesota study by Owens (7), published in 1967, found a 50 percent reduction in accidents between a 2-year before period and a 2-year after period on two rural STOP-controlled approaches where rumble strips were installed. However, this involved a reduction from four accidents in the 2-year before period to two accidents in the 2-year after period. Owens concluded that this reduction in accident frequency was not statistically significant. A second location was not included in the safety evaluation because the accident experience before rumble strip installation was considered to be unusually high.

Illinois study: A 1970 study by the Illinois Division of Highways (8) evaluated three different rumble strip designs and layouts that were installed in the field in 1962. Of these, only one design/layout combination had a large enough accident sample size to develop significant accident statistics and was also deemed adequate as a warning device. The rumble strip installations of this type involved two rumble strips spaced 25 ft apart at 1,000 ft in advance of the intersection plus a rumble strip pad covering the entire approach for the final 300 ft in advance of the STOP sign. This pattern was installed at five intersections on the state highway system.

Before/after comparisons of total accidents were made at these locations. Of the five intersections, the accident rate decreased at two intersections and increased at two others. At the fifth location, the one with the highest accident rate, the accident rate increased about 40 percent during the next 3 years after rumble strips were installed, then decreased following installation of a flashing beacon. During the 3-year period preceding the installation of rumble strips 93 accidents occurred at the five intersections, while 98 accidents occurred during the 3 years following rumble strip installation. Apparently rumble strips were considerably more effective at reducing accidents at four-way and one-way stops than at two-way stops.

A comparison of accident types and severity before and after rumble strip installation indicated a substantial reduction in the proportion of injury accidents during the after period. Control locations selected for comparison experienced a slight increase in injury accidents during the same period. The only consequential change in accident type was a 50 percent reduction in ran-stop-sign accidents. This study excluded all accidents “that were in no way influenced by the presence or lack of rumble strips.” The criteria used to make this determination are not explained.

The authors concluded that rumble strips are effective only so long as they are startlingly different from the normal driving. The authors speculated that reaction to rumble strips becomes less pronounced as drivers become more familiar with them and that rumble strips should be used as a temporary method of alerting traffic to an unusual condition for an interim period of time required to complete a more permanent correction of an existing hazard. The authors stated that rumble strips are of little or no value as a permanent installation and recommended that they should never be con-

sidered as a part of the normal highway design for a permanent installation.

The report recommended use of rumble strips only under the following circumstances:

- When the intersection is hidden from view by either a horizontal or vertical curve,
- When the intersection has a history of accidents caused by failure to observe a traffic control device, or
- When the traffic control device follows a long tangent.

TRRL study: The British Transport and Road Research Laboratory (TRRL) (9) evaluated the effect on accidents of rumble strips at 10 sites on main rural highways in the United Kingdom. The sites included locations on the approaches to roundabouts (traffic circles), four-way intersections, T-intersections, horizontal curves, and small towns at sites where speed control and driver awareness were considered to be critical. The study design used was a before/after analysis with control sections. The length of the before and after study periods ranged from 10 to 23 months.

The study found that total accident frequency at the 10 sites decreased from 56 accidents in the before period to 34 accidents in a comparable after period. This decrease in accident frequency was not statistically significant. However, the frequency of accidents related to high speed or lack of driver awareness decreased from 44 in the period before rumble strip installation to 22 in the period after rumble strip installation. This difference was statistically significant at the 95 percent confidence level.

There were no statistically significant differences between daytime and nighttime conditions in the changes in accidents at these sites.

Virginia study: An evaluation was conducted by the Virginia Department of Highways and Transportation (10) in 1981 of nine intersections in Virginia where rumble strips were installed on STOP-controlled approaches. These installations generally consisted of two patterns of transverse rumble strips on each intersection approach, placed at varying distances in advance of the STOP sign. The evaluation found that total accident frequency was reduced by 37 percent, from 141 total accidents to 89 total accidents, between 2-year study periods before and after the rumble strip installation. Fatal accidents were reduced by 93 percent, from 14 fatal accidents before rumble strip installation to one fatal accident after rumble strip installation. Injury accidents were reduced by 37 percent and property-damage-only accidents were reduced by 25 percent.

Total accident rates were reduced by 44 percent from before to after rumble strip installation.

Thirty-nine of the 141 accidents in the before period were classified as being types susceptible to correction by rumble strip installation—particularly rear-end accidents and ran-STOP-sign accidents. The accident rate for these accident types was reduced by 89 percent.

No conclusions were drawn by the authors concerning the statistical significance of these findings.

Iowa study: In a 1982 study for the Iowa Department of Transportation, Carstens (11) evaluated the installation of rumble strips on primary and secondary highway approaches in Iowa. The installation evaluated consisted of three patterns of four transverse rumble strips per pattern, on each intersection approach treated.

Carstens found that primary highway intersections where rumble strips were installed experienced a statistically significant reduction in accident rate in the first year or two following their installation. The study included 10 four-way and 11 T-intersections for which before/after accident data were available. Accident rate at these 21 study intersections decreased by 51 percent for total accidents and by 38 percent for run-STOP-sign accidents between the before and after periods. The largest accident reductions were found for primary highway intersections with before period accident rates more than 2.0 accidents per million entering vehicles, while there was little or no change in accident experience at locations with lower before-period accident rates. This indicates either that rumble strips are most effective at locations characterized by higher accident rates or that regression to the mean may be responsible for all or part of the observed safety benefits. No control sections were used to adjust for any general trends in accident experience.

Carstens found no statistically significant change in accident rate at 88 intersections on secondary roads where rumble strips were installed. As in the case of the primary highway intersections, the highest reductions in accident rate occurred for intersections with the highest accident rates in the before period, but the net reduction for secondary roads was not statistically significant. Carstens concluded that rumble strips are more effective at primary highway intersections than secondary road intersections for some or all of the following reasons:

- Primary highways serve a higher proportion of drivers who are unfamiliar with the highway.
- Trips tend to be longer on primary highways so that fatigue and the monotony of driving may play a more important role than on secondary roads.
- Traffic volumes are higher on primary highways, so the number of potential conflicts is greater.
- The geometric layout of primary highway intersections is often more complex than that of secondary road intersections.

Carstens made an interesting comparison of the daytime and nighttime effects of rumble strips at the primary highway locations. It was found that the daytime accident rate declined by 51 percent at the lighted locations and by 83 percent at the locations without lights. By contrast, the nighttime accident rate declined by 67 percent at the unlighted locations and by only 6 percent at the lighted locations. Although the sample size was quite small, these data suggest that rumble strips may be more effective in reducing nighttime accidents at unlighted intersections than at lighted intersections.

Israeli study: Zaidel, Hakkert, and Barkan (12) evaluated the effect of rumble strips on traffic operations and accidents on STOP-controlled intersection approaches in Israel.

Initially, paint stripes were used to create a “visual speed illusion” associated with a converging pattern of stripes. This pattern was intended to give drivers the illusion that they were speeding up so that they would respond by slowing down. This approach was tried because paint stripes are substantially less expensive than rumble strips. Later, the use of rumble strips was evaluated on the same intersection approach.

An accident evaluation was conducted that included a study period of 3 years before and 4 years after the installation of the rumble strips. During the period before rumble strip installation, the intersection experienced approximately two to three right-angle accidents per year. During the 4 years after rumble strip installation, the same location experienced only one right-angle accident per year. While the numbers of accidents are very small, and certainly no statistical significance can be attached to these results, they provide some assurance that rumble strips on intersection approaches can be effective in reducing accidents.

Louisiana study: A 1987 evaluation conducted by Moore (13) for the Louisiana Department of Transportation and Development considered the effectiveness of rumble strip installations on STOP-controlled intersection approaches, consisting of 13 aggregate surfaced areas or raised rumble strips on each intersection approach treated. Moore found that installation of rumble strips on 24 intersection approaches resulted in a slight reduction in both the frequency and severity of accidents. Based on comparison of a 2-year period before rumble strip installation and a 2-year period after rumble strip installation, total accident frequency was reduced by 29 percent and fatal and injury accident frequency was reduced by 14 percent. Daytime accidents were reduced by 14 percent and nighttime accidents were reduced by 50 percent. Unfortunately, no exposure data were used to investigate the effect of any changes in traffic volumes between the before and after periods.

Pennsylvania study: An unpublished study by the Pennsylvania Department of Transportation (14), evaluated rumble strip installations at eight locations where rumble strips were installed on STOP-controlled approaches to intersections. Total accidents decreased by 40 percent and run-STOP-sign accidents decreased by 59 percent from before to after rumble strip installation. The statistical significance of these changes in observed accident experience was not determined.

Safety Effects of Rumble Strips on Roadway Shoulders

This section reviews the accident evaluations that have been conducted for placement of rumble strips on roadway shoulders.

The earliest experiments with shoulder rumble strips or “singing shoulders” were conducted on the Garden State Parkway in New Jersey in 1955 (15). Textured concrete rumble strips were constructed in Illinois during the mid 1960s and were found to be effective in the opinion of people who

drove over them during field tests (16). Shoulder grooving was tested in Arizona (17) in the early 1970s and Florida (18) tried raised pavement markers as rumble strips on the highway to Key West during the late 1970s.

Recent research on rumble strips placed continuously or at regular intervals along roadway shoulders, especially the California and FHWA studies discussed below (19,20), has shown that they can reduce run-off-road accidents by 20 to 50 percent. Both of these evaluations were based on accident rates, rather than just accident counts, and both included test sites, where rumble strips were installed, as well as control sites where rumble strips were not installed. Thus, both evaluations were generally better designed than the evaluations of rumble strips in the traveled way discussed above.

In addition to the accident evaluations, casual field observation also supports the effectiveness of continuous shoulder rumble strips. For example, the Wisconsin State Patrol has indicated their strong support for continuous shoulder rumble strips on freeways, because their officers have observed vehicles leave the traveled way and then recover successfully because the drivers were apparently alerted by the rumble strip. Wisconsin uses shoulder rumble strips on both asphalt and portland cement concrete shoulders.

All of the safety evaluations of shoulder rumble strips found in the literature address rumble strips placed continuously or at regular intervals along the shoulders of extended highway sections. There are no evaluations that address the accident reduction effectiveness of shoulder rumble strips used only at selected critical locations such as exit ramps, entrance ramps, or narrow bridge approaches.

Each evaluation of shoulder rumble strips is described below.

California study: The California Department of Transportation (Caltrans) has used rumble strips extensively on asphalt shoulders of rural freeways in desert regions of California. Caltrans has given priority to use of shoulder rumble strip projects in desert areas because drivers appear most prone to lose their concentration in such areas of monotonous driving conditions. Some projects have involved use of rumble strips on the right shoulder only, while other projects have involved rumble strips placed on both the right (outside) and left (median) shoulder of the freeway. The rumble strips were placed on the shoulders with a special roller during shoulder resurfacing.

An evaluation of the safety effects of continuous rumble strips on asphalt shoulders was conducted by Caltrans (20) for seven projects representing approximately 135 miles of rural freeway. The safety evaluation focused on the effect of rumble strips on run-off-road accidents, since this accident type is closely related to driver inattention. An evaluation of one year of accident data before and one year after installation of the shoulder rumble strips found that run-off-road accident rate was reduced by 49 percent (194 run-off-road accidents in the before period vs. 100 run-off-road accidents in the after period). This decrease in run-off-road accident rate was found to be statistically significant at the 99 percent confidence level. During essentially the same time periods, the number of run-off-road accidents for the corresponding control sites increased by 20 percent (272 accidents in the before period vs. 326 accidents in the after period). The control sites for this study

included seven sites on which shoulder rumble strips were not installed and two sites on which shoulder rumble strips were present during both the before and after periods.

Rumble strips on the right shoulder were found to reduce run-off-road accidents by 63 percent, while rumble strips on the left (median) shoulder reduced run-off-road accidents by 18 percent. The apparent lack of effectiveness of rumble strips in reducing run-off-road accidents on the left (median) side of the highway may result from data at one site where the rate of run-off-road accidents increased substantially from before to after rumble strip installation, for unexplained reasons.

The study was based on passenger car accidents only and did not consider trucks. However, there were very few truck accidents on the roads in question and it was believed that rumble strips would have little effect on them.

In summary, the Caltrans study showed very substantial accident reduction benefits from installation of continuous shoulder rumble strips. The observed reduction of 49 percent in run-off-road accident rate is equivalent to a reduction of 19 percent in total accident rate, so rumble strip installation had a very substantial impact on the safety performance of the 135 mi of desert freeway where the rumble strips were installed. To express the safety benefits in a different form, rumble strip installation for this 135 mi of freeway resulted in an annual reduction of 10 fatal accidents, 52 injury accidents, and 26 property-damage-only accidents. Given the relatively low cost of rumble strip installation (a maximum of \$2,300 per mile for all four shoulders of a divided freeway, for these projects), it is clear that installation of shoulder rumble strips is a very cost-effective accident countermeasure.

FHWA study: A 1985 study conducted for FHWA by AMAF Industries (20) was based on data from 24 sites in 11 states (Arizona, California, Florida, Georgia, Mississippi, Nevada, North Carolina, South Carolina, South Dakota, Utah, and Wisconsin). The evaluation of accident experience before and after rumble strip installation in this FHWA study was based on detailed analysis of 10 sites located in Arizona, California, Mississippi, Nevada, and North Carolina. Three of the test sites from the California study described above were included in this detailed analysis. The FHWA study found that, after selected test sites were improved by placing rumble strips on the roadway shoulders, run-off-road accident rates on the test sites decreased by 20 percent, while run-off-road accident rates on comparable control sites increased by 9 percent. The observed decrease in test section accident rates was found to be statistically significant at the 95 percent confidence level. The observed accident reduction effectiveness varied widely between the sites where shoulder rumble strips were installed, from an increase in run-off-road accident rate of 9.3 percent at one site in Nevada to a decrease in run-off-road accident rate of 67.1 percent at another site in North Carolina. Such large site-to-site variations are common for sites with small accident sample sizes. Most of the observed changes in accident rate for individual sites were not statistically significant.

The FHWA study included rumble strips on both portland cement concrete and asphalt shoulders, but did not distinguish between them in the accident evaluation. Similarly, the accident evaluation did not distinguish between run-off-road accidents on the right and left sides of the highway, although both were included in the evaluation.

This FHWA study confirms the accident reduction effectiveness of shoulder rumble strips, although the quantitative accident reduction effectiveness estimate was lower in the FHWA study than in the California study (20 percent vs. 49 percent). It is likely that the desert sites evaluated by Caltrans do, in fact, have a more serious run-off-road accident problem than other, less monotonous sites. Therefore, the 20 percent estimate from the FHWA study may be a more reasonable value of the accident reduction effectiveness that could be expected from broader use of shoulder rumble strips. Even with only 20 percent accident reduction effectiveness, installation of shoulder rumble strips was found to be highly cost-effective. The FHWA study found a benefit/cost ratio greater than 50 for shoulder rumble strips when installed in conjunction with shoulder construction or resurfacing.

Washington State study: Shoulder rumble strips were installed by the Washington State Department of Transportation (21) at six locations between 1986 and 1990. Raised pavement markers were used on the shoulder at one location, raised 12-in. wide rumble strips at another location, and grooves rolled into the shoulder pavement were used at four additional locations. An accident evaluation for five of the six locations found a statistically significant decrease in accident frequency at only one of the five locations. However, overall accident frequency at the five sites, collectively, decreased by 18 percent from before to after rumble strip installation. The report does not indicate whether this overall change in accident experience was statistically significant, but it is in agreement with the findings of the FHWA study.

EFFECT OF RUMBLE STRIPS ON VEHICLE SPEEDS

This section describes the reported experience of rumble strips on vehicle speeds, based on research performed by or for highway agencies. These studies indicate that rumble strip installation on intersection approaches does result in a small reduction in vehicle speeds. Some vehicles are slowed more than others, however, and it appears that speed variance on the intersection approach may be increased. Rumble strips, in conjunction with fixed and dynamic signing, were found to be ineffective in producing speed limit compliance in a small town.

Each study that has addressed the effect of rumble strips on vehicle speeds is summarized below.

Contra Costa County: Kermit and Hein (5) found that rumble strips on the approaches to intersections resulted in more gradual deceleration by drivers. To demonstrate this, Kermit and Hein present speed data for an approach to a T-intersection where drivers must slow down to turn but are not required to stop. Rumble strips were used on this approach to encourage drivers to begin slowing down farther from the intersection. Table 2 shows that rumble strip installation at this location increased the deceleration rates used by drivers between 450 and 1,000 ft from the intersection and decreased the deceleration rates used by drivers within 450 ft of the intersection.

TABLE 2
STEPS AND ACCELERATIONS OF AN INTERSECTION APPROACH WHERE DRIVERS ARE REQUIRED TO SLOW
BUT NOT STOP (5)

Location	Measurement	Before Rumble Strip Installation	After Rumble Strip Installation
A	85th percentile speed (mph) at 1,000 ft from the intersection and before the first rumble strip	44.0	46.0
	Average deceleration rate (ft/sec/sec) from Location A to Location B	0.57	1.43
B	85th percentile speed (mph) at 450 ft from the intersection after three rumble strips have been crossed	41.0	37.0
	Average deceleration rate (ft/sec/sec) from Location B to Location C	3.46	2.70
C	85th percentile speed (mph) at intersection	14.8	15.1

Minnesota study: In a study of rumble strips on the approaches to rural intersections in Minnesota, Owens (7) measured speeds of free-flowing vehicles at distances of 1,500; 1,000; 500; and 300 ft from the intersections on STOP-controlled intersection approaches, both before and after rumble strips were installed. The presence of rumble strips was found to reduce average speeds by 2 to 3 mph at each of these observation points, which indicates that rumble strips are effective in reducing vehicle speeds. Table 3 summarizes the effect of the rumble strips on vehicle speeds at each selected distance for the six intersection approaches combined.

While rumble strips were found to decrease vehicle speeds, they increased the speed variance on the intersection approaches at all distances from the intersection greater than 300 ft. This increase in speed variance indicates that the rumble strips cause some drivers to slow down more than others, which could be associated with an increase in rear-end accidents. However, no similar effect on accidents was observed in the accident evaluation conducted as part of the same study or in the other studies evaluated for this synthesis.

Maine Facility study: Dynamic and passive signing was used, including signing in conjunction with rumble strips, to achieve

compliance with speed zoning in a small town. This study was conducted on the Maine facility, a section of two-lane highway in Maine where the Federal Highway Administration placed instrumentation during the early 1970s (22). No treatment was effective in achieving as much as 30 percent compliance with the existing speed limit. This result indicates that rumble strips are not generally effective as a treatment to increase speed limit compliance.

TRRL study: TRRL (9) studied the effects of rumble areas on speed at 10 sites where rumble areas were installed in the traveled way upstream of roundabouts (traffic circles), four-way intersections, T-intersections, horizontal curves, and small towns. Speeds were measured, upstream of the rumble areas, 400 m (1,312 ft) from the hazard, and between the rumble area and the hazard at a location 50 m (164 ft) upstream of the hazard. Table 4 shows the speed data for these 10 sites. An analysis of the differences in speed between the 50 m and 400 m locations found that the effects of the rumble areas on speed were not consistent. In some cases, the presence of the rumble areas appeared to cause drivers to choose a larger speed reduction between the 400 m and 50 m points on the approach. However, at other sites, the opposite appeared to

TABLE 3
MEAN SPEEDS AT SPECIFIED DISTANCES FROM A STOP-CONTROLLED INTERSECTION (7)

Distance from intersection (ft)	Average speed (mph)			Statistically significant before/after difference ?
	Before rumble strip installation	After rumble strip installation	Difference	
300	31.01	27.99	3.02	Yes
500	36.57	33.59	2.98	Yes
1000	43.70	41.39	2.31	Yes
1500	47.26	44.47	2.79	Yes
Away from area	52.09	52.58	-0.49	No

TABLE 4
CHANGES IN MEAN SPEED BEFORE AND AFTER RUMBLE STRIP INSTALLATION AT SELECTED SITES IN THE UNITED
KINGDOM (9)

	SITE	VEHICLE TYPE	Mean Speed Before (km/h)		Mean Speed After (km/h)		Percentage change		Level of significance of change	
			50 m	400 m	50 m	400 m	50 m	400 m	50 m	400 m
Roundabouts	Wandsworth	Light	54.1	78.5	50.3	75.1	-7.0	-4.3	0.1%	0.1%
		Heavy	46.9	68.7	43.9	66.8	-6.4	-2.8	1%	Not Sig
	Black Cat	Light	53.3	83.9	58.1	89.2	9.0	6.3	0.1%	0.1%
		Heavy	45.7	71.6	50.8	75.4	11.1	5.3	0.1%	0.1%
Cross-Roads	Kislingbury	Light	81.3	81.8	78.4	86.7	-3.5	5.9	1%	0.1%
		Heavy	67.8	69.2	72.0	75.6	6.1	9.2	0.1%	0.1%
	Muddleswood	Light	44.7	78.9	43.3	72.6	-3.1	-7.9	1%	0.1%
		Heavy	38.1	68.0	37.4	63.4	-1.8	-6.7	Not Sig	1%
T-Junction	Corby	Light	50.3	77.2	48.7	74.7	-3.1	-3.2	1%	1%
		Heavy	42.4	57.8	42.7	62.1	0.7	7.4	Not Sig	0.1%
Bends	Woodend	Light	60.6	67.4	57.8	66.6	-4.6	-1.1	0.1%	Not Sig
		Heavy	52.3	66.6	50.5	64.9	-3.4	-2.5	Not Sig	Not Sig
	Glan Conwy	Light	59.5	66.3	59.0	68.6	-0.8	3.4	Not Sig	1%
		Heavy	54.6	63.0	53.9	64.2	-1.2	1.9	Not Sig	Not Sig
	Tempsford	Light	65.1	85.2	66.0	81.1	1.3	-4.8	Not Sig	0.1%
		Heavy	57.3	72.6	60.1	72.1	4.8	-0.6	0.1%	Not Sig
	Skeffington	Light	71.2	70.2	70.9	76.6	-0.4	9.1	Not Sig	0.1%
		Heavy	58.8	53.7	63.2	60.4	7.4	12.4	0.1%	0.1%
Village Approach	Horndean	Light	57.8	74.1	59.5	81.1	2.9	9.4	0.1%	0.1%
		Heavy	53.3	65.6	56.0	71.4	5.0	8.8	2%	0.1%

be true. The data for all sites combined showed a small net increase in the amount of speed reduction chosen by drivers between the 400 m and 50 m locations, but this increase in speed reduction was not statistically significant.

Israeli study: Zaidel, Hakkert & Barkan (12) evaluated the use of rumble strips on one STOP-controlled intersection approach in Israel. A total of 38 rumble strips were placed over a distance of 269 m (883 ft) upstream from the STOP line. Speeds were measured at eight locations on the intersection approach, ranging from 15 to 420 m (49.2 to 1,378 ft) upstream of the intersections.

Table 5 illustrates the effect of the rumble strips on the mean and standard deviation of vehicle speeds on an intersection approach. The data in the table show that mean speeds were reduced by 5 to 43 percent on the intersection approach and that the speed reduction percentage was generally higher closer to the intersection. Table 5 also confirms the finding from the Minnesota study that speed variance (the square of the standard deviation) on an intersection approach increases with the installation of rumble strips. The table helps to make clear how rumble strips affect driver behavior. When rumble strips are present, drivers generally begin to slow down sooner and some drivers slow more than others. This generally increases

vehicle deceleration rates early in the braking maneuver, but decreases vehicle deceleration rates close to the intersection. It is evident that some drivers slow down more than others in the earlier stage of the braking maneuver, as the speed variance on the intersection approaches increases. However, there is no evidence that the increase in speed variance has any adverse effect on safety.

University of Toledo study: A recent study performed at the University of Toledo (23) evaluated the effectiveness of rumble strips in reducing vehicle speeds during the initial portion of the deceleration maneuver on approaches to STOP-controlled intersections. Table 6 compares the mean speeds of vehicles at a location 300 ft downstream of the first rumble strip pattern on the intersection approach before and after rumble strip installation on seven intersection approaches in Ohio.

On five of the seven approaches, there was a reduction in the mean vehicle speed that was statistically significant at the 95 percent confidence level; there was no statistically significant change in mean vehicle speed at the other two locations. These results are similar to the Israeli study discussed above in that there appears to be greater slowing early in the braking maneuver and, consequently, lesser slowing later in the maneuver.

TABLE 5
MEAN SPEEDS AND SPEED VARIANCES BEFORE AND AFTER RUMBLE STRIP INSTALLATION IN ISRAEL (12)

Time Period/Measurement	Distance from intersection (m)							
	420	330	285	255	165	105	45	15
Before rumble strips								
Mean speed (km/hr)	73.2	72.1	70.8	70.1	64.6	57.5	41.6	24.7
Standard deviation (km/hr)	11.7	11.7	11.6	11.6	10.9	9.6	8.0	5.1
After rumble strips								
Mean speed (km/hr)	69.5	63.1	54.0	43.5	32.9	31.6	24.5	14.7
Standard deviation (km/hr)	11.5	12.8	15.4	18.5	14.0	11.6	8.3	6.2
Percent reduction in mean speed	5.1	12.5	23.7	37.9	49.1	45.0	41.1	40.5
Percent increase in speed variance	-1.7	9.4	32.8	59.5	28.4	20.8	3.8	21.6

TABLE 6
EFFECT OF RUMBLE STRIPS ON VEHICLE SPEEDS ON APPROACHES TO STOP-CONTROLLED INTERSECTIONS (23)

Location of Rumble Strips	Mean speed (mph) (300 ft downstream of first rumble strip)			Statistically Significant ?
	Before	After	Reduction	
SR 281, East of SR 108	41.9	35.9	6.0	Yes
SR 281, West of SR 108	47.9	39.9	8.0	Yes
SR 576, North of SR 34	43.9	45.9	-2.0	No
SR 576, South of SR 34	45.9	41.9	4.0	Yes
US 20, East of US 127	51.9	49.9	2.0	Yes
US 20, West of US 127	53.9	51.9	2.0	No
US 20, West of SR 108	53.9	49.9	4.0	Yes

EFFECT OF RUMBLE STRIPS ON DRIVER COMPLIANCE WITH TRAFFIC CONTROL DEVICES

The effect of rumble strips on driver compliance with traffic control devices has been evaluated primarily for compliance with STOP signs at T- and four-way intersections. There have been five studies that evaluated the effect of rumble strips installed on an intersection approach on STOP-sign compliance. Drivers on STOP-controlled approaches were generally classified by field observers as making a full stop, making a partial (or rolling) stop, or not stopping. These studies generally found that it was rare for motorists to proceed through a stop sign without stopping at all. However, installation of rumble strips on an intersection approach generally increased the proportion of drivers who made a full stop. One study also addressed the issue of centerline violations by drivers on intersection approaches with rumble strips (see also the discussion of this issue in Chapter Four).

Each study that evaluated the effect of rumble strips on driver compliance with traffic control devices is summarized below.

Contra Costa County: Kermit & Hein (5) found that the installation of rumble strips on one particular STOP-controlled intersection approach increased the percentage of drivers making a full stop from 46 to 76 percent. The percentage of drivers making either a full or partial stop increased from 96 to 100 percent. Thus, the rumble strips eliminated noncompliance by the relatively few drivers who completely disregarded the presence of the STOP sign.

Minnesota study: Owens (7) found that the installation of rumble strips at a rural T-intersection increased the percentage of full stops by drivers from 37 to 63 percent. The rest of the drivers made a partial stop at the STOP sign. The author states that the number of drivers who made no stop in response to the STOP sign was negligible in both the before and after periods. This increase in STOP sign compliance the author found to be highly statistically significant.

A study of centerline violations on STOP sign approaches before and after rumble strip approaches found that few drivers crossed the centerline to avoid going over the rumble strips. However, the observed number of centerline violations was small and the difference was not statistically significant.

Illinois study: The 1970 study by the Illinois Department of Transportation (8) found that the number of vehicles that stopped or partially stopped following passage over rumble strips at five intersections was found to be 95 percent. This compares to 91 percent of the same behavior at four comparable locations without rumble strips.

Iowa study: Carstens (11) found that, at two similar STOP-controlled intersections, about 77 percent of approach traffic that did not encounter a conflict stopped or nearly stopped at the intersection where rumble strips were present, compared with about 66 percent of traffic which stopped at the intersection where there were no rumble strips.

Israeli study: Zaidel, Hakkert, and Barkan (12) found that installation of rumble strips on an intersection approach increased STOP sign compliance from 91 percent to 95 percent.

EFFECTIVENESS OF RUMBLE STRIPS FOR WORK ZONE APPLICATIONS

Rumble strips have been used to supplement warning signs and other traffic control devices in advance of (and within) freeway work zones involving lane restrictions, width reductions, sharp detour transitions, or other conditions that might warrant major speed reductions. A review of the effectiveness of rumble strips in work zone applications has recently been prepared for FHWA by Noel, Sabra, and Dudek (1). This review indicates that rumble strips in work zones have been studied under only a limited number of applications and that these studies have produced inconsistent findings.

Recent studies by Richards, et al. (24) indicated that rumble strips were ineffective treatments for controlling work zone speeds. Rumble strips were compared to several other techniques such as flagging, law enforcement, changeable message signs, effective lane width reduction, and conventional and advisory speed signing. The rumble strips evaluated by Richards et al. were ½-in. high polycarbonate rumble strips temporarily attached to the pavement surface. The researchers noted that problems were encountered in creating a bond between the rumble strips and the pavement surface (see related discussion in Chapter Four).

Three rumble strip patterns were investigated by Richards et al.: clusters of eight rumble bars with equal spacing; clusters of eight rumble bars with unequal (logarithmic) spacing; and individual rumble bars at spacings of 52 to 66 ft. In response to a questionnaire, drivers indicated that they believed that the rumble strip clusters with equal spacing produced the greatest speed reduction and that individual rumble strips produced the least speed reduction. However, none of the rumble strip patterns actually had any statistically significant effect on vehicle speeds.

Pigman and Agent (25) reported on field studies where rumble strips were used to reduce the number of late merges from lanes that were closed due to road work. The rumble strips evaluated consisted of eight rumble bars per cluster with a 24-in. spacing between successive bars. The rumble strips were installed in the lane to be closed at distances of 1.5, 1.0, 0.6, 0.3, and 0.1 mi in advance of the lane closure taper. All of the rumble strips consisted of a hard plastic/vinyl material with dimensions of ½ in. × 4 in. × 23¾ in. Each rumble bar consisted of six strips installed side by side to cover the width of a 12-ft lane. Pigman and Agent reported that this rumble strip installation decreased the percentage of traffic in the closed lane at 0.1 mi in advance of the taper from 11.0 percent to 4.1 percent. Thus, it appears that rumble strips are effective, at least in a work zone setting, in getting motorists to change lanes further upstream. The researchers found that the rumble strips produced a noticeable decrease in speed as traffic approached the taper, but the speed still averaged more than 55 mph in the distance range from 1.0 to 0.5 mi in advance of the taper.

An evaluation of one brand of temporary rumble strips, conducted by its manufacturer (26), included speed studies

in work zones with three alternative traffic control schemes: (1) using standard construction signs; (2) adding 35-mph regulatory speed limit signs; and (3) adding rumble strips. The tests showed that mean traffic speeds were reduced by more than 8 mph with rumble strips, as compared to the standard construction zone signing, and by more than 4.5 mph as compared to the standard construction zone signing plus 35-mph speed limit signing.

Another speed evaluation was conducted during joint repair and resurfacing on Interstate Route 77 in Ohio while two-way traffic was maintained on one side of the roadway (27). The crossover used by traffic to move from one side of the roadway to the other involved a long downgrade and vertical and horizontal curvature with opposing superelevations. Rumble strips were installed because of concerns about vehicle speeds, given the restricted geometrics. This work zone had a posted speed limit of 50 mph.

Speed measurements were made using radar at two locations within the two-lane, two-way work zone. The first location was at the end of the transition taper to the single lane. This location was just over a crest vertical curve and just downstream of a 50-mph regulatory speed limit sign. The 85th

percentile speed at this location was 62 mph. The second location where speeds were measured was at a point between the last rumble strip and the start of the crossover to return to the normal lanes. At this location, which was at the end of a downgrade, the 85th percentile speed was found to be 55 mph—7 mph less than that measured at the first point. Construction personnel and officials of the Ohio Department of Transportation were of the opinion that the speed reduction between these two locations was an effect of the rumble strips. However, this cannot be proven, because the work zone was not evaluated with and without the rumble strips in place.

The evidence as to whether rumble strips are effective as a speed control device in work zones is inconclusive. In general, rumble strips are probably effective when they call a driver's attention to traffic control devices or to potential hazards that the driver might not otherwise have seen. However, they are probably not effective when the potential hazards are already evident to the driver. Rumble strips do appear to be effective at lane closures in work zones in encouraging drivers to leave the closed lane further upstream. There have been no accident evaluations of the effectiveness of rumble strips in work zones.

POTENTIAL ADVERSE EFFECTS OF RUMBLE STRIPS

The discussion of the traffic operational and safety effects of rumble strips in Chapter Three has indicated that they can be effective in reducing accidents that are not easy to eliminate by other means. Therefore, rumble strips have a definite role as a traffic control device to enhance safety. However, highway agency responses to the survey conducted in the preparation of this synthesis (see responses to Question 8 in Appendix A) have indicated that rumble strips also have some potential adverse effects. Highway agencies should be aware of these potential adverse effects in deciding where to place rumble strips and what rumble strip design to use.

The potential adverse effects of rumble strips that have been reported by highway agencies include: noise; motorist use of opposing lanes to avoid rumble strips; maintenance problems; motorist concerns; bicyclist concerns; motorcyclist concerns; truck concerns; installation concerns; and overuse of rumble strips.

The noise issue is a serious problem that has led many highway agencies to change their policies and restrict the use of rumble strips in residential areas. More research is needed to characterize the problems created by rumble strips for bicyclists and motorcyclists. The other potential adverse effects of rumble strips are manageable problems that should not prevent rumble strips from being used where they are needed. However, these potential adverse effects should be considered by highway agencies in developing rumble strip designs and deciding how to implement them at particular locations.

NOISE CREATED BY RUMBLE STRIP INSTALLATIONS

The most common problem cited by highway agencies concerning the use of rumble strips is noise that disturbs nearby residents. Sixteen of the highway agencies that responded to the survey in Appendix A reported receiving complaints from nearby residents about noise generated by vehicles traversing rumble strips.

Noise complaints are especially likely from residents adjacent to rumble strips installed in the traveled way, because every vehicle (or nearly every vehicle) on the roadway crosses the rumble strip. During daytime hours, noise generated by rumble strips may be merely a nuisance to nearby residents, but at night the sound of vehicles traversing the rumble strip may prevent residents from sleeping. Several highway agencies reported that they had reduced noise levels by partially filling in the rumble strip to change its height, depth, or shape.

A recent study by Higgins and Barbel (28) concluded that rumble strips produce a low-frequency noise that increases the noise level by as much as 7 dB(A) above the noise levels produced by traffic on normal pavements. Higgins and Barbel concluded that driver perception of rumble strip noise was

better for grooved rumble strips than for raised rumble strips; however, the noise outside the vehicle, which adjacent residents would hear, did not vary with rumble strip configuration. Pigman and Barclay (29) found that noise inside the vehicle was 5 to 15 dB(A) higher than ambient traffic noise. Pigman and Barclay evaluated the effect of rumble strip spacing on noise levels. A spacing of 10 ft between rumble strips produced the lowest noise levels. Spacings of 5 and 10 ft between rumble strips produced noise levels that increased linearly with vehicle speed, while spacings of 1 to 3 ft produced noise levels that varied erratically and were, therefore, considered undesirable.

Most highway agencies reported that they considered the noise problem to be serious enough that they had adopted policies against use of rumble strips in residential areas. Thus, rumble strips in the traveled way may not be desirable at any location near residences. Rumble strips are more appropriate for use in the traveled way in rural areas and in commercial or industrial areas of cities.

Rumble strips on shoulders are less likely than rumble strips in the traveled way to disturb nearby residents because noise is generated only by errant vehicles, not by every vehicle. It may be acceptable to use shoulder rumble strips on urban freeways in residential areas if the residences are far enough from the freeway or a noise barrier is provided. Highway agency practices concerning the use of rumble strips should be considered in the design process for urban freeways in determining whether noise barriers are warranted.

MOTORIST USE OF OPPOSING LANES TO AVOID RUMBLE STRIPS

Responses from highway agencies indicated concern that some motorists will cross into opposing lanes or onto the shoulder to avoid rumble strips placed in the traveled way. Such maneuvers are typically made by local residents or commuters who pass the location every day and know that the rumble strips are present. This behavior is indicative of the dislike of rumble strips by some motorists (see later discussion of motorist complaints). It is probable that the rumble strips serve no useful purpose for the motorists who avoid them, because if they are aware of the rumble strip, they are undoubtedly also aware of the roadway feature (intersection, horizontal curve, etc.) that the rumble strips are calling attention to. However, it is highly undesirable to have motorists unnecessarily entering the opposing lanes, in potential conflict with opposing traffic.

Motorists who drive into the opposing lane to avoid a rumble strip appear to be concerned about the jarring effect of the rumble strip on their vehicle. This appears to be a concern especially for raised rumble strips that are very high and grooved

rumble strips that are very deep. It is not known whether partially filling in a rumble strip to change its height, depth, or shape is effective in reducing the percentage of motorists who avoid rumble strips.

While seven highway agencies reported problems with motorists intentionally avoiding rumble strips, only three agencies reported implementation of a potential solution to the problem. Pennsylvania extends rumble strips in work zones across both the traveled way and the shoulder, to remove the temptation for motorists to move onto the shoulder to avoid the rumble strip. Nebraska and South Dakota have used discontinuous rumble strips that extend across only the normal wheelpath areas of the lane on STOP-controlled intersection approaches. This design is intended to allow motorists familiar with the installation to drive around the rumble strip without leaving their lane. Unfamiliar motorists presumably traverse the rumble strip because it extends across both normal wheelpath areas. Figure 10 presents a photograph of a typical discontinuous rumble strip installation.

Several discontinuous rumble strip installations like the one shown in Figure 10 were visited in the field as part of the preparation of this synthesis, and they appear to function well. In a 12-ft lane, it is possible to avoid the rumble strip without encroaching on the opposing lane or shoulder. However, where the same type of rumble strip is used in a 10-ft lane, some encroachment on the opposing lane or shoulder is necessary.

MAINTENANCE PROBLEMS

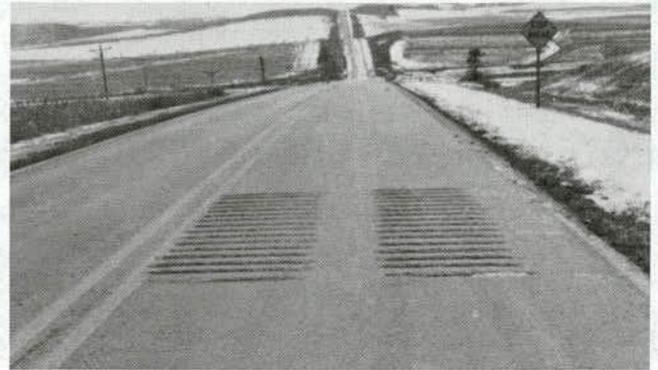
Highway agencies have reported several types of maintenance problems associated with rumble strips. These problems include durability of rumble strips, snowplowing concerns, and drainage/erosion concerns.

Durability of Rumble Strips

Eleven highway agencies reported a concern with the lack of durability of rumble strips, which led to frequent replacement or maintenance activities. This was particularly a concern with raised rumble strips in the traveled way, which tend to become worn down by traffic passages. Some agencies indicated that they preferred grooved rumble strips to raised ones for this reason. Chapter Six on the cost and service life of rumble strips contains data on the wear rate of grooved rumble strips.

Several highway agencies indicated that the most severe problems with rumble strip wear were in areas where vehicles are normally braking on an intersection approach. The braking action of vehicles, particularly trucks, tends to accelerate wear of rumble strips on asphalt pavements. One agency indicated that they no longer place rumble strips within 400 ft of an intersection for this reason.

Highway agencies that used temporary raised rumble strips in work zones reported problems in maintaining a bond between the rumble strip and the pavement surface. It was difficult to get temporary asphalt rumble strips to adhere to an asphalt surface; this problem would result in the rumble strip material coming up off the surface. The Illinois Department of Transportation has reported that existing epoxy practices were not



(12-ft lane width)



(10-ft lane width)

FIGURE 10 Discontinuous rumble strips on intersection approaches.

always satisfactory in producing a bond between the temporary polycarbonate rumble strips and the pavement surface.

A highway agency that uses raised pavement markers (buttons) placed in the traveled way as rumble strips reported that large trucks tended to damage these markers and the markers had to be replaced frequently.

Snowplowing Problems

Several highway agencies reported winter maintenance problems related to rumble strips. For example, highway agencies stated that raised rumble strips in the traveled way caused problems during snowplowing. Plow operators did not always remember to lift the plow blade to avoid striking (and, in some cases, removing) the rumble strip. One highway agency stated that they allow rumble strips to remain in place in the traveled way only during summer months and that they remove them during winter maintenance periods.

Highway agencies have reported that continuous shoulder rumble strips cause problems in snowplowing on the traveled way if the rumble strips are placed too close to the traveled way. One agency initially placed shoulder rumble strips 6 in. from the edge of the traveled way. They now place their

rumble strips 2.5 ft from the edge of the traveled way to avoid interference with snowplowing.

Shoulder rumble strips may also create some problems in plowing the shoulder itself. One highway agency reported that their plows had to operate at reduced speeds on shoulders with rumble strips.

Drainage/Erosion Problems

Highway agencies have reported that shoulder rumble strips can create problems by disrupting drainage patterns on the shoulder and channeling water onto roadside slopes. This may be a particular problem for rumble strips on portland cement concrete shoulders that extend to the outside edge of the shoulder. In this case, water flow off the shoulder may be concentrated at the rumble strips, resulting in erosion of the adjacent section of the roadside embankment. A solution to this problem is to use a rumble strip that does not extend to the outside edge of the shoulder. If the rumble strip does not reach the outside edge of the shoulder, there may be some ponding of water in the rumble strip area, but this should not create a roadside erosion problem.

Inflexibility in Future Traffic Operations

The installation of shoulder rumble strips limits the ability to use the shoulder as a travel lane during future construction and maintenance activities that involve a lane closure. This reduces the flexibility that highway agencies have in planning future highway work activities. Shoulder rumble strips also make it more difficult to convert a shoulder to temporary use as a travel lane, as has been done on freeways in several urban areas. On the other hand, shoulder rumble strips may have the advantage of discouraging motorists from using shoulders at locations where shoulder travel is considered undesirable by highway agencies.

One advantage of the use of raised pavement markers for shoulder rumble strips, particularly for portland cement concrete shoulders, as illustrated in Figure 8, is that the markers can be removed, if necessary, to restore a smooth riding surface that can be used as a travel lane. However, raised pavement markers may have a shorter service life than corrugated rumble strips that are formed into the pavement.

Motorist Concerns

Highway agencies have received complaints both from motorists who do not like rumble strips and from motorists who do not understand rumble strips.

Motorists who do not like rumble strips are generally concerned about vibration and potential damage to their vehicle. A few instances of actual vehicle damage were reported, but vehicle damage does not appear to be very common; however, there are no reliable quantitative estimates of the frequency of vehicle damage associated with particular rumble strip designs. This problem appears to be associated with both raised and grooved rumble strips. One highway agency reported that a truck could lose its load if grooved rumble strips were made too deep or too wide. This agency recommended a

maximum groove depth of ½-in. (preferably ⅜-in.) and a maximum groove width of 12 in. (preferably 3.5 to 4 in.). Another agency reports complaints from vehicle owners about loss of front-end alignment due to impacts with rumble strips.

Clearly, motorist acceptance of rumble strips will be increased if the bar height or groove depth is kept to a minimum. On the other hand, the height or depth must be sufficient to generate an audible or tactile sensation large enough to gain the motorists's attention. Data in Chapter Five show that about two-thirds of highway agencies currently limit the maximum bar height or groove depth to ½-in.

Highway agencies also reported a concern about motorists who do not understand rumble strips and mistake the noise generated by a rumble strip for a mechanical problem with their vehicle. One agency reported that they had observed motorists stopping to check their tires after passing over a shoulder rumble strip. Another agency reported complaints about rumble strips from motorists who thought that they were imperfections in the road surface and did not realize that they were intended as a safety device. These experiences indicate a need for public education about the purpose of rumble strips, particularly shoulder rumble strips, which are being installed for the first time in many areas. Because of the motorist's lack of familiarity with rumble strips, some agencies have adopted a policy of installing RUMBLE STRIP warning signs where rumble strips are placed in the traveled way, particularly for new installations or for temporary installations such as work zones. Warning signs with the legend RUMBLE STRIPS AHEAD have also been used in advance of work zones where rumble strips are present.

Bicyclist Concerns

Several highway agencies indicated that bicyclists have expressed concerns about both traveled way and shoulder rumble strips. Bicycles are not generally a concern on freeways, where nearly all states prohibit bicycles, but the needs of bicyclists should be considered in evaluation of shoulder rumble strip installations for nonfreeway facilities.

The concern of bicyclists about rumble strips in the traveled way is primarily related to the potential for loss of control if a rider strikes a rumble strip unaware. However, there are no reliable data on the extent to which traveled way rumble strips create problems for bicyclists. This issue merits further research.

Highway agencies also report concerns expressed by bicyclists about shoulder rumble strips. Where paved shoulders are provided, the shoulder is the preferred travel area for bicyclists. A concern has been expressed that shoulder rumble strips may encourage bicyclists to ride in the traveled way in situations when both the rider and the highway agency would prefer for them to use the shoulder. While rumble strips are often installed for 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 that discourages bicycle riding in that area. If a spacing of 2 ft or more is used between the edge of the traveled way and the rumble strips, bicyclists may be able to ride between them. However, it should be recognized that moving the rumble strips farther from the traveled way decreases the recovery area available to errant vehicles.

One agency reported that they do not use rumble strips in the traveled way on designated bicycle routes unless there is a separate bicycle lane. Another agency reported that they are experimenting with chip-seal resurfacing of shoulders to create a rumble effect for errant vehicles, as an alternative to rumble strip installation in areas where bicyclists frequently ride on shoulders.

Motorcyclist Concerns

Highway agencies have reported concerns expressed by motorcyclists about rumble strips placed in the traveled way, similar to the concerns that have been expressed in the past by motorcyclists about locations where grooved pavements have been used to reduce wet-weather accidents. There is no information about whether rumble strips in the traveled way create serious problems for motorcyclists, but this issue merits further research.

Discontinuous rumble strips like those illustrated in Figure 10 might seem to be advantageous to motorcyclists because they may be able to steer around them. However, there is a potential concern if motorcyclists ride between the rumble bars because the center portion of the road is where oil and grease are most likely to collect on the pavement surface. Where the rumble strip is used in advance of a STOP sign, motorcyclists may be forced to brake on a portion of the pavement surface with a reduced friction coefficient.

Truck Concerns

It has been reported that traveled way rumble strips are less effective in slowing trucks than in slowing passenger cars (1,19). This effect is not well documented, but it seems reasonable that, since normal truck operation involves higher noise and vibration levels than passenger car operation, truck drivers may be less likely to detect rumble strips. This concern should not discourage rumble strip usage because passenger cars constitute the vast majority of the traffic stream at most locations. Rumble strips could increase the speed variance of the traffic stream, if passenger cars slow more than trucks, but there is no evidence that increases in speed variance from rumble strip usage lead to safety problems.

No-Passing Zones at Rumble Strip Sites

Installation of rumble strips on an intersection approach on a two-lane highway can limit passing opportunities for the opposing direction of travel. Where rumble strips are placed on an intersection approach, passing by vehicles traveling in the opposite direction should be prohibited even if that passing restriction is not warranted because of limited sight distance. Prohibition of passing by opposing vehicles prevents them from traversing the rumble strips when headed away from, rather than toward the intersection. Some highway agencies are concerned with the reduced traffic operational level of service that can result from passing prohibitions that accompany rumble strip installation.

Installation Concerns

A concern has been expressed by some highway agencies about the amount of time that a roadway or lane must be closed to install rumble strips. Construction techniques to minimize the amount of lane closure time are needed.

Overuse of Rumble Strips

Several highway agencies commented on the importance of avoiding the temptation to use rumble strips where they are not needed. If every intersection had rumble strips on its approaches, rumble strips would soon lose their ability to focus the attention of the motorist on an unexpected hazard. This could generally reduce the effectiveness of rumble strips at all locations, including the locations where they are truly needed. The ability to gain the motorist's attention results because passing over a rumble strip is an unusual experience. Furthermore, many of the potential adverse effects of rumble strips discussed above will be less of a concern if rumble strips are not overused.

The overuse of rumble strips is primarily a concern related to rumble strips placed in the traveled way. Rumble strips placed on shoulders, where they are encountered only by errant vehicles, are appropriate for more frequent use (e.g., on most freeways or on most rural highways). A rumble strip on the traveled way is encountered by every motorist. When used on shoulders, motorists encounter rumble strips only when they need to.

RUMBLE STRIP DESIGN AND INSTALLATION

This chapter describes the rumble strip designs and installation methods that have been used by highway agencies. Separate discussions are provided for rumble strips placed in the traveled way, rumble strips on asphalt shoulders, and rumble strips on portland cement concrete shoulders.

RUMBLE STRIPS PLACED IN THE TRAVELED WAY

Most rumble strips placed in the traveled way consist of a pattern of raised or grooved bars spaced relatively close to one another and oriented in a transverse direction across the roadway. A photograph of a typical rumble strip installation in the traveled way has been presented in Figure 2. The same effect has been accomplished by some highway agencies using raised pavement markers placed in the traveled way.

Figure 11 illustrates a typical rumble strip installation in the traveled way of a highway. Typical values of the dimensions

shown in Figure 11 are given in Table 7, which summarizes the design practices of 24 state highway agencies for rumble strips placed in the traveled way. Most raised rumble strips consist of asphalt bars placed on the surface of the traveled way; wooden forms are used to create the desired shape for the bar. Most grooved rumble strips consist of indentations placed in the pavement surface by grinding or sawing.

Table 7 summarizes for each highway agency the applications for which specific rumble strip designs are intended (intersection approaches, lane drops, horizontal curves, work zones) and whether raised or grooved rumble strips are used. Rumble strip dimensions and features also presented in the table include the length of the pattern of rumble bars, measured longitudinally along the highway; the number of rumble bars per pattern; the width of each rumble bar; the center-to-center between successive bars; the height of the raised bar or the depth of the grooved bar; the cross-sectional shape of the bar (rectangular, tapered, vee-shaped, or rounded);

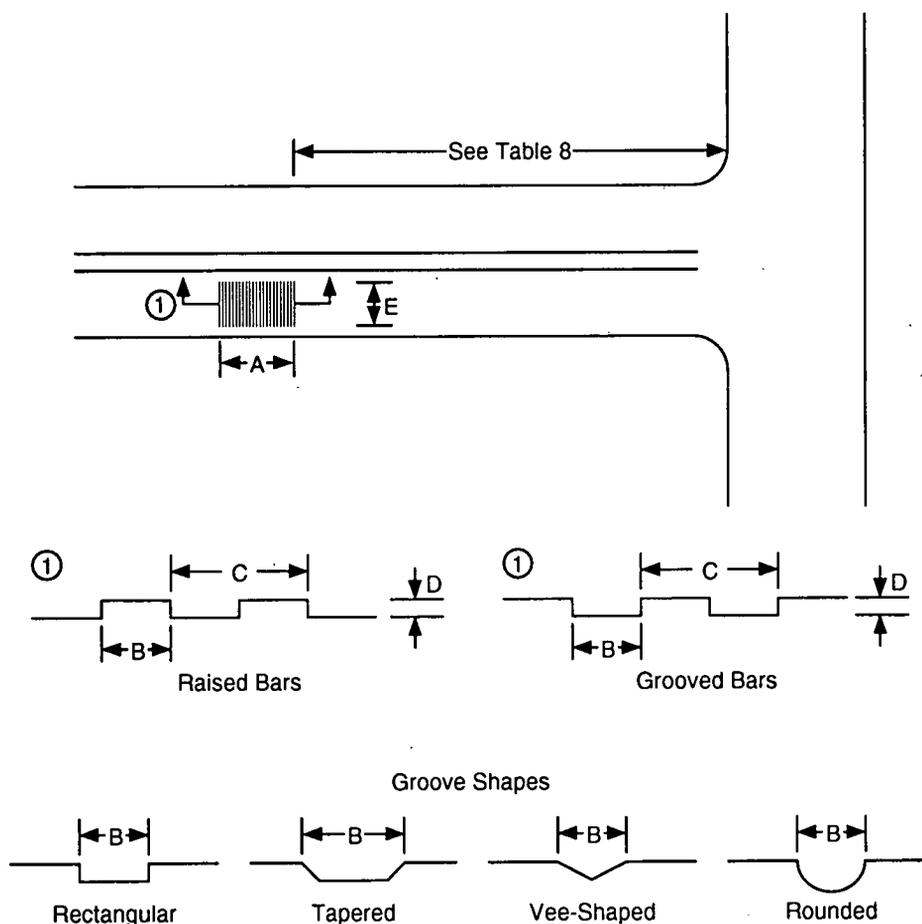


FIGURE 11 Typical dimensions and shapes for rumble strips placed in the traveled way.

TABLE 7
DIMENSIONS AND DESIGN CRITERIA FOR RUMBLE STRIPS PLACED IN THE TRAVELED WAY

State	Application	Raised/ Grooved	Length of Pattern A	No. of Bars per Pattern	Bar Width B	Bar Spacing (CL-CL) C	Height or Depth D	Shape	Strip Width E	Comments
Alabama	Intersections	Raised	6.67'	5	8"	18"	0.625"	Tapered	Variable	
Arkansas	Intersections	Grooved	10.33'	5	3.5-5"	24"	1.5"	Rectangular	Full lane	
Colorado	Intersections Lane drops Horizontal curves	Grooved (permanent)	11.33'	12	4"	12"	0.500"	Rectangular	Full lane	
	Work zones	Raised (temporary)	Varies	Varies	4"-6"	12"	0.500"	Rectangular or Tapered	Full lane	
Florida	Intersections	Raised	5.17'	6	2"	12"	0.500"	Tapered	Fwys: full lane Nonfwys: Full lane-1.5'	
Georgia	Intersections Horizontal curves	Raised	20'	-	-	-	-	-	Full lane	
Hawaii	Intersections Horizontal curves	Raised (RPM)	24'	9	N/A	36"	-	RPM (button)	3'	Raised pavement markers across lane on 6" centers
Idaho	Intersections	Grooved (A pattern)	11'	8	6"	18"	-	-	-	On intersection approach, both A & B patterns are used; typically, 5 strips are used: 2 A patterns followed by 3 B patterns Variable spacing gives an accelerating noise
		Grooved (B pattern)	17'	12	6"	18"	-	-	-	
Illinois	Intersections	Grooved	25'	25	4"	12"	0.188"	Rectangular	Full lane	
		Raised	25'	19	8"	16"	0.188"	Rectangular	Full lane	
	Work zones	Raised (temporary)	25'	6	-	60"	-	-	Full lane	High-strength polycarbonate
Iowa	Intersections	Grooves	24'	25	4"	12"	0.375"	Rectangular	Full lane -18"	No rumble strip on rightmost 18" of lane
Kansas	Intersections	Grooves	24'	25	4"	12"	0.375"	Rectangular	Full lane	No rumble strip on rightmost 18" of lane
Kentucky	Intersections	Raised	15.67'	10	8"	12"	0.250-0.375"	Rectangular	Full lane	45 mph or less
	Work zones	Raised	24.67'	10	8"	24"	0.375-0.500"	Rectangular	Full lane	Over 45 mph
Michigan	Intersections	Grooved	3.33'	4	4"	12"	0.375-0.500"	Rectangular	Full lane	

TABLE 7
CONTINUED

State	Application	Raised/ Grooved	Length of Pattern A	No. of Bars per Pattern	Bar Width B	Bar Spacing (CL-CL) C	Height or Depth D	Shape	Strip Width E	Comments
Mississippi	Intersections	Raised	8.50'	9	4-8"	12'	0.500-1.000"	Rounded	Full lane	In some cases, rumble strip patterns end 1' from each edge of the lane
Nebraska	Intersections	Raised	24.5'	17	6"	18"	Max 0.75"	Rounded	3.5'	Broken rumble strips used on intersection approaches; these consist of a 3.5' rumble strip in each wheelpath areas
		Grooved	24.33'	19	4"	16"	Max 0.75"	-	Full lane-1'	
New Hampshire	Work zones	Raised (temporary)	25'	6	-	60"	-	-	Full lane	High-strength polycarbonate
North Dakota	Intersections	Grooved (in AC pavt)	25.33'	26	4"	12"	0.375"	Rectangular	Full lane	Also use exposed-aggregate rumble strip pads
			15.33'	16	4"	12"	0.375"	Rectangular	Full lane	
		Raised (epoxy)	24.67'	19	8"	16"	-	-	Full lane	
			15.33'	12	8"	16"	-	-	Full lane	
Ohio	Intersections etc.	Raised	12.67'	10	8"	16"	0.25"	Rectangular	Full lane	
		Grooved	11.33'	12	4"	12"	0.500"	Tapered	Full lane	
Oklahoma	Intersections	Grooved	2.85'	5	8"	2.25"	0.875"	Vee	Full lane	
		Grooved	2.85'	5	8"	2.25"	0.875"	Rounded	Full lane	
		Grooved	4.33'	5	12"	4"	0.500"	Rectangular	Full lane	
		Raised	20'	15	8"	16"	0.50-0.75"	Rounded	Full lane	
Oregon	Intersections	-	4.33'	5	-	-	-	-	-	
Pennsylvania	Work zones	Raised	14.33- 19.33'	15-20	4"	12"	0.50"	Rectangular	Full lane	
South Dakota	Intersections	Raised	24.5'	17	6"	18"	0.50"	Tapered	3.5'	Broken rumble strips used on intersection approaches; these consist of a 3.5' rumble strip in each wheelpath areas
West Virginia	Intersections	Grooved	11.33'	12	4"	12"	Max 0.75"	Tapered	Full lane	
Wisconsin	Intersections Horizontal curves	Raised or Grooved	4.33'	4	4"	12"	0.375"	-	Full lane	On asphalt pavements
		Grooved	23.25'	24	3"	12"	0.500"	Tapered	Full lane	On PCC pavements

and the length of the bars, relative to the width of the lane in which the rumble strip is placed.

The table shows that rumble strip design practices vary widely. For example, the number of bars per pattern varies from 4 to 25 and the depth of rumble strip grooves varies from 3/16-in. (0.188 in.) to 1.5 in. Other than the factors discussed in the section on potential adverse effects of rumble strips, there are no data to indicate any preference for any particular rumble strip design among those given above.

Figure 12 shows typical dimensions for the discontinuous rumble strip pattern used in Nebraska and South Dakota to allow drivers to avoid running over the rumble strip without encroaching on the opposing lane (see the discussion of this discontinuous rumble strip pattern in Chapter Four).

Practices for spacing between rumble strip patterns along the approaches to STOP-controlled intersections also vary widely. Table 8 illustrates the variety of rumble strip spacings used by the highway agencies on intersection approaches. As stated previously, there are no data concerning the relative effectiveness of these different rumble strip arrangements.

A typical construction specification for rumble strips placed in the traveled way is presented in Appendix B.

RUMBLE STRIPS PLACED ON ASPHALT SHOULDERS

Most rumble strips placed on asphalt shoulders consist of grooves placed in the asphalt by a roller during the compaction of the asphalt surface course on the shoulder. Figure 5 is a photograph of a typical continuous rumble strip on an asphalt shoulder. Such patterns are generally continuous along extended sections of asphalt shoulder. One state highway agency, the Hawaii Department of Transportation, has used raised pavement markers (buttons) to create rumble strips at regular intervals on asphalt shoulders. A few highway agencies have used rumble strip patterns placed intermittently on asphalt shoulders like the intermittent rumble strip patterns that are used on portland cement concrete shoulders.

Figure 13 illustrates typical continuous and intermittent rumble strip applications on asphalt shoulders. Typical values for the dimensions shown in Figure 13 are given in Table 9, which summarizes the design practices of 18 state highway agencies.

Table 9 presents the rumble strip type (continuous/intermittent) used on asphalt shoulders by each highway agency. In virtually all cases, highway agencies have used grooved, rather than raised, rumble strips on asphalt shoulders. For intermittent rumble strip patterns, the table also indicates the typical spacing between patterns, the length of each pattern, and the number of grooves per pattern. For both continuous and intermittent rumble strip patterns, the table indicates the center-to-center spacing between adjacent grooves; the width of each groove; the height or depth of each groove; the shape of each groove (rectangular, tapered, vee-shaped, rounded); the distance from the edge of the traveled way to the inside edge of the rumble strip pattern; the width of the rumble strip pattern; and the distance from the outside edge of the rumble strip pattern to the outside edge of the shoulder.

The most common design for rumble strips on asphalt shoulders is to place grooves at 8- to 9-in. center-to-center spacing. These grooves are rolled into the asphalt during initial construction or resurfacing of the shoulder. A modified roller with steel rods attached at the appropriate spacing is used for this purpose. The depth of these grooves varies from 1/2 to 1 in. Figure 14 shows a photograph of a continuous rumble strip being placed on an asphalt shoulder with a modified roller.

A typical construction specification for rumble strip placement on asphalt shoulders using a roller is presented in Appendix C.

RUMBLE STRIPS PLACED ON PORTLAND CEMENT CONCRETE SHOULDERS

Rumble strips are placed at intervals on portland cement concrete shoulders. Some highway agencies have provided rumble strips for extended sections of portland cement concrete shoulders, typically on freeways, while others use them in the vicinity of key decision points such as exit and entrance ramps. Photographs of typical rumble strip installations on portland cement concrete shoulders have been presented in Figures 6 and 7.

Figure 15 illustrates a typical rumble strip installation on a portland cement concrete shoulder. Typical values of the dimensions shown in Figure 15 are given in Table 10, which summarizes the design practices of 21 state highway agencies

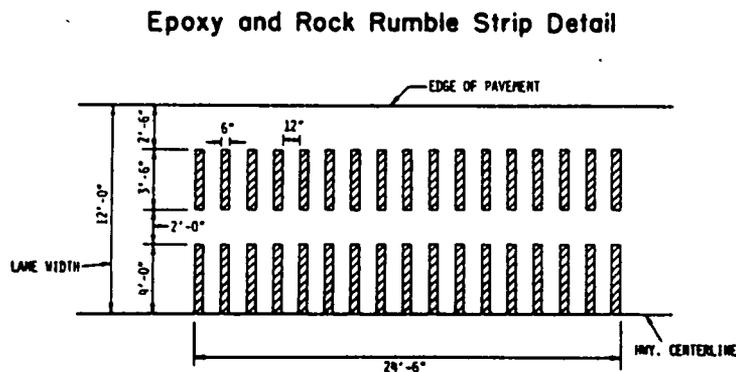


FIGURE 12 Dimensions of discontinuous rumble strips placed in the traveled way on an intersection approach (30).

TABLE 8
SPACINGS OF RUMBLE STRIPS IN THE TRAVELED WAY ON INTERSECTION APPROACHES

State	No. of Rumble Strip Patterns per Approach	Rumble Strip Locations (in order of increasing distance from the intersection)
Alabama	5	250 to 600' from intersection (depending on approach speed)
		50' beyond previous pattern
		50' beyond previous pattern
		100' beyond previous pattern
		100' beyond previous pattern
Colorado	5	300' from intersection
		400' from intersection
		500' from intersection
		700' from intersection
		1000' from intersection
Florida	7	100' from intersection
		150' from intersection
		200' from intersection
		250' from intersection
		350' from intersection
		450' from intersection
		650' from intersection
Georgia	3	400' from intersection
		585' from intersection
		805' from intersection
		NOTE: STOP AHEAD sign @ 735' from intersection.
Idaho	6	Pattern A @ 400' from intersection
		Pattern A @ 430' from intersection
		Pattern A @ 470' from intersection
		Pattern A @ 520' from intersection
		Pattern B @ 650' from intersection
		Pattern B @ 830' from intersection
		NOTE: Patterns A and B are defined in Table 7
Illinois	3	300' from intersection
		500' from intersection
		200' upstream of STOP AHEAD sign
		NOTE: Location of STOP AHEAD sign is variable
Iowa	3	300' from intersection
		Halfway between the two other locations
		200' upstream of STOP AHEAD sign
		NOTE: Location of STOP AHEAD sign is variable
Kansas	3	1350' from intersection
		1450' from intersection
		1550' from intersection
		NOTE: STOP AHEAD signs located @ 550' and 1250' from the intersection

TABLE 8
CONTINUED

State	No. of Rumble Strip Patterns per Approach	Rumble Strip Locations (in order of increasing distance from the intersection)
Michigan	3	400' upstream of the STOP AHEAD sign
		500' upstream of the STOP AHEAD sign
		700' upstream of the STOP AHEAD sign
		NOTE: STOP AHEAD sign located from 400' to 750' from the intersection
Mississippi	5	200' from intersection
		275' from intersection
		375' from intersection
		525' from intersection
		725' from intersection
Nebraska	2	1600' from intersection
		1675' from intersection
		NOTE: STOP AHEAD sign is located 1500' from the intersection
North Dakota	6	250' from intersection
		305' from intersection
		70' upstream of junction sign
		135' upstream of junction sign
		235' upstream of junction sign
		360' upstream of junction sign
		NOTE: location of junction sign is variable
Ohio	10	Rumble strip spacings vary as a function of approach speed
Oklahoma	3	500' from intersection
		1000' from intersection
		2000' from intersection
		NOTE: STOP AHEAD sign located 900' upstream from the intersection
Oregon	5	Rumble strip spacing is variable from 150 to 500'
South Dakota	2	300 to 600' from intersection (depending on approach speed)
		150' upstream of STOP AHEAD sign
		NOTE: Location of STOP AHEAD sign is variable
West Virginia	10	Rumble strip spacings vary as a function of approach speed
Wisconsin	3	300' from intersection
		425' from intersection
		900' from intersection
		NOTE: STOP AHEAD sign is located @ 700' upstream from the intersection

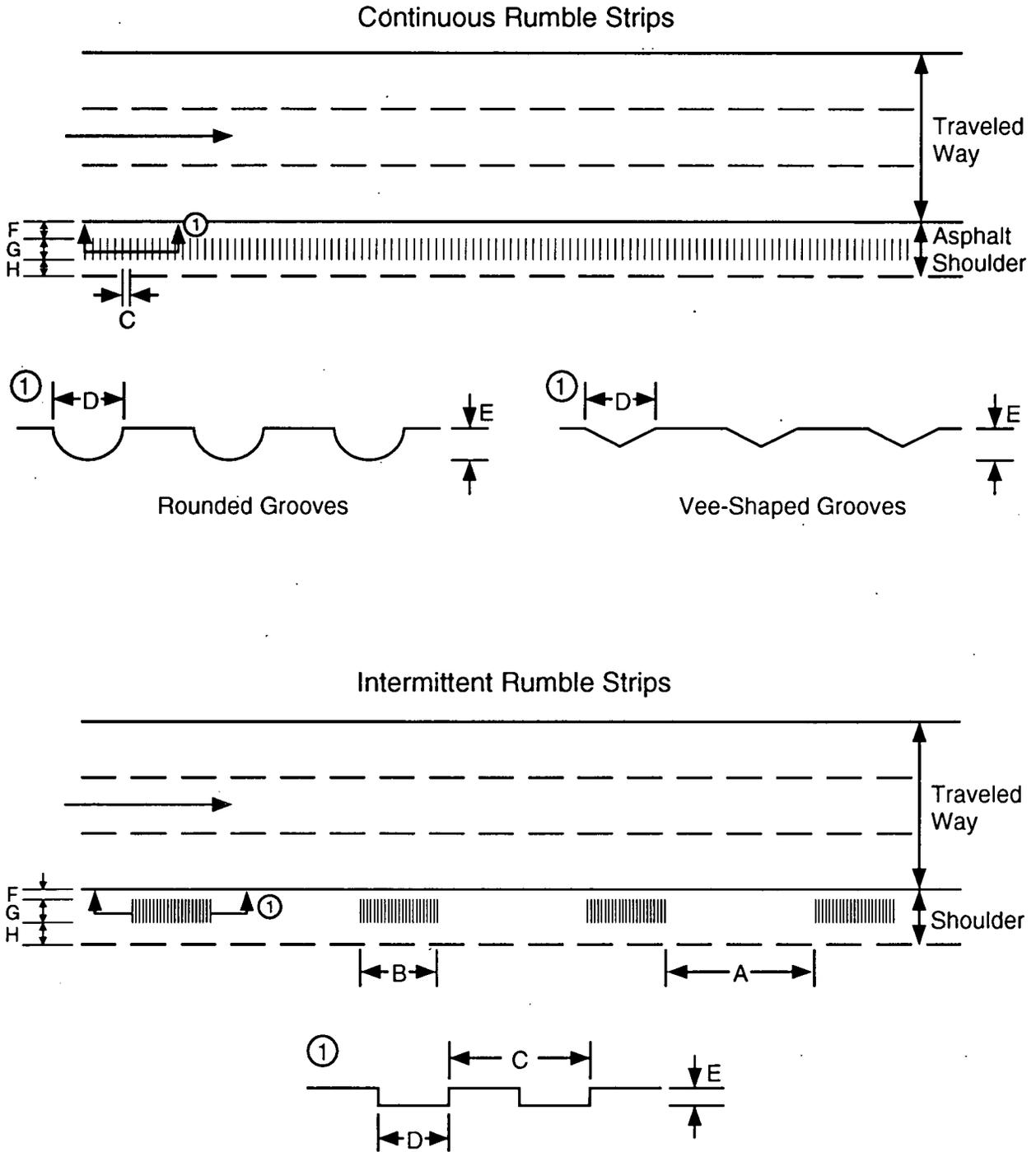


FIGURE 13 Typical dimensions and shapes for rumble strips on asphalt shoulders.

TABLE 9
DIMENSIONS AND DESIGN CRITERIA FOR RUMBLE STRIPS ON ASPHALT SHOULDERS

State	Rumble Strip Frequency	Spacing Between Patterns A	Length of Pattern B	No. of Grooves per Pattern	Groove Spacing (CL-CL) C	Groove Width D	Groove Depth E	Groove Shape	Distance from Traveled Way to Pattern F	Width of Pattern G	Distance from Pattern to Outside Edge of Shoulder H	Comments
California	Continuous	-	-	-	8"-9"	1"	1-2"	Rounded	1.5'	3'	-	
Colorado	Continuous	-	-	-	8"-9"	.75"-1"	0.75"-1"	Rounded	1'	2'	6'	
Florida	Intermittent	200'	5.17'	6	12"	2"	0.50"	Tapered	0'	Fwys: full shldr Nontwys: Full shldr-1.5'	-	
Hawaii	Continuous	-	-	-	36"	-	-	RPM	0.25'	1'	-	used only on approaches to horizontal curves
Idaho	Intermittent	60'	4.50'	8	6"	-	-	-	-	-	-	8 rumble strips at 6" centers every 60'
Illinois	Continuous	-	-	-	8"	2.5"	1"	Rounded	1'	3'	-	
Kansas	Continuous	-	-	-	8"	2"	1"	Rounded	0.5'	3'	-	
Michigan	Continuous	-	-	-	8"	2.5"	1"	Rounded	1'	3'	-	
Mississippi	Continuous	-	-	-	8"-9"	0.875"	0.875"	Rounded	1'	2'	4'	
Nevada	Continuous	-	-	-	8"-9"	0.875"	0.875"	Rounded	1'	3'	4'	
New Mexico	Continuous	-	-	-	8"-9"	0.500"	0.500"	Rounded	1'	2'	4'	
Oklahoma	Continuous	-	-	-	8"	2.25"	0.875"	Vee	1'	2'	-	AC continuous - multilane
		-	-	-	8"	2.25"	0.875"	Rounded	1'	2'	-	
		-	-	-	12"	4"	0.500"	Rectangular	1'	2'	-	
	Continuous	-	-	-	8"	2.25"	0.875"	Vee	1'	2'	6'	AC continuous - 2-lane
		-	-	-	8"	2.25"	0.875"	Rounded	1'	2'	6'	
		-	-	-	12"	4"	0.500"	Rectangular	1'	2'	6'	
	Intermittent	52.8'	2.85'	5	8"	2.25"	0.875"	Vee	1'	3.33'	-	AC intermittent - multilane
		52.8'	2.85'	5	8"	2.25"	0.875"	Rounded	1'	3.33'	-	
		52.8'	4.33'	5	12"	4"	0.500"	Rectangular	1'	3.33'	-	
	Intermittent	52.8'	2.85'	5	8"	2.25"	0.875"	Vee	1'	2'	6'	AC intermittent - 2-lane
		52.8'	2.85'	5	8"	2.25"	0.875"	Rounded	1'	2'	6'	
		52.8'	4.33'	5	12"	4"	0.500"	Rectangular	1'	2'	6'	
Intermittent	52.8'	-	1	-	4"	0.75"	Tapered	1'	3.33'	9.33'	AC intermittant - single-groove	
	52.8'	-	1	-	3.5"	0.50"	Rectangular	1'	3.33'	9.33'	multilane or two-lane; alternate angles of grooves 45 or 60 degrees	
Oregon	Continuous	-	-	-	9"	-	-	-	-	-	-	
Tennessee	Continuous	-	-	-	8"-9"	0.75"	0.75"	Rounded	-	3'	-	
Utah	Continuous	-	-	-	8"-9"	1.5"	1"	Rounded	1'	2'	-	Used only on rural hways with design speed of 50 mph or more
Washington	Intermittent	50'	3.5'	6	7.5"	4"	0.75"	Rectangular	0.5'	Right-5'	-	
		50'	3.5'			Left-3.5'	-					
Wisconsin	Continuous	-	-	-	8"	2.5"	0.75"	Tapered or Rounded	2.5'	2.5'	-	
Wyoming	Continuous	-	-	-	8"-9"	2"	1"	Rounded	0.5'	3'	-	

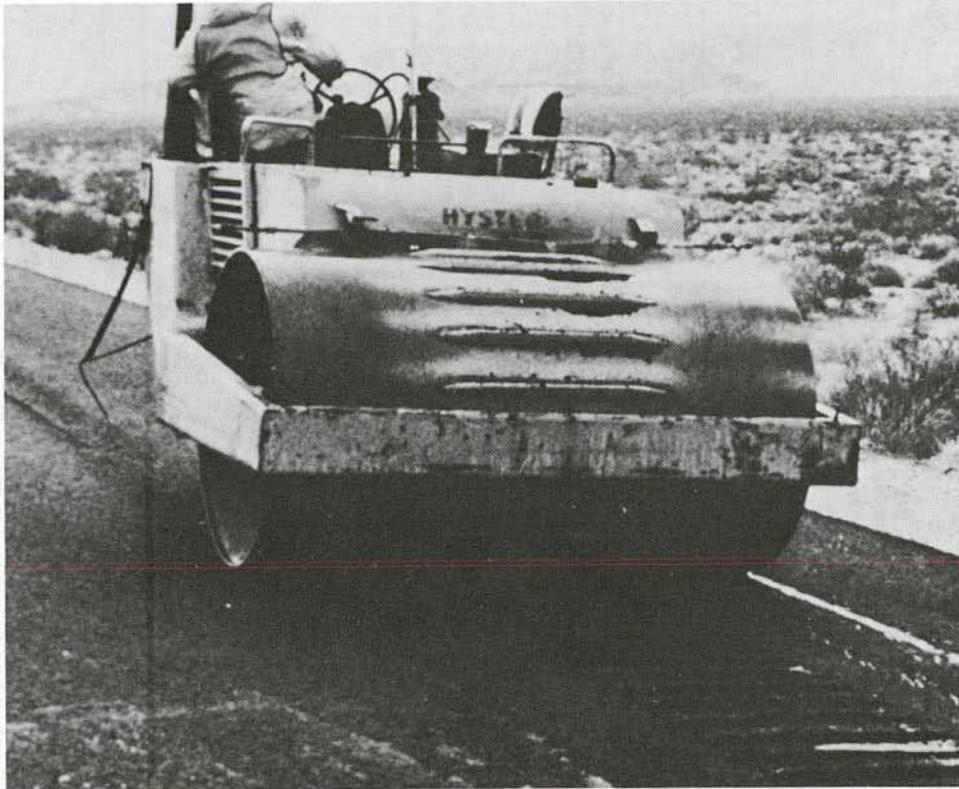


FIGURE 14 Roller being used to place rumble strips on an asphalt shoulder.

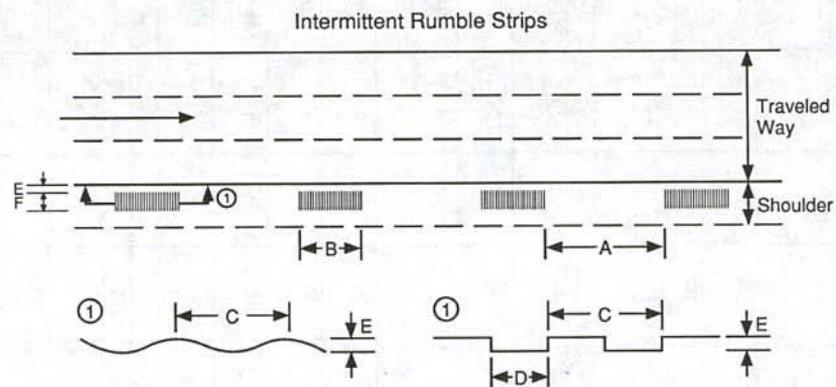


FIGURE 15 Typical dimensions and shapes for rumble strips on portland cement concrete shoulders.

TABLE 10
DIMENSIONS AND DESIGN CRITERIA FOR RUMBLE STRIPS ON PORTLAND CEMENT CONCRETE SHOULDERS

State	Spacing Between Patterns (CL-CL) A	Length of Pattern B	No. of Bars per Pattern	Bar Spacing (CL-CL) C	Bar Width D	Bar Height E	Shape	Distance from Traveled Way to Pattern F	Width of Pattern G	Minimum Shoulder Width	Comments
Arizona	30-60'	4'	17	3"	N/A	1"	Rounded	2'	Full shldr width	-	Pattern spacing depends on design speed; longer spacings used at higher design speeds
Colorado	100'	11.33'	12	12"	4"	0.500"	Rectangular	0'	Full shldr width	6'	leave outside 3' without strip on bicycle routes
Florida	200'	5.17'	6	12"	2"	0.500"	Tapered	0'	Fwys: Full shldr Nonfwys: Full shld-1.5'	-	
Georgia	60'	5.83'	16	4.5"	N/A	1"	Rounded 1" radius	0'	Full shldr width	-	
Idaho	60'	3.67'	8	6.0"	-	-	-	-	-	-	8 rumble strips at 6" centers placed every 60'
Illinois	60-100'	3'-6'	5-10	8"	2.5"	1"	Rounded	1'	3'	-	
Kansas	90'	4'	9	6"	4"	0.75"	Tapered	0.5'	Full shldr width	-	
Kentucky	60'	5.33'	6	12"	4"	0.50"	Tapered	1'	4'	-	
Louisiana	60'	6'	16	4.5"	N/A	1"	Rounded 1" radius	0.5'	6'	-	minimum distance of 1' from outside edge of rumble strip to outside edge of shoulder
Michigan	-	5.81'	16	4.5'	N/A		Rounded 1" radius	1'	Full shldr width	-	rural PCC shoulders
	-	5.81'	16	4.5'	N/A		Rounded 1" radius	1'	Full shldr width	-	urban PCC shoulders minimum distance of 1' from outside edge of rumble strip to outside edge of shoulder
Mississippi	60'	6'	16	4.5"	N/A	1"	Rounded 1" radius	0.17'	2'	-	
Nebraska	-	4'	11	4.5"	N/A	1"	Rounded 1" radius	0.5'	Full shldr-2'	-	
Nevada	54'	6'	16	4.5"	N/A	1"	Rounded 0.5" radius	0'	Full shldr width	-	
North Dakota	-	6'	6	12"	N/A	1"	Rounded 1" radius	3'	4'	-	
Oklahoma	52.8'	4'	6	8.2"	4"	0.75"	Tapered	1'	3.33'	9.33'	
		3.33'	10	4-12"	N/A	0.75"	Rounded	1'	3.33'	9.33'	
Pennsylvania	60'	6'	16	4.5"	N/A	1"	Rounded	0'	Full shldr width	-	
Texas	-	1'	4	3"	N/A	0.50"	Rounded	0'	Full shldr width	-	
Utah	50'	6'	16	4.5"	N/A	0.75"	Rounded	Right-4' Left-1'	Full shldr width	-	Distance from traveled way to rumble strip: 4' on 10' outside shoulder 1' on 4' inside shoulder
West Virginia	40'	3'	12	3"	N/A	1"	Rounded	-	-	-	
Wisconsin	30'	6'	6	12"	4"	0.625"	Rectangular	1.5'	2'	-	Sawed pattern
		6'	6	12"	N/A	1"	Rounded 1" radius	1.5'	2'	-	Formed pattern
Wyoming	55'	4'	11	4.5"	N/A	1"	Rounded 0.5" radius	3'	Full shldr width	-	
		4'	8	3"	1.5"	1"	Rounded. taper	3'	Full shldr width	-	

TABLE 11
TYPICAL RUMBLE STRIP APPLICATIONS IN WORK ZONES (1)

State	Rumble Strips			
	Type	Design	Application	Problems
Pennsylvania (31)	Intermittent raised strips of bituminous overlay.	1/2-in x 4-in @ 12-in spacing. See figure E-1.	In advance of crossovers, but not for speed control.	<ul style="list-style-type: none"> Noise No effects on trucks
Illinois (32)	Raised high-strength polycarbonate (intermittent).	See Figure E-3 (one piece of construction material with two channels).	In advance of construction tapers.	
California (33)	Raised and grooved strips (intermittent).	3/4 in or less in height if raised and 1-in or less in depth if indented.	In advance of workers.	<ul style="list-style-type: none"> Noise and vibration Unusual maneuvers to avoid rumble strips Bicyclists and motorcyclists
Ohio (34)	Intermittent raised strips of asphaltic concrete or depressed grooves. See Figure E-5.	Grooved: 1/2 in x 3.5 in x 11.3 ft @ 8-in spacing. Raised: 1/2 in x 8 in x 12.5 ft @ 8-in spacing.	In advance of construction taper.	<ul style="list-style-type: none"> Hazard for bicycle travel
Kentucky (35)	Intermittent raised bituminous asphalt.	See Figure E-6.	Construction zones, but only with approval from Central Office Division.	

for rumble strips placed on portland cement concrete shoulders. In all but one case, the rumble strips for portland cement concrete shoulders consist of grooves or indentations formed into the concrete surface during the finishing process. One agency reported sawing grooves into the shoulder surface at some locations.

Table 10 presents each agency's practices for the length of the rumble strip pattern, longitudinally along the highway; the number of grooves in the pattern, the center-to-center spacing between grooves; the depth of the grooves, the shape of the grooves (rectangular, tapered, or rounded); the distance from the edge of the traveled way to the edge of the rumble strip pattern; the width of the rumble strip pattern; and the minimum shoulder width on which rumble strips are placed. Table 10 shows the wide variation in rumble strip designs currently used for portland cement concrete shoulders; there are no data to indicate whether any of these patterns performs better than any other.

Appendix D presents a typical construction specification for rumble strips placed on portland cement concrete shoulders.

RUMBLE STRIPS FOR USE IN WORK ZONES

Table 11 summarizes current state highway agency practices in work zones. This table was developed in a recent study by Noel, Sabra, and Dudek (1).

The work zone traffic control manual of the Pennsylvania Department of Transportation (31) includes rumble strips among its miscellaneous devices and materials. The manual approves the use of rumble strips in work zones for alerting drivers to unusual maneuvers and references the standard design shown in Figure E-1 presented here in Appendix E. The manual specifies that rumble strips should always be extended onto the shoulder to discourage drivers from making erratic maneuvers to avoid the rumble strip. Figure E-1 illustrates two rumble strip patterns used in Pennsylvania. Pattern A involves five sets of rumble strips with a separation distance decreasing from 200 ft to 50 ft. These rumble strips span the entire traveled way width, extend onto the shoulder, and are constructed from bituminous material. Pattern B is constructed in a unique method in which ½-in. deep and 4-in. wide plywood forms are nailed in place at 12-in. spacing to

form grooves with a separation distance decreasing from 200 ft to 50 ft. An asphalt overlay is applied to cover the full width of the strip area and the plywood forms are then removed. This application minimizes construction and repair of the existing pavement and provides for easy removal. Pattern A is typically used in advance of a work zone taper area and Pattern B is typically used in the transition area in advance of a temporary detour (see typical traffic control diagram in Figure E-2 in Appendix E).

The Illinois Department of Transportation (32) uses pre-fabricated strips made of polycarbonate material as temporary work zone rumble strips. The strips are grouped in sets of five with a uniform spacing of 5 ft between strips, as illustrated in Figure E-3 in Appendix E. The sets are uniformly positioned at 200 ft apart. A schematic of this application is illustrated in Figure E-4 in Appendix E. The rumble strips used by Illinois extend across the entire width of the traveled way, but do not extend onto the shoulder. As stated in Chapter Four, the Illinois Department of Transportation has encountered problems in maintaining an adequate epoxy bond between the rumble strips and the pavement surface.

California (33) permits rumble strips in work zones only when their use is determined to be the only reasonable solution to an identified problem. The rumble strips used in work zones by Caltrans must be less than ¾-in. high, if raised, or less than 1-in. deep, if grooved.

Ohio (34) and Kentucky (35) have not developed any separate specifications for work zone rumble strips, but use the same specifications that are applicable to rumble strips in the traveled way outside of work zones. Both states use intermittent rumble strip patterns with and without uniform spacing (see Figures E-5 and E-6 in Appendix E). Ohio's design consists of ten patterns of either raised or grooved rumble strips with six to 18 bars or grooves per pattern. The spacing between the rumble strip patterns varies from 50 to 250 ft. Kentucky's design provides uniform rumble strip patterns with spacings between the patterns and between the individual strips within a pattern that varies as a function of prevailing speed.

Several types of rumble strips suitable for temporary application in work zones are commercially available. A portable rumble strip that can be installed temporarily at one location and then reused at other locations is currently being field tested as part of the Strategic Highway Research Program (SHRP).

COST AND SERVICE LIFE OF RUMBLE STRIPS

COST OF RUMBLE STRIPS

Cost data for rumble strips are available only for limited cases, because rumble strips are often not treated as a separate payment item in highway construction contracts and because cost records for specific activities are not usually kept for rumble strips installed by state highway agency maintenance forces. Rumble strip construction costs, particularly in states that now install rumble strips on highway shoulders as a matter of policy in new construction and resurfacing projects, are typically included in the payment item for asphalt or portland cement concrete paving. One agency, the Kansas Department of Transportation, reported that their paving costs have not risen since they began including rumble strips in their payment items for paving. This, of course, may reflect the current competitive situation in the construction industry. All cost data in this chapter were provided by highway agencies during 1991, unless otherwise stated.

Rumble Strips Placed in the Traveled Way

Costs for placement of rumble strips in the traveled way are typically quoted as a cost per linear foot of rumble strip bars or grooves or as a lump sum per intersection approach. Note that the bars and grooves of such rumble strips run transverse to the roadway and that the payment per linear foot is determined by measuring along each bar or groove of the rumble strip, rather than along the roadway. Raised bars typically consist of asphalt material placed on the surface of the traveled way, while grooves are placed in the pavement surface by grinding or sawing.

One highway agency estimates that raised rumble strips cost \$1.40 per linear foot. Reported costs for grooved rumble strips range from \$0.89 to \$2.23 per linear foot. On a lump sum basis, one highway agency reports costs of \$400 per intersection approach for grooved rumble strips and \$500 per intersection approach for raised rumble strips. Another agency reports a cost of \$3,000 per intersection approach for rumble strip installation. Such large variations in cost are indicative of agency-to-agency variations in rumble strip specifications and the vagaries of the bidding process for construction contracts.

Rumble Strips Placed on Asphalt Shoulders

Costs of rumble strip installation on asphalt shoulders are essentially equivalent to the cost of installation in the traveled way if the rumble strips are placed in the shoulder surface by grinding or sawing. When rumble strips are rolled into an asphalt shoulder during resurfacing, reported costs from \$150

to \$580 per mile for a continuous 2- to 5-ft wide rumble strip along one shoulder. This is equivalent to a cost of \$600 to \$2,320 per mile to treat all four shoulders of a divided freeway.

Rumble Strips Placed on Portland Cement Concrete Shoulders

Every agency that provided cost information in response to the highway agency survey discussed in Appendix A reported that the cost of placing rumble strips in portland cement concrete shoulders was part of the construction bid item for concrete paving and was not priced separately. However, one agency reported that when rumble strips had been added to a contract by a change order the cost incurred had been \$0.05 per square yard of the rumble strip pattern.

The cost of placing sawed or grooved rumble strips in existing portland cement concrete pavements varies with aggregate hardness, increasing as the hardness of the aggregate increases. Data for 1992 indicate that the average cost for a sawed or grooved rumble bar with a width of 4 in. and a depth of $\frac{3}{8}$ - to $\frac{1}{2}$ -in. is \$3.50 per linear foot. Therefore, on a 10-ft shoulder, if the typical bar length is 9 ft, a single bar would cost \$31.50, and a cluster of six bars would cost \$189.

Temporary Rumble Strips in Work Zones

One vendor indicates that temporary rumble strips for application in work zones cost about \$4.00 per strip (1). These strips are approximately 2-ft wide, so that six strips must be used, side by side, at a total cost of \$24.00 to extend for the entire width of a 12-ft lane. This cost does not include the labor required to install the rumble strips.

SERVICE LIFE OF RUMBLE STRIPS

Only limited information is available on the service life of rumble strips. Most highway agencies reported that they expect that the service life of a rumble strip should be the same as the service life of the pavement itself: 7 to 8 years between resurfacing for asphalt pavements; 25 years or more for portland cement concrete pavements. One toll road authority reported that they have experienced a service life of about 5 years for rumble strips on asphalt pavement in the traveled way on toll plaza approaches, which is about the same as their standard interval between resurfacing at a high-wear location.

As reported in the discussion of potential adverse effects of rumble strips, durability of rumble strips placed in the traveled way is a concern of highway agencies. For raised rumble strips, highway agencies reported the need for periodic

WEAR IN WHEEL TRACK

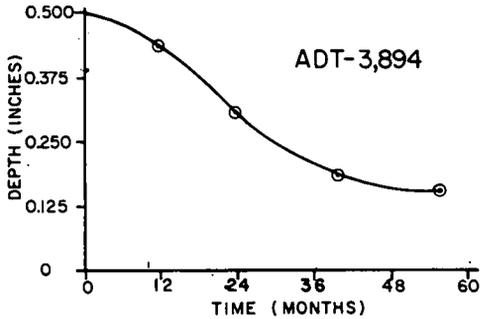
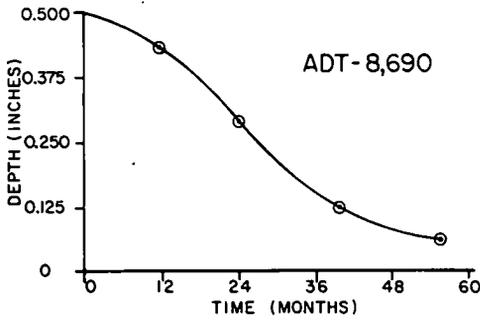


FIGURE 16 PennDOT data on wear of rumble strip grooves in the traveled way on dense-graded asphalt pavement (14).

WEAR IN WHEEL TRACK

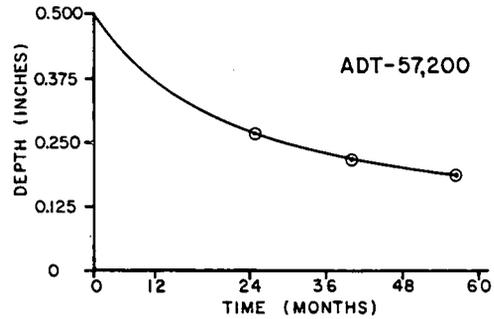
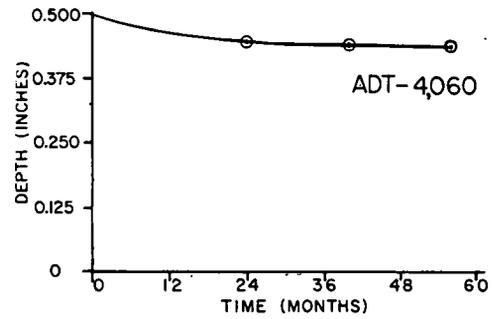
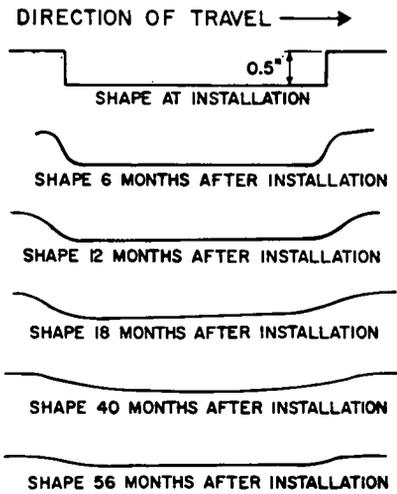


FIGURE 18 PennDOT data on wear of rumble strip grooves in the traveled way on portland cement concrete pavement (18).

WEAR IN WHEEL TRACK



ASPHALT PAVEMENT

FIGURE 17 PennDOT data on change in shape over time for rumble strips in the traveled way on dense-graded asphalt pavement (14).

maintenance to build them up after they had worn down. Similarly, grooved rumble strips tend to wear at the edges of the grooves and the grooves tend to close up gradually over time, especially in asphalt pavements (see discussion of Pennsylvania data below). On the other hand, shoulder rumble strips are not subjected to continuous traffic wear and it seems reasonable to expect that they will perform adequately until the shoulder requires resurfacing.

The Pennsylvania Department of Transportation has studied the wear of grooves, with an initial depth of 0.5 in., placed in the pavement surface of the traveled way. Figure 16 illustrates the rate of wear of rumble strip grooves in an asphalt surface. The grooves are worn to about half of their initial depth within 2 years. Note in Figure 16 that the rate of wear of the grooves is affected by traffic volume. Figure 17 illustrates the changes in shape of a groove in an asphalt pavement as it wears. Figure 18 shows comparable data for wear of grooves in a portland cement concrete surface. The rate of wear is much less in portland cement concrete than in asphalt and is also a strong function of traffic volume. Even on the high-volume pavement for which data are presented in Figure 18, it takes 5 years for a groove to wear to half of its initial depth. On lower volume portland cement concrete pavements, the groove deterioration over 5 years is minimal.

CONCLUSIONS AND RECOMMENDATIONS

This chapter presents conclusions and recommendations concerning the use of rumble strips to enhance safety. The information presented in previous chapters is summarized to help highway agencies obtain safety benefits from using rumble strips where they are appropriate and to avoid inappropriate uses.

RUMBLE STRIPS PLACED IN THE TRAVELED WAY

The following conclusions concerning the application of rumble strips placed in the traveled way have been developed from this synthesis:

- Rumble strips in the traveled way are warning devices intended to alert drivers to the possible need to take some action, but the driver must decide what action is appropriate. Signing may be used in conjunction with rumble strips to help the driver determine the appropriate action (e.g., STOP AHEAD sign, horizontal curve warning sign, speed limit sign, etc.). Rumble strips in the traveled way should be placed so that either the upcoming decision point, or a sign identifying the potentially required action is clearly visible as the driver passes over the rumble strip. Rumble strips should be placed in advance of decision points so that drivers have adequate time to take any required action.

- Rumble strips in the traveled way are used:
 - on approaches to intersections,
 - on approaches to toll plazas,
 - on approaches to horizontal curves,
 - in the lane to be closed, on the approach to a mainline lane drop, and
 - on approaches to or within work zones.

- Rumble strips placed in the traveled way may consist of transverse raised bars or grooves in any of the designs identified in Table 7. Exposed-aggregate rumble pads may also be used to create the same effect.

- The accident reduction effectiveness of rumble strips placed on intersection approaches has not been precisely quantified, but studies suggest that rumble strips can provide a reduction of at least 50 percent in the types of accidents most susceptible to correction. These include rear-end accidents and accidents involving running through a STOP sign or traffic signal. Rumble strips can also be expected to reduce vehicle speed on intersection approaches and to increase driver compliance with STOP signs.

- No similar accident reduction effectiveness estimates are available for other applications of rumble strips in the traveled way.

- Rumble strips placed in the traveled way should not be overused. If rumble strips are used at too many locations they

may lose their ability to gain the motorist's attention. Rumble strips placed in the traveled way are most desirable at locations where there is a documented accident problem and where more conventional treatments—such as signing—have been tried and found to be ineffective. At a few locations, it may be desirable to install rumble strips in the traveled way, even where there is no documented accident history, if accident problems have been encountered at similar locations.

- Rumble strips are not generally effective as speed control devices. Their primary function is to draw the driver's attention to traffic control devices or potential hazards that drivers who are unfamiliar with the roadway may fail to see. Where a substantial proportion of drivers fail to see speed limit signs or roadway features at which they would normally reduce speed, using rumble strips to call their attention to those signs or roadway features may result in a reduction in vehicle speeds. However, rumble strips should not be expected, in and of themselves, to reduce the speeds selected by drivers at locations where there is no apparent reason to slow down.

- Rumble strips placed in the traveled way in residential areas may be objectionable to nearby residents because of the noise generated by vehicles continuously passing over the rumble strips.

- Rumble strips should generally be limited to a maximum height or depth of 0.5 in. to minimize the jarring action to vehicles produced by the rumble strip and the possibility of vehicle damage. However, all rumble strip designs should be verified as producing an audible or tactile sensation of sufficient magnitude to alert drivers.

- Rumble strips should be configured so that substantial proportions of drivers are not tempted to go around the rumble strip by driving onto the shoulder or into an adjacent lane. This can be accomplished by extending the rumble strip over part of the shoulder as well as the full width of the traveled way or by using a discontinuous rumble strip design such as that illustrated in Figure 10.

- Rumble strip installation in the traveled way on bicycle routes, where substantial numbers of bicyclists ride in the roadway, should be discouraged.

- Improved methods are needed for installing temporary rumble strips on pavement surface. Current methods do not appear to create a durable bond between the rumble strip and the pavement surface.

SHOULDER RUMBLE STRIPS

The following conclusions concerning the application of rumble strips placed on roadway shoulders have been developed from this synthesis:

- Rumble strips placed on roadway shoulders may consist of continuous rumble strip grooves placed in the surface of

an asphalt shoulder, rumble strip patterns installed at regular intervals on asphalt or portland cement concrete shoulders, or rumble strip patterns installed at critical locations along asphalt or portland cement concrete shoulders (such as at exit ramps, entrance ramps, or on narrow bridge approaches). Designs in current use for shoulder rumble strips are summarized in Tables 9 and 10.

- Rumble strips on roadway shoulders are warning devices intended to alert drivers that they are leaving (or have left) the traveled way and that a steering correction is needed to return to the traveled way.

- Continuous rumble strips on asphalt shoulders or rumble strips installed at regular intervals along extended sections of asphalt or portland cement concrete shoulders have generally reduced the rate of run-off-road accidents by 20 percent or more. On highways with extremely monotonous driving conditions, such as freeways in desert regions of the West, reductions in run-off-road accident rate as high as 50 percent have been observed.

- No similar accident reduction effectiveness estimates are available for shoulder rumble strips installed just at critical locations such as exit ramps, entrance ramps, and narrow bridge approaches.

- Overuse of shoulder rumble strips is not a major concern because only errant vehicles or other vehicles driving onto the shoulder encounter them. In other words, shoulder rumble strips are encountered only when they are needed. Therefore, highway agencies may wish to consider broader use of shoulder rumble strips for reducing run-off-road accidents on their highway systems. Some highway agencies have installed shoulder rumble strips on most freeways or most rural highways.

- Shoulder rumble strips may reduce the flexibility of highway agencies to convert the shoulder to use as a travel lane during work zone operations or to relieve congestion. Future use of the shoulder as a travel lane can be achieved more easily, particularly on portland cement concrete shoulders, if shoulder rumble strips are provided by raised pavement markers rather than by corrugations formed into the pavement. However, raised pavement markers may have shorter service lives than corrugated rumble strips.

- Use of shoulder rumble strips, either continuously or at regular intervals, over extended highway sections should be carefully considered on bicycle routes. Bicycle considerations are primarily a concern in installation of shoulder rumble strips on nonfreeway facilities. Although rumble strips often extend across only a portion of the shoulder width, the area between the rumble strip and the outside edge of the shoulder is often covered with debris. Installation of shoulder rumble strips may not be desirable if it results in a substantial number of bicyclists riding in the traveled way rather than on this shoulder. It may be desirable to increase the distance between the edge of the traveled way and the rumble strips to 2 ft or more to accommodate bicyclists. However, it should also be recognized that moving the rumble strips farther from the traveled way decreases the recovery area available to errant vehicles. Use of alternative approaches to rumble strip installation, such as exposed-aggregate rumble pads, should be considered.

- The inside edge of a shoulder rumble strip pattern generally should be at least 1 ft from the edge of the traveled way to minimize the possibility that the rumble strip will inter-

fere with snowplow operations on the traveled way. Larger distances between the edge of the traveled way and the rumble strips may be desirable to accommodate bicycles (see above) and snowplowing. Shoulder rumble strips have also been reported to interfere with snowplowing of the shoulder itself. For example, one highway agency reported the need to reduce the plowing speed on shoulders with rumble strips. Highway agencies should investigate these problems, as they apply to their climate and plowing equipment, before beginning wide-scale installation of shoulder rumble strips.

- There are disadvantages in extending shoulder rumble strips all the way to the outside edge of the shoulder. This may concentrate water flow off of the shoulder at the rumble strips and may lead to roadside erosion.

PUBLIC INFORMATION PROGRAMS

A public information program is recommended to educate motorists about the purposes of rumble strips, including both traveled way and shoulder installations. Some motorists have been seen to stop and check their tires after encountering rumble strips; other motorists have called highway agencies to complain about imperfections in the pavement surface. Clearly, such motorists do not understand rumble strips and need additional information. Public information campaigns are particularly appropriate in areas where rumble strips are being installed for the first time.

In some cases, use of RUMBLE STRIP warning signs in connection with rumble strip installation may also be appropriate to help inform the public. However, it does not appear that RUMBLE STRIP warning signs will be very effective or appropriate at locations where rumble strips are being used to call attention to existing signs that are not being seen by the traveling public.

FUTURE RESEARCH NEEDS

Future research is needed on several specific issues concerning rumble strips:

- Better data are needed on the safety effectiveness of rumble strips placed in the traveled way. A well-designed safety evaluation is needed to quantify the accident reduction effectiveness of rumble strips. In addition to test sites where rumble strips are installed, this evaluation should include comparable control sites where rumble strips are not installed. A formal experimental plan should be developed that specifies the number of sites to be evaluated, the duration of the evaluation periods, the statistical techniques to be used, and the accident types to be considered. Traffic volumes on the test and control sites should be documented both before and after rumble strip installation.

- Research is needed to better distinguish between the safety effectiveness of shoulder rumble strips on the left and right sides of the traveled way. Of the two major evaluations of rumble strips that have been conducted, one did not address this issue and the other found unexplained anomalies.

- Current rumble strip designs should be tested to determine whether they create control problems for bicyclists and motorcyclists. If control problems are found, alternative rum-

ble strip 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 rumble pads merit further investigation to determine their effectiveness and service life for use in the traveled way and on shoulders.

- Further noise studies are needed to determine whether rumble strip designs that minimize noise that disturbs nearby

residents can be effective in alerting motorists. Guidelines that specify the minimum distance from rumble strips to the nearest residence are needed.

- The attitudes of senior citizens toward rumble strips should be investigated. In particular, it should be determined if the noise and vibration generated by rumble strips is more objectionable to older drivers than to younger drivers and whether any problems created for older drivers can be minimized by alternative rumble strip designs.

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33. *State of California Manual on Traffic Controls for Construction and Maintenance Work Zones*, California Department of Transportation (1985).
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APPENDIX A

SURVEY OF HIGHWAY AGENCIES

A survey of state and local highway agencies and toll road and turnpike authorities was conducted to obtain information on use of rumble strips to enhance safety. The major objective of the survey was to obtain information on current rumble strip practices and to identify contacts for obtaining further information on:

- Number and type of agencies that have used rumble strips
- Applications for which rumble strips have been used in the traveled way and on shoulders
- Reasons for use of rumble strips
- Effectiveness of rumble strips and perceived problems with their use
- Warrants or guidelines for rumble strip use
- Specifications for the materials, dimensions and patterns, or installation methods used for rumble strips
- Cost and service life of rumble strips

The survey was conducted by means of a mail questionnaire, which is presented in Figure A-1.

The questionnaire was mailed to all 50 state highway agencies, to 98 selected local agencies, and to 15 selected toll road and turnpike authorities. In all cases, the questionnaire was sent to the state traffic engineer, but contributions from traffic, construction, and maintenance personnel were requested in the survey responses. The local agencies included 88 cities and 10 counties. These agencies were selected primarily from the Institute of Transportation Engineers directory. In the local agencies, the questionnaire was sent to the most senior traffic engineer listed in the directory. The number of local agencies in each state was chosen roughly in proportion to the population of each state. A minimum of one local agency was selected in each state. Toll road and turnpike authorities were identified in several directories, including the directory of the American Road and Transportation Builders Association.

RESPONSE RATE

Table A-1 summarizes the response rate to the mail survey. Responses were received from a total of 123 of the 163 agencies to whom the questionnaire was sent, for an overall response rate of 75.5 percent. The response rate was 92 percent for state highway agencies, 63 percent for local agencies, and 100 percent for toll road authorities.

Question 1 Highway Agency Use of Rumble Strips

Table A-2 summarizes the highway agency responses to Question 1. The table shows that rumble strips have been used by 98 percent of state highway agencies, 24 percent of local agencies, and 87 percent of toll roads. The responses from a few of these agencies indicate that they used rumble strips at one time, but no longer do so. However, it appears that most of these agencies are currently using rumble strips.

Rumble strips have been used by all but one of the state highway agencies that responded to the survey and by all but two of the toll roads. This widespread use of rumble strips illustrates their potentially significant role in promoting highway safety.

Obviously, rumble strip usage is not as prevalent in local agencies as in state highway agencies and toll roads. The apparent reasons for this difference in rumble strip use are that local agencies are less likely to operate freeways or other roads with full access control; less likely to operate high-speed roadways; less likely to operate roads used for long-distance trips, where driver inattention might be a major problem; and, less likely to operate roads with shoulders. In addition, most of the local agencies surveyed represent urban communities where rumble strip use may be minimized because of noise concerns.

Table A-1. QUESTIONNAIRES SENT AND RESPONSES RECEIVED FOR RUMBLE STRIP SURVEY

	State highway agencies	Local agencies	Toll roads	Total
Number of questionnaires sent	50	98	15	163
Number (percent) of responses received	46 (92.0)	62 (63.3)	15 (100.0)	123 (75.5)

Table A-2. RESPONSES CONCERNING HIGHWAY AGENCY USE OF RUMBLE STRIPS ON ROADWAYS OR SHOULDERS

Response	State highway agencies	Local agencies	Toll roads	Total
Yes	45 (97.8)	15 (24.2)	13 (86.7)	73 (59.4)
No	1 (2.2)	47 (75.8)	2 (13.3)	50 (40.6)
Total	46	62	15	123

NOTE: The numbers in parentheses are column percentages.

Question 2 Rumble Strip Applications

Question 2 addressed the specific applications for which rumble strips have been used by highway agencies. The question was structured to obtain separate responses concerning rumble strip usage in the traveled way and on shoulders.

Table A-3 summarizes the reported highway agency usage of rumble strips placed in the traveled way. The table shows that, of highway agencies that have used rumble strips, rumble strips in the traveled way have been used by 91 percent of state highway agencies, 47 percent of local agencies, and 69 percent of toll roads. Table A-3, and all subsequent tables, include only highway agencies that stated in response to Question 1 that they have used rumble strips.

Table A-4 summarizes the specific applications for which highway agencies have used rumble strips placed in the traveled way. By far the most common application of rumble strips placed in the traveled way is on the approaches to intersections and other junctions. Other common applications of rumble strips in the traveled way are on approaches to toll plazas, horizontal curves, and work zones. Four agencies reported using rumble strips in the traveled way in advance of lane drops. Other reported applications of rumble strips in the traveled way include:

- On the approach to the end of a freeway (2 agencies)
- On the approach to a speed limit reduction from 65 to 55 mph (1 agency)
- On the approach to school crossing on high-volume roads (1 agency)
- On roadway edgelines on horizontal curves (1 agency)
- On centerlines of two-lane, two-way roadways (1 agency)
- As a chatter strip used to delineate two-way left-turn lanes, exclusive turn lanes, and gore areas (1 agency)

Highway agency usage of rumble strips on shoulders is summarized in Table A-5. The table shows that, of highway agencies that use rumble strips, rumble strips on shoulders have been used by 89 percent of state highway agencies, 7 percent of local agencies, and 69 percent of toll roads. Local agencies do not commonly use rumble strips on shoulders because they do not operate high-speed roadways and roadways with shoulders as commonly as do state highway agencies and toll road authorities. In addition, noise concerns limit rumble strip usage in urban areas.

Table A-3. RESPONSES CONCERNING HIGHWAY AGENCY USE OF RUMBLE STRIPS PLACED IN THE TRAVELED WAY

Response	State highway agencies		Local agencies		Toll roads	Total
Yes	41	(91.1)	7	(46.7)	9 (69.2)	57
No	4	(8.9)	8	(53.3)	4 (30.8)	16
Total	45		15		13	73

NOTE: The numbers in parentheses are column percentages.

Table A-4. RESPONSES CONCERNING LOCATIONS AT WHICH HIGHWAY AGENCIES HAVE USED RUMBLE STRIPS IN THE TRAVELED WAY

Locations	State highway agencies		Local agencies		Toll roads	Total
APPROACHES TO:						
Intersections and other junctions	37	(82.2)	7	(46.7)	0 (0.0)	44 (60.3)
Toll plazas	12	(26.7)	0	(0.0)	7 (53.8)	19 (26.0)
Horizontal curves	10	(22.2)	5	(33.3)	0 (0.0)	15 (20.5)
Narrow bridges	0	(0.0)	0	(0.0)	0 (0.0)	0 (0.0)
Lane drops	2	(4.4)	2	(13.3)	0 (0.0)	4 (5.5)
Railroad-highway grade crossings	0	(0.0)	0	(0.0)	0 (0.0)	0 (0.0)
Work zones ^a	11	(24.4)	1	(6.7)	5 (38.5)	17 (23.3)
Other applications	6	(13.3)	9	(60.0)	0 (0.0)	17 (20.5)

^a Or within work zones

NOTE: The numbers in parentheses represent the percentage of highway agencies that have used each rumble strip application. Percentages add to more than 100 percent because of multiple responses.

Table A-5. RESPONSES CONCERNING HIGHWAY AGENCY USE OF RUMBLE STRIPS ON HIGHWAY SHOULDERS

Response	State highway agencies		Local agencies		Toll roads	Total
Yes	39	(86.7)	1	(6.7)	9 (69.2)	46 (63.0)
No	6	(13.3)	14	(93.3)	4 (30.8)	27 (37.0)
Total	45		15		13	73

NOTE: The numbers in parentheses are column percentages.

Table A-6 summarizes the specific applications for which rumble strips have been used on shoulders. The most common application of rumble strips on shoulders is at specified intervals or continuously along extended sections of highway. Over 60 percent of agencies that use rumble strips have used them for this application. Seven agencies reported the use of rumble strips on shoulders on the approaches to narrow bridges (bridges for which the full upstream shoulder width is not carried across the bridge). Rumble strips have also been used on shoulders at toll plazas, horizontal curves, lane drops, and work zones. No applications of rumble strips on shoulders were listed by the responding agencies beyond those already listed in the questionnaire.

Question 3 Uses of Rumble Strips on Highway Shoulders

Question 3 of the survey addresses the situations in which rumble strips have been used on highway shoulders. Specific responses were requested concerning the shoulder materials, highway types, side of highway, and project types where shoulder rumble strips have been used.

The shoulder materials on which highway agencies have installed rumble strips are summarized in Table A-7. The table shows that, of the highway agencies that have used rumble strips on shoulders, 16 percent have used rumble strips on portland cement concrete shoulders only, 33 percent have used rumble strips on asphalt concrete shoulders only, and 51 percent have used rumble strips on both portland cement and asphalt concrete shoulders.

Table A-6. RESPONSES CONCERNING LOCATIONS AT WHICH HIGHWAY AGENCIES HAVE USED RUMBLE STRIPS ON HIGHWAY SHOULDERS

Locations	State highway agencies		Local agencies		Toll roads		Total	
At specified intervals along highway shoulders ^a	35	(77.8)	1	(6.7)	9	(69.2)	45	(61.6)
APPROACHES TO:								
Intersections and other junctions	1	(2.2)	0	(0.0)	0	(0.0)	1	(1.4)
Toll plazas	0	(0.0)	0	(0.0)	2	(15.4)	2	(2.7)
Horizontal curves	3	(6.7)	0	(0.0)	0	(0.0)	3	(4.1)
Narrow bridges	7	(15.6)	0	(0.0)	0	(0.0)	7	(9.6)
Lane drops	2	(4.4)	0	(0.0)	0	(0.0)	2	(2.7)
Railroad-highway grade crossings	0	(0.0)	0	(0.0)	0	(0.0)	0	(0.0)
Work zones ^b	1	(2.2)	0	(0.0)	0	(0.0)	1	(1.4)
Other applications	4	(8.9)	2	(6.7)	0	(0.0)	5	(6.8)

^a Or continuously along highway shoulders.

^b Or within work zones.

NOTE: The numbers in parentheses represent the percentage of highway agencies that have used each rumble strip application. Percentages add to more than 100 percent because of multiple responses.

Table A-7. RESPONSES CONCERNING HIGHWAY SHOULDER TYPES ON WHICH AGENCIES HAVE USED RUMBLE STRIPS

Shoulder type	State highway agencies		Local agencies		Toll roads		Total	
Portland cement concrete shoulders	6	(15.4)	0	(0.0)	2	(22.2)	8	(16.3)
Asphalt shoulders	10	(25.6)	1	(100.0)	5	(55.6)	16	(32.7)
Both portland cement and asphalt shoulders	23	(59.0)	0	(0.0)	2	(22.2)	25	(51.0)
Not applicable ^a	6		14		4		24	
Total	45		15		13		73	

^a Rumble strips have not been used on shoulders by these agencies

NOTE: The numbers in parentheses are column percentages.

Table A-8 identifies the highway types on which highway agencies have used shoulder rumble strips. The table indicates that, of highway agencies that have used rumble strips on shoulders, 76 percent have used rumble strips on freeways (or other highways with full access control, such as toll roads), 39 percent have used rumble strips on multilane divided nonfreeways, 35 percent on two-lane highways, 22 percent on multilane undivided nonfreeways, and 2 percent on urban streets. This table makes it clear that shoulder rumble strips have not generally been found to be appropriate for low-speed urban facilities.

Table A-9 shows that, of highway agencies that have used rumble strips on shoulders of divided highways, 21 percent have used them on the right shoulder only, 3 percent have used them on the left (median) shoulder only, and 76 percent have used them on both the right and left shoulders.

The types of projects in which shoulder rumble strips have been installed are given in Table A-10. The table indicates that, of highway agencies that have installed rumble strips on shoulders, 82 percent have installed them in new construction or major reconstruction projects and 36 percent have installed them in retrofitting projects on existing highways. These findings suggest that it is much more common for highway agencies to install shoulder rumble strips when a highway section is built or reconstructed than for highway agencies to go back and install shoulder rumble strips in the absence of other construction work at a site.

Question 4 Number of Sites

The responses to this question indicated a great deal of diversity in the scale of highway agency usage of rumble strips. Responses concerning rumble strip use in the traveled way indicated that some agencies have only one rumble strip installation (probably on an experimental basis), while others have more than 200 rumble strip installations. Use of shoulder rumble strips ranged from as little as 1 mi to as much as 750 mi of highway.

Question 5 Placement Interval

This question elicited varied responses. Some agencies responded with the spacing between rumble strips (which was intended) and others responded with the spacing between individual grooves in a rumble strip. All dimensions, patterns, and spacings for rumble strips—based on this survey and on highway agency specifications—are summarized in Chapter Five of this report.

Table A-8. RESPONSES CONCERNING HIGHWAY TYPES ON WHICH HIGHWAY AGENCIES HAVE USED RUMBLE STRIPS ON SHOULDERS

Highway type	State highway agencies		Local agencies		Toll roads		Total	
Freeways (highways with full access control)	28	(71.8)	0	(0.0)	9	(100.0)	37	(75.5)
Multilane divided nonfreeways	19	(48.7)	0	(0.0)	0	(0.0)	19	(38.8)
Multilane undivided nonfreeways	11	(28.2)	0	(0.0)	0	(0.0)	11	(22.4)
Two-lane highways	16	(41.0)	1	(100.0)	0	(0.0)	17	(34.7)
Urban streets	1	(2.6)	0	(0.0)	0	(0.0)	1	(2.0)

NOTE: The numbers in parentheses represent the percentage of highway agencies that have used rumble strips on shoulders. Percentages add to more than 100 percent because of multiple responses.

Table A-9. RESPONSES CONCERNING SIDE OF HIGHWAY ON WHICH HIGHWAY AGENCIES HAVE USED RUMBLE STRIPS ON SHOULDERS OF DIVIDED HIGHWAYS

Side of highway	State highway agencies		Local agencies		Toll roads		Total	
Right shoulder only	7	(22.6)	0	(0.0)	1	(12.5)	8	(20.5)
Left (median) shoulder only	1	(3.2)	0	(0.0)	0	(0.0)	1	(2.6)
Both shoulders	23	(74.2)	0	(0.0)	7	(87.5)	30	(76.9)
Not applicable ^a	14		15		5		34	
Total	45		15		13		73	

^a Rumble strips have not been used on shoulders of divided highways by these agencies.

NOTE: The number in parentheses are column percentages excluding the agencies that have not used shoulder rumble strips on divided highways.

Table A-10. RESPONSES CONCERNING PROJECT TYPES IN WHICH HIGHWAY AGENCIES HAVE USED RUMBLE STRIPS ON SHOULDERS

Project type	State highway agencies		Local agencies		Toll roads		Total	
New construction or major reconstruction	30	(76.9)	1	(100.0)	6	(75.0)	37	(82.2)
Existing highways (retrofit)	14	(35.9)	0	(0.0)	2	(25.0)	16	(35.6)

NOTE: The numbers in parentheses represent the percentage of highway agencies that have used rumble strips on shoulders and that responded to this question. Percentages add to more than 100 percent because of multiple responses.

Question 6 Reasons for Using Rumble Strips

Very consistent answers were obtained to this question, although each respondent had their own way of phrasing the answer. In summary, agencies stated that they used rumble strips as a device call the driver's attention to a potential hazard.

Rumble strips in the traveled way were used in advance of a potential hazards, such as intersections or horizontal curves, to alert the driver to the presence of the intersection or curve. Highway agencies stated that they expected to reduce accidents by reducing vehicle speeds and making unfamiliar or inattentive drivers aware of the potential hazard.

Rumble strips on shoulders were used to alert motorists who had left the traveled way of the need to correct their path. The reason given by highway agencies for using rumble strips on the shoulder was to make drivers aware that their vehicle has left the road so that the driver can steer back onto the road and avoid encroaching on the roadside.

Question 7 Rumble Strip Performance

Highway agencies were asked in Question 7 whether their rumble strip installations have performed satisfactorily. The responses to this question are presented in Table A-11. The table shows that 89 percent of highway agencies indicated that the rumble strips they installed had performed satisfactorily. Reasons for unsatisfactory performance included maintenance problems and complaints from local residents about noise generated by vehicles traversing rumble strips. Only two agencies indicated that they had removed rumble strips for unsatisfactory performance. A more complete list of sources of unsatisfactory performance and unexpected problems with rumble strips encountered by highway agencies is provided in the discussion of Question 8.

Question 8 Unexpected Problems

Table A-12 presents the assessment of highway agencies as to whether unexpected problems have been created by use of rumble strips. Unexpected problems of one type or another have been reported by 67 percent of highway agencies. For the most part, these problems have not been serious enough to cause highway agencies to discontinue the use of rumble strips. However, in many cases, these problems have brought about appropriate changes in how and where rumble strips are used.

The following unexpected problems involving rumble strip performance have been reported by highway agencies:

- Complaints from neighboring residents due to noise created by vehicles traversing rumble strips (16 agencies)
- Maintenance problems with raised rumble strips including wear due to vehicle braking actions (11 agencies)
- Motorists encroaching on opposing lanes or shoulders to avoid the rumble strip (7 agencies)
- Snowplowing problems created by the presence of a raised rumble strip in the traveled way (6 agencies)
- Bicyclist complaints about the presence of rumble strips on the traveled way or shoulders (5 agencies)

Table A-11. HIGHWAY AGENCY RESPONSES CONCERNING WHETHER RUMBLE STRIPS HAVE PERFORMED SATISFACTORILY

Response	State highway agencies	Local agencies	Toll roads	Total
Satisfactory	36 (85.7)	14 (93.3)	12 (92.3)	62 (88.6)
Not satisfactory	6 (14.3)	1 (6.7)	1 (7.7)	8 (11.4)
No response	3	0	0	3
Total	45	15	13	73

NOTE: The numbers in parentheses are column percentages.

Table A-12. HIGHWAY AGENCY RESPONSES ON WHETHER ANY UNEXPECTED PROBLEMS HAVE BEEN CREATED BY RUMBLE STRIPS

Response	State highway agencies	Local agencies	Toll roads	Total
Yes	32 (74.4)	7 (50.0)	8 (61.5)	47 (67.1)
No	11 (25.6)	7 (50.0)	5 (38.5)	23 (32.9)
No response	2	1	0	3
Total	45	15	13	73

NOTE: The numbers in parentheses are column percentages.

- Damage to vehicles if the height of a rumble strip or the depth of the grooves is too great (3 agencies)
- Degradation of rumble strip effectiveness due to use in the traveled way at too many locations (3 agencies)
- Lack of driver recognition or understanding of rumble strips as a warning device (e.g., unnecessary stops by some drivers to check their tires) (2 agencies)
- Motorcyclist complaints concerning rumble strips in the traveled way (2 agencies)
- Creation of an unnecessary no-passing zone for the opposing direction of travel for rumble strips on intersection approaches (1 agency)
- Degradation of rumble strip performance over time as motorists became used to a rumble strip in the traveled way (1 agency)
- Degradation of ride quality on the shoulder due to the presence of rumble strips when traffic is diverted from the traveled way to the shoulder during construction (1 agency)
- Lack of driver acceptance of rumble strips as a warning device; complaints about the use of rumble strips (1 agency)

This list includes all unexpected problems reported by at least one agency. Other agencies may have experienced these same problems without noting them in the survey response. Each of these unexpected problems is addressed in relevant sections of the main text of this synthesis.

Question 9 Formal Effectiveness Evaluations

Approximately 29 percent of highway agencies indicated that they had performed a formal evaluation of the effectiveness of rumble strips in reducing vehicle speeds, accidents, or roadside encroachments, as indicated in Table A-13. Most agencies provided a copy of their evaluation report(s) and these are summarized in appropriate portions of the main text of this report. A few states indicated that they had performed formal evaluations several years ago, but that the results of those evaluations were no longer available.

Table A-13. RESPONSES CONCERNING WHETHER HIGHWAY AGENCIES HAVE PERFORMED FORMAL EVALUATIONS OF THE EFFECTS OF RUMBLE STRIPS ON VEHICLE SPEEDS, ACCIDENTS, OR ROADSIDE ENCROACHMENTS

Evaluation performed?	State highway agencies	Local agencies	Toll roads	Total
Yes	16 (38.1)	3 (20.2)	1 (7.7)	20 (28.6)
No	26 (61.9)	12 (80.0)	12 (92.3)	50 (71.4)
No response	3	0	0	3
Total	45	15	13	73

NOTE: The numbers in parentheses are column percentages for all highway agencies that responded to this question.

Question 10 Warrants, Guidelines, or Manuals

Question 10 asked highway agencies whether they had established warrants or guidelines for rumble strip usage and whether rumble strips are addressed in the agency's design or traffic control manual or in other agency policies.

Table A-14 shows the 41 percent of the highway agencies indicated that they had established formal warrants or guidelines for rumble strips. The percentage of state highway agencies and toll roads with formal warrants and guidelines was higher than the percentage for local agencies.

Table A-15 indicates that 34 percent of highway agencies have addressed them in their design or traffic control manual. As in the case of warrants or guidelines, a higher percentage of state agencies and toll roads than local agencies have included rumble strips in their manuals.

Question 11 Specifications

Table A-16 shows that 60 percent of the highway agencies that have used rumble strips have established formal specifications for the materials, dimensions and patterns, or installation methods used in rumble strips. State highway agencies and toll road authorities were much more likely than local agencies to have formal rumble strip specifications.

Table A-14. RESPONSES CONCERNING WHETHER HIGHWAY AGENCIES HAVE ESTABLISHED WARRANTS OR GUIDELINES FOR USE OF RUMBLE STRIPS

Response	State highway agencies	Local agencies	Toll roads	Total
Yes	19 (42.2)	4 (30.8)	6 (46.2)	29 (41.4)
No	25 (57.8)	9 (69.2)	7 (53.8)	41 (58.6)
No response	1	2	0	3
Total	45	15	13	73

NOTE: The numbers in parentheses are column percentages for all highway agencies that responded to this question.

Table A-15. RESPONSES CONCERNING WHETHER RUMBLE STRIPS ARE ADDRESSED IN THE HIGHWAY AGENCY'S DESIGN OR TRAFFIC CONTROL MANUAL OR IN OTHER AGENCY POLICIES

Response	State highway agencies	Local agencies	Toll roads	Total
Yes	17 (39.5)	3 (21.4)	4 (30.8)	24 (34.3)
No	26 (60.5)	11 (78.6)	9 (69.2)	46 (65.7)
No response	2	1	0	3
Total	45	15	13	73

NOTE: The numbers in parentheses are column percentages for all highway agencies that responded to this question.

Table A-16. RESPONSES CONCERNING WHETHER HIGHWAY AGENCIES HAVE ESTABLISHED FORMAL SPECIFICATIONS FOR THE MATERIALS, DIMENSIONS, AND PATTERNS, OR INSTALLATION METHODS USED FOR RUMBLE STRIPS

Response	State highway agencies	Local agencies	Toll roads	Total
Yes	31 (72.1)	4 (26.7)	8 (61.5)	43 (60.6)
No	12 (27.9)	11 (73.3)	5 (38.5)	28 (39.4)
No response	2	0	0	2
Total	45	15	13	73

NOTE: The numbers in parentheses are column percentages for all highway agencies that responded to this question.

Question 12 Cost Data

The responses to Question 12 indicated that 31 percent of state highway agencies, 20 percent of local agencies, and 46 percent of toll road authorities have cost data on rumble strips available. The cost data in the main text of this report are based on follow-up contacts with these agencies.

Question 13 Service Life Data

The responses to Question 13 indicated that 7 percent of state highway agencies, 13 percent of local agencies, and 31 percent of toll road authorities have service life data on rumble strips available. The service life estimates in the main text of this report are based the relatively limited data obtained from follow-up contacts with these agencies.

Question 14 Other Positive and Negative Experiences with Rumble Strips

Question 14 asked highway agencies to report other positive and negative experiences with rumble strips. Approximately 35 percent of the responding agencies provided such comments and these comments have been used by the author in the preparation of this report. All problems with rumble strips noted in response to Question 14 have been incorporated in the list of responses on unexpected problems provided under Question 8 if they were not already included in the agency's response to Question 8.

Question 15 Contact Person

In response to Question 15, each highway agency provided the name of a contact person for obtaining follow-up information. Many of these contacts were used in the preparation of this report.

NCHRP PROJECT 20-5, Topic 22-13 SURVEY ON HIGHWAY AGENCY USAGE OF RUMBLE STRIPS TO ENHANCE SAFETY

Dear State or Local Highway Engineer:

The National Cooperative Highway Research Program (NCHRP) of the Transportation Research Board (TRB) is preparing a Synthesis of Highway Practice report on the use of rumble strips to enhance safety. This effort is sponsored by the American Association of State Highway and Transportation Officials (AASHTO) in cooperation with the Federal Highway Administration (FHWA). The report being prepared by Mr. Douglas W. Harwood will summarize the current usage of rumble strips by state and local highway agencies and will include all available data on the effectiveness of rumble strips in improving safety.

As part of this research, we would appreciate it if you would take a few minutes of your time to complete the following questionnaire on your agency's use of rumble strips. The response may require contributions from traffic, construction, and maintenance engineers and others in your organization. Thank you for your assistance.

- 1. Has your agency used rumble strips to enhance safety of roadways or shoulders?
 YES NO
 (If the answer to Question 1 is NO, please skip the remainder of the questions and return the questionnaire to the address shown below.)
- 2. If you responded YES to Question 1, for what applications have rumble strips been used? (check all that apply):

RUMBLE STRIPS PLACED IN THE TRAVELED WAY

- Approaches to intersections and other junctions
- Approaches to toll plazas
- Approaches to horizontal curves
- Approaches to narrow bridges
- Approaches to lane drops
- Approaches to railroad-highway grade crossings
- Approaches to (or within) highway work zones
- Other applications (please specify):

Figure A-1. Questionnaire Used for Highway Agency Survey.

RUMBLE STRIPS PLACED ON HIGHWAY SHOULDERS

- At specified intervals along highway shoulders
- Approaches to intersections and other junctions
- Approaches to toll plazas
- Approaches to horizontal curves
- Approaches to narrow bridges
- Approaches to lane drops
- Approaches to railroad-highway grade crossings
- Approaches to (or within) highway work zones
- Other applications (please specify):

3. If rumble strips have been used on highway shoulders, have they been used on (check all that apply):

- Portland cement concrete shoulders
- Asphalt concrete shoulders
- Both portland cement and asphalt concrete shoulders
- Freeways
- Multilane divided nonfreeways
- Multilane undivided nonfreeways
- Two-lane highways
- Urban streets
- Right shoulder only on divided highways
- Left (median) shoulder only on divided highways
- Both shoulders on divided highways
- New construction or major reconstruction
- Existing highways (retrofit)

4. At approximately how many sites have rumble strips been used by your agency?

Number of locations

Number of miles of roadway

5. If rumble strips have been placed in series at a specified interval, what placement interval has been used?

For rumble strips placed in the roadway: ft

For rumble strips placed on highway shoulders:

- on portland cement concrete shoulders ft
- on asphalt concrete shoulders ft

Figure A-1 (Continued)

6. Why were rumble strips installed by your agency? What were the existing problems and what results did you expect from the use of rumble strips? (please describe):

7. Have the rumble strips used by your agency performed satisfactorily? YES NO

Comments:

8. Have any unexpected problems been created by rumble strips (e.g., safety problems, maintenance problems, etc.)? YES NO

If YES, please describe:

9. Has any formal evaluation been conducted of the effect of rumble strips on vehicle speeds, accidents, or roadside encroachments? YES NO

If YES, what did the evaluation conclude:

Please enclose a copy of the evaluation (if possible) or suggest where we might obtain a copy.

Figure A-1 (Continued)

10. Has your agency established warrants or guidelines for rumble strip usage? YES NO
Are rumble strips addressed in your agency's design or traffic control manual or in other agency policies? YES NO

(If YES, please enclose a copy of the relevant warrants, guidelines, or section of your manual, if possible.)

11. Has your agency established a formal specification for the materials, dimensions and patterns, or installation methods used for rumble strips? YES NO

(If YES, please enclose a copy of the specification, if possible.)

12. Does your agency have data available on the cost of rumble strip installation? YES NO

13. Does your agency have data on the service life of rumble strip installations? YES NO

14. Do you have any other positive or negative experiences concerning rumble strips that you would like to report? (please describe):

15. May we have the name of an engineer in your agency that we might contact to obtain follow-up information?

Name _____

Title _____

Agency _____

Mailing Address _____

() _____
Area Code Number

Please mail the completed questionnaire to:

Mr. Douglas W. Harwood
Principal Traffic Engineer
Midwest Research Institute
425 Volker Boulevard
Kansas City, Missouri 64110

If you have any questions or comments, please feel free to phone Mr. Harwood at (816) 753-7600, Ext. 571.

THANK YOU FOR YOUR ASSISTANCE.

Figure A-1 (Continued)

APPENDIX B

TYPICAL SPECIFICATIONS AND STANDARDS FOR RUMBLE STRIPS PLACED IN THE TRAVELED WAY

AS 8A-2
August 15, 1977

AS 8A-2
Page 2

Application Standard

Ohio Department of Transportation

Rumble Strips

I. Purpose

The purpose of this standard is to establish departmental guidelines for the use of rumble strips. This standard supersedes the rumble strip policy dated February 13, 1973.

II. General

Rumble strips are considered traffic control devices in themselves and may be used to supplement other existing standard or conventional traffic control devices. Rumble strips are used to alert drivers of unusual or unexpected traffic conditions or geometrics and to bring the driver's attention to other warning devices. Rumble strips provide a tactile and audible warning which supplements visual stimuli.

This application standard furnishes departmental design guidelines for rumble strip installations and procedures for approval of a rumble strip installation. A location with a traffic problem should not be given consideration for installation of rumble strips unless all other appropriate standard traffic control devices have been utilized and have failed to resolve the traffic problem satisfactorily.

III. Rumble Strip Design

A rumble strip shall consist of:

- (A) raised strips of asphaltic concrete, epoxy or thermoplastic material, or
- (B) depressed grooves, formed by saw cutting the existing pavement (or other acceptable procedure).

The maximum height or depth shall be 1/2 inch. The strip cross section may be rectangular, domed or trapezoidal in shape.

IV. Rumble Strip Pad Design and Placement

There should be five to twenty grooves or raised strips placed in a rumble strip pad. The raised strips or grooves shall be placed perpendicular to the direction of traffic. An installation should consist of 3 to 10 rumble strip pads. The intervals between rumble strip pads should be reduced as the distance to the hazard diminishes to create a sensation of acceleration to the motorists.

The first rumble strip pad should be placed in advance of the advance warning devices. The last rumble strip pad should be placed a minimum of 250 feet in advance of the traffic condition, gore, construction area, or stop position, etc. Rumble strip pads should not be placed on short horizontal or vertical curves where loss of vehicle control may occur due to the action of the rumble strips on a vehicle's suspension system.

V. Applications

Typical installation details for the raised strips and depressed grooves are shown in drawings 8A-2a and 8A-2b.

(A) Typical locations for application of rumble strips are as follows:

1. Rural stop approaches with high accident rates.
2. On roadway shoulders and gore areas of interchanges as channelizing devices.
3. Signalized intersections with high accident rates.
4. Exit ramp deceleration lanes.

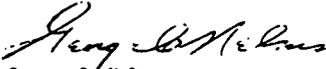
(B) Other possible locations are as follows:

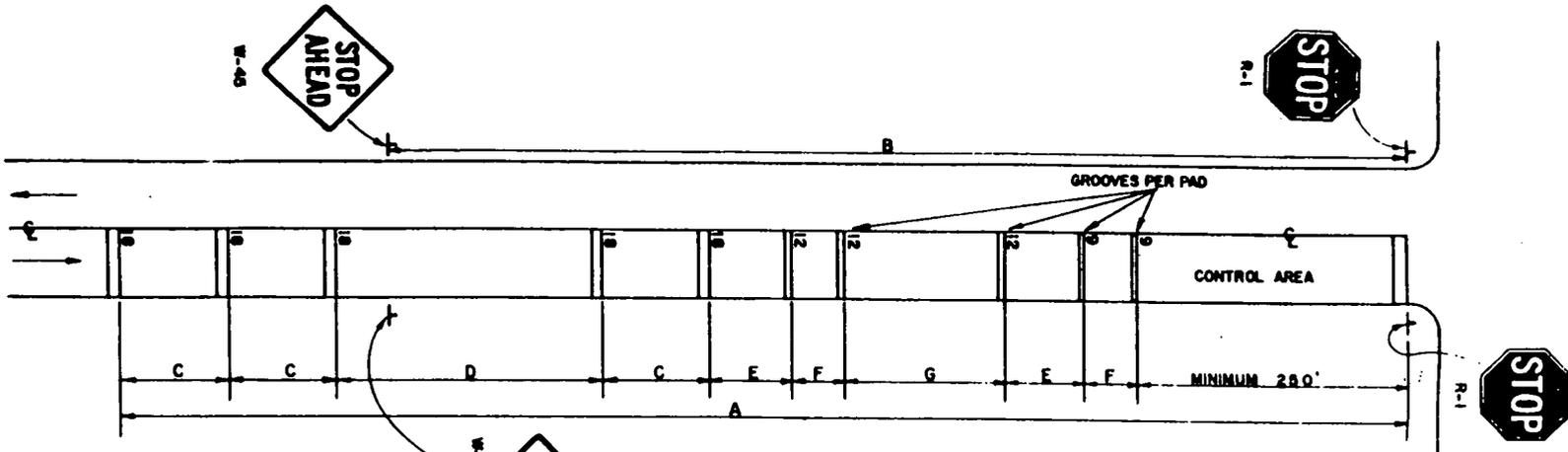
1. Transitional areas from "high-type" to "low-type" facilities.
2. Locations with abrupt changes in horizontal alignment.
3. Construction areas.
4. Paved shoulders of roadways.
5. Intersections with inadequate stopping distance caused by vertical or horizontal alignment.
6. Approaches to toll booths.
7. Railroad crossings with sight distance restrictions and accident potential.

VI. Procedure for Installation Approval (Rural State Highway System Only)

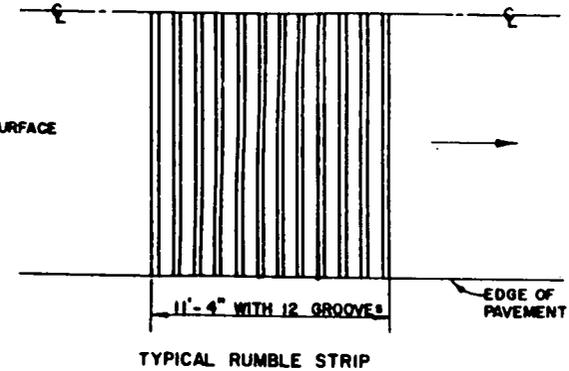
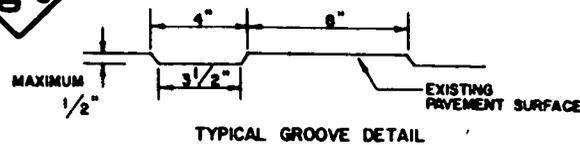
- (A) Approval of a location for installation of rumble strips shall only be given by the Engineer of Traffic.
- (B) A complete traffic engineering study shall be made and submitted to the Bureau of Traffic for each location proposed for installation of rumble strips.
- (C) Following the written approval of the Engineer of Traffic, the district will be authorized to proceed with the installation of the rumble strips.

- (D) Rumble strip installations shall be monitored by the District Traffic Engineer for a period of not less than 12 months after opening to traffic. An after study by the District shall be submitted to the Bureau of Traffic for review and evaluation. This after study should include any constructive comments relative to design, construction or operation of the installation so that the design criteria and guidelines may be improved as necessary. All rumble strip installations should be reevaluated periodically by the District to assure that they are still justified and effective.


George C. Helms
Chief Engineer, Operations



APPROACH SPEED	DISTANCE (FEET)						
	A	B	C	D	E	F	G
50-55 MPH	200	750-950	100	250	75	50	150
40-45 MPH	100	680-840	85	210	65	45	125
35 or LESS	80	590-705	70	165	50	35	100

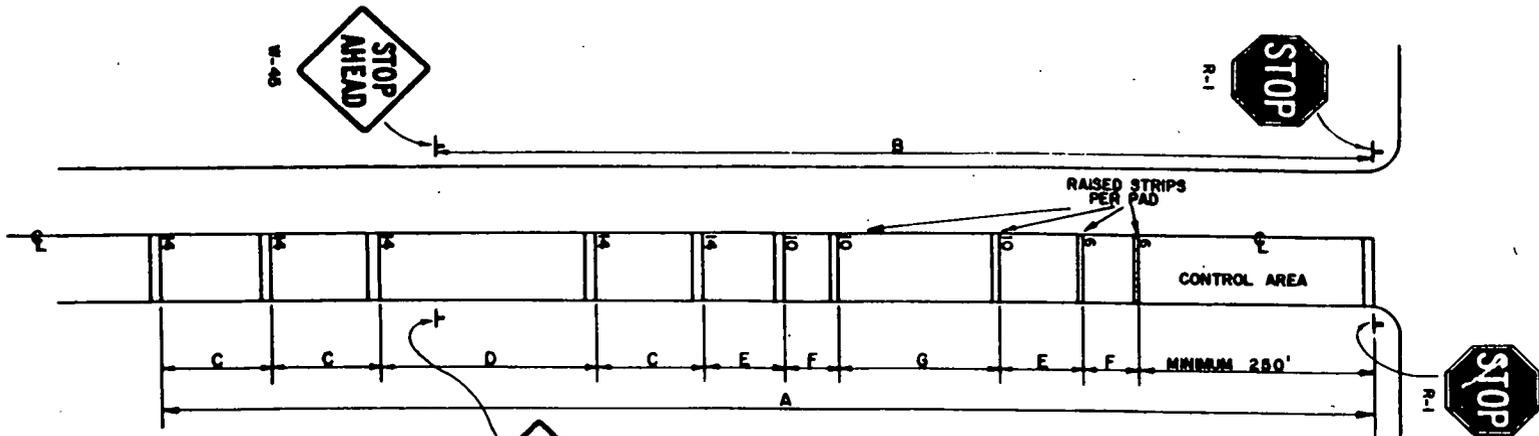


GENERAL NOTES

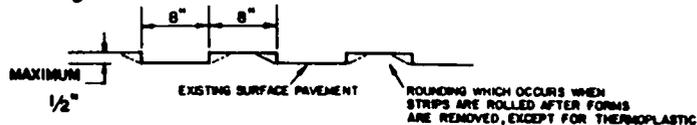
1. THE PROPOSED RUMBLE STRIPS SHALL CONSIST OF PARALLEL GROOVES CUT AT ONE (1) FOOT CENTER TO CENTER.
2. EACH GROOVE SHALL BE CUT TO A DEPTH OF APPROXIMATELY 3/8 INCH, WITH ALLOWANCE FOR PAVEMENT SURFACE IRREGULARITIES AND VARIATIONS. WIDTH OF THE GROOVE AT THE PAVEMENT SURFACE IS TO BE 4 INCHES, WITH TAPERED SIDES SUCH THAT GROOVE WIDTH AT THE BOTTOM IS APPROXIMATELY 3 1/2 INCHES. CONSTRUCTION METHODS OTHER THAN SAW CUTTING MUST BE APPROVED BY THE ENGINEER OF TRAFFIC PRIOR TO USE.

3. THIS APPLICATION STANDARD WAS DEVELOPED FOR STOP APPROACHES. THE CONTROL AREA LENGTH SHALL BE A MINIMUM OF 250 FEET FOR ALL APPLICATIONS AND MAY BE EXTENDED AS NECESSARY. THE CONTROL AREA FOR CURVES (ON MAINLINES, DIRECTIONAL RAMPS, EXIT RAMPS OR OTHER NON-STOP APPROACHES) SHALL BE THE AREA FROM THE CLOSEST RUMBLE STRIP TO THE CURVE TO THE P.C. (POINT OF CURVE) CLOSEST TO THE RUMBLE STRIP. CONTROL AREA LENGTHS FOR VARIOUS RUMBLE STRIP APPLICATIONS MUST BE OF SUFFICIENT LENGTH TO ALLOW THE MOTORISTS TO BRAKE THEIR VEHICLES PROPERLY.

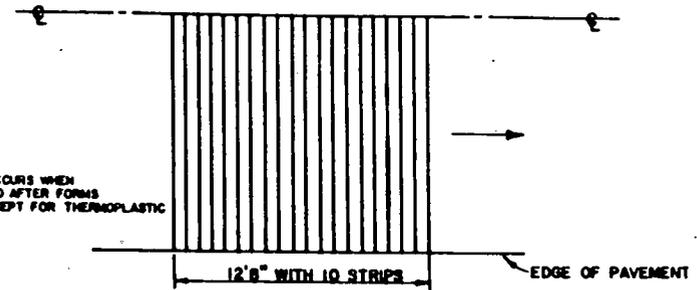
BUREAU OF TRAFFIC CONTROL OHIO DEPARTMENT OF TRANSPORTATION	
TYPICAL GROOVED RUMBLE STRIP INSTALLATION FOR STOP APPROACHES	DATE 8/77
APPROVED <i>[Signature]</i> ENGINEER OF TRAFFIC	
DR. LIU, CH. CDR.	AS-BA-20



APPROACH SPEED	DISTANCE (FEET)						
	A	B	C	D	E	F	G
50-55 MPH	200	750-900	100	250	75	50	150
40-45 MPH	100	600-840	85	210	65	45	125
35 or LESS	80	600-705	70	165	50	35	100



TYPICAL STRIP DETAIL



TYPICAL RUMBLE STRIP PAD

GENERAL NOTES

1. THE RUMBLE STRIPS SHALL CONSIST OF PARALLEL RAISED STRIPS 16 INCHES CENTER TO CENTER.
2. EACH STRIP SHALL HAVE A HEIGHT OF APPROXIMATELY 1/4 INCH AND A WIDTH OF 8 INCHES. CONSTRUCTION METHODS SHALL BE AS FOLLOWS:
 - A. ASPHALTIC CONCRETE STRIPS - SAND ASPHALT SHALL BE PLACED IN 3/2 INCH PLYWOOD FORMS AND THEN ROLLED DOWN TO 1/4 INCH AFTER REMOVING THE FORMS.
 - B. EPOXY STRIPS - MORTAR IS PLACED IN

- C. THERMOPLASTIC STRIPS - LOCATIONS SHALL BE LAID OUT ON PAVEMENT USING REFERENCE POINTS AND/OR PREMARKING LINES. THERMOPLASTIC MATERIAL SHALL BE APPLIED BY THE EXTRUSION PROCESS USING A MANUAL APPLICATOR.

ROADWAY SURFACES SHALL BE ADEQUATELY PREPARED AND/OR PRIMED, AS REQUIRED, BEFORE INSTALLATION OF STRIPS. A CONSTRUCTION METHOD OTHER THAN THE ABOVE MUST BE APPROVED BY THE ENGINEER OF TRAFFIC PRIOR TO USE.

3. THIS APPLICATION STANDARD WAS DEVELOPED FOR STOP APPROACHES. THE CONTROL AREA LENGTH SHALL BE A MINIMUM OF 250 FEET FOR ALL APPLICATIONS AND MAY BE EXTENDED AS NECESSARY.

THE CONTROL AREA FOR CURVES (ON MAINLINES, DIRECTIONAL RAMP, EXIT RAMP OR OTHER NON-STOP APPROACHES) SHALL BE THE AREA FROM THE CLOSEST RUMBLE STRIP TO THE CURVE TO THE P.C. (POINT OF CURVE) CLOSEST TO THE RUMBLE STRIP. CONTROL AREA LENGTHS FOR VARIOUS RUMBLE STRIP APPLICATIONS MUST BE SUFFICIENT LENGTH TO ALLOW THE MOTORISTS TO BRAKE THEIR VEHICLES PROPERLY.

BUREAU OF TRAFFIC CONTROL 080 DEPARTMENT OF TRANSPORTATION		DATE
TYPICAL RAISED RUMBLE STRIP INSTALLATION FOR STOP APPROACHES		6/77
APPROVED <i>[Signature]</i>		
ENGINEER OF TRAFFIC		
DR. L. J. C. CDR	AS-BA-2b	

APPENDIX C

TYPICAL SPECIFICATIONS AND STANDARDS FOR RUMBLE STRIPS PLACED ON ASPHALT SHOULDERS

411D

411D

411D

411D

S T A T E

O F

T E N N E S S E E

(Rev. 10-30-89)

Sheet 2 of 2

(Rev. 10-31-88)ASE
(Rev. 5-08-89)ASE
(Rev. 10-30-89)WAC

May 19, 1986
Sheet 1 of 2

SPECIAL PROVISION

REGARDING

SCORING FLEXIBLE PAVEMENT

Description. This work shall consist of constructing scored pavement in accordance with the details shown on the Plans.

Construction. The scoring of the pavement shall be performed with a steel wheel roller or a combination steel wheel-rubber tire roller, at the option of the Contractor. All rubber tires on the rolling equipment shall have a smooth or "slick" tread design. The steel roller used to score the pavement shall weigh a minimum of six tons and shall be modified as follows:

1. Semicircular sections of 1-1/2 inch diameter pipe 3 feet long shall be welded on one steel roller drum at approximately 8-1/2 inch centers (8 inches min., 9 inches max.), with the rounded side of the pipe away from the drum. Each semicircular pipe shall be located on the drum so as the center of the pipe is the same as the center of gravity of the roller, therefore maintaining equal pressure along the pipe. Each 3 foot length of semicircular pipe shall include a 6 inch bevel at each end and a 2 foot long full depth center section. The beveled 6 inch long opening at each end of the semicircular pipe sections shall be covered with a welded steel plate fitted flush with the beveled surfaces. The finished scored pavement shall conform to the dimensions shown on the Plans and in this Special Provision.
2. Each roller shall be equipped with an acceptable guide that is clearly visible to the operator so that proper alignment and placement of the scoring can be obtained.

The scoring roller drum can be developed either by modifying one of the steel roller drums on original roller equipment or by attaching a special scoring roller drum assembly, which provides for raising and lowering the scoring drum, to the original roller equipment. Regardless of the type of equipment used, the scoring drum shall be provided with a water spray system to prevent buildup of bituminous material. If the scoring roller drum can not be raised and lowered, planking or other appropriate means shall be used to position the roller for the scoring operation. Scoring shall be performed only at the locations shown on the Plans.

The scoring of pavement shall be performed in one pass of the roller after the final pass of the finish roller or as directed by the Engineer. No equipment, vehicles, etc. shall be permitted on the scored pavement for a period of 24 hours after scoring.

Method of Measurement. Scoring Pavement will be measured longitudinally along the edge of each scoring sequence.

Basis of Payment. The accepted quantities will be paid for at the contract unit price per linear mile for Scoring Pavement which price shall be full compensation for all roller modifications, equipment, tools, labor and any other incidentals necessary to complete this item.

Payment will be made under:

<u>Item No.</u>	<u>Pay Item</u>	<u>Pay Unit</u>
411-01.25	Scoring Pavement	Linear Mile

4-411.00 COMPUTATIONS FOR ASPHALTIC CONCRETE SURFACE (HOT MIX)

Item No. 411-01 Grading "D" Surface

$$\frac{\text{Compacted Volume (Cu. Yd.)} \times 3816 \text{ Lb./Cu. Yd.}}{2000 \text{ Lb./Ton}} = \text{Tons} \quad \begin{array}{l} \times 0.94 = \text{Tons Item 411-01.01} \\ \times 0.06 = \text{Tons Item 411-01.02} \end{array}$$

Note: One inch per square yard weighs 106 + pounds

Item No. 411-02 Grading "E" Surface

$$\frac{\text{Compacted Volume (Cu. Yd.)} \times 3870 \text{ Lb./Cu. Yd.}}{2000 \text{ Lb./Ton}} = \text{Tons} \quad \begin{array}{l} \times 0.94 = \text{Tons Item 411-02.01} \\ \times 0.06 = \text{Tons Item 411-02.02} \end{array}$$

Note: One inch per square yard weighs 107.5 + pounds

Item No. 411-03 Grading "E" Shoulders

$$\frac{\text{Compacted Volume (Cu. Yd.)} \times 3708 \text{ Lb./Cu. Yd.}}{2000 \text{ Lb./Ton}} = \text{Tons Item 411-03.10}$$

Note: One inch per square yard weighs 103 + pounds

Item No. 411-03 Grading "F" Surface

$$\frac{\text{Compacted Volume (Cu. Yd.)} \times 3600 \text{ Lb./Cu. Yd.}}{2000 \text{ Lb./Ton}} = \text{Tons} \quad \begin{array}{l} \times 0.92 = \text{Tons Item 411-03.01} \\ \times 0.08 = \text{Tons Item 411-03.02} \end{array}$$

Note: One inch per square yard weighs 100 + pounds

NOTE: Not to be used unless directed

4-411.03 SCORING SHOULDERS

On all new construction and resurfacing projects of Interstate in rural areas, Item No. 411-01.25 Scoring Pavement per Linear Mile shall be called for on the plans. Both inside and outside shoulders should be scored.

Rural areas, for this purpose, are all counties except Shelby, Davidson, Hamilton and Knox.

Scoring of shoulders in urban areas can also be constructed. This should be evaluated on a project by project basis.

The item shall be footnoted as follows:

SEE SPECIAL PROVISION 411D.

For estimating purposes, the item will be measured longitudinally along the edge of each shoulder and will usually be four (4) times the project length less deductions for entrance and exit ramps.

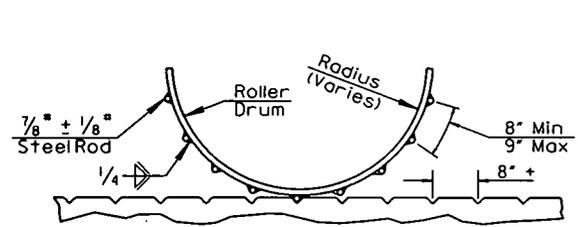
STATE	PROJECT NO.
MISS.	

GENERAL NOTES

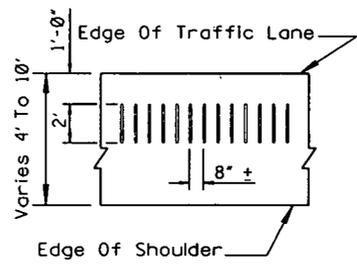
1. Shoulder Grooving shall be applied on left and right shoulders of rural roadways (interstate, primary divided, and undivided) 34' and wider as called for on plans.
2. Shoulder Grooving shall be omitted across principal intersecting roadways or other interruptions in normal shoulder width as directed by the Engineer.
3. Shoulder Grooving shall be constructed by making indentations in the asphaltic concrete.

The indentations may be formed by rolling the hot asphalt concrete using $\frac{1}{8} \pm \frac{1}{8}$ " steel rods welded to the drum. The rod segments shall be 2' long and be fully welded to the roller drum at approximately 8" centers.

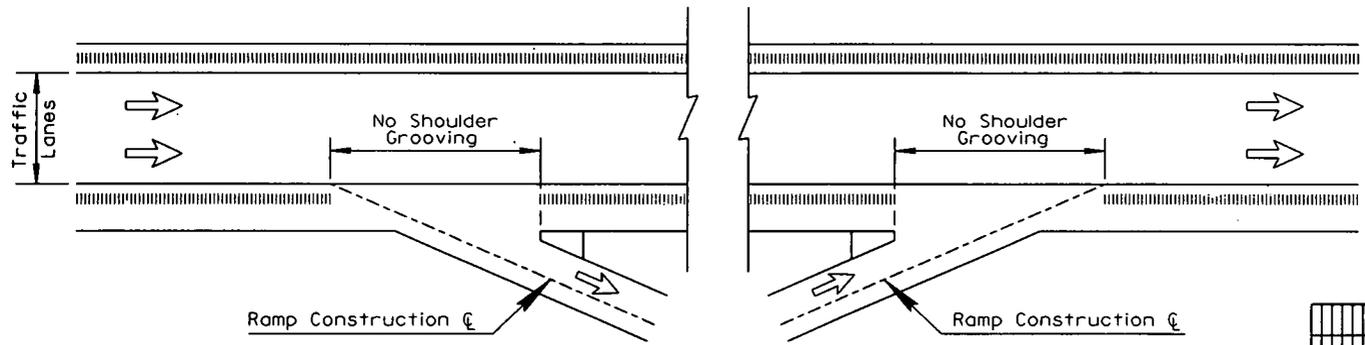
4. Each roller shall be equipped with an acceptable guide that extends in front of the roller and is clearly visible to the operator in order that proper alignment of the completed scored shoulder is obtained.
5. The contractor may utilize other equipment or methods to construct the shoulder grooving if approved by the Engineer.
6. The costs for shoulder grooving will be absorbed in other pay items.



STEEL DRUM DETAIL

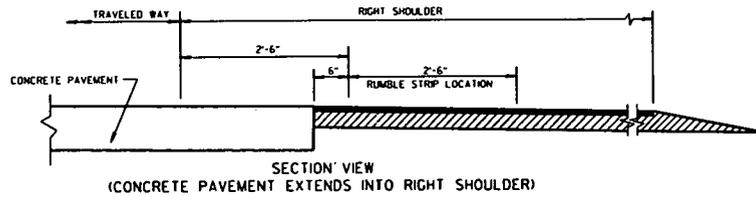


SHOULDER GROOVING DETAIL



PLAN

MISSISSIPPI DEPARTMENT OF TRANSPORTATION	
GROOVING FOR BITUMINOUS SHOULDERS	
DATE: 2-1-91	PROJECT NUMBER:
FILENAME: ZG&B-130_216BDOVE.DGN	SHEET NUMBER:
DESIGN TEAM: J.C.S. OROD	

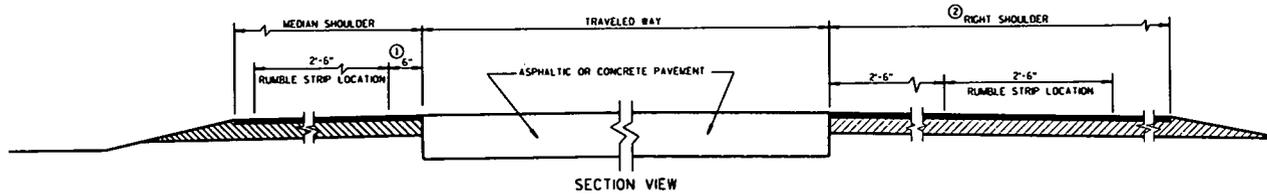


GENERAL NOTES

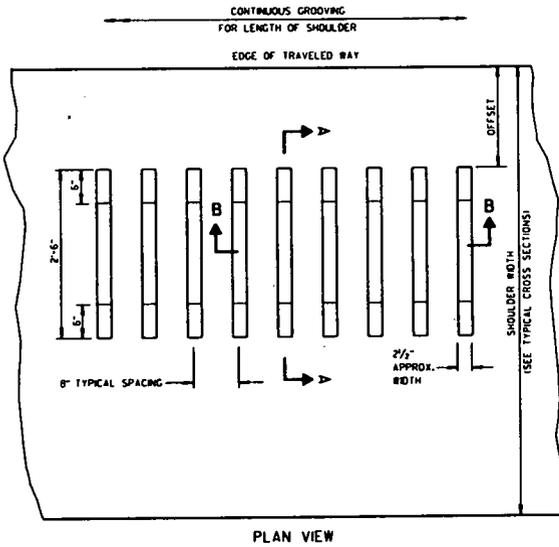
DETAILS OF CONSTRUCTION SHOWN ON THIS DRAWING SHALL CONFORM TO THE PERTINENT REQUIREMENTS OF THE STANDARD SPECIFICATIONS AND APPLICABLE SPECIAL PROVISIONS.

FINISH ROLLING OF THE ASPHALTIC SHOULDER SHALL INCLUDE THE SURFACE OVER THE RUMBLE STRIP DEPRESSIONS.

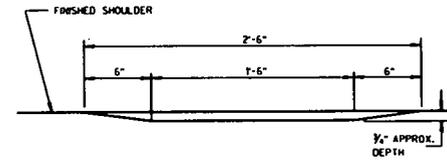
- ① 2'-6" FOR MEDIAN SHOULDERS THAT HAVE A PAVED WIDTH OF 5'-0" OR MORE.
- ② DIMENSIONS ALSO APPLY WHEN RUMBLE STRIPS ARE REQUIRED IN THE RIGHT SHOULDER OF RAMPS.



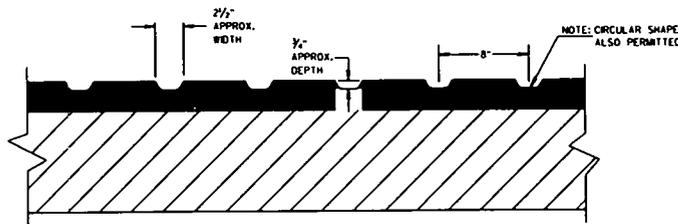
TYPICAL LOCATIONS OF ASPHALTIC SHOULDER RUMBLE STRIPS IN RURAL DIVIDED HIGHWAYS (ONE ROADWAY IS SHOWN)



PLAN VIEW



SECTION A-A



SECTION B-B

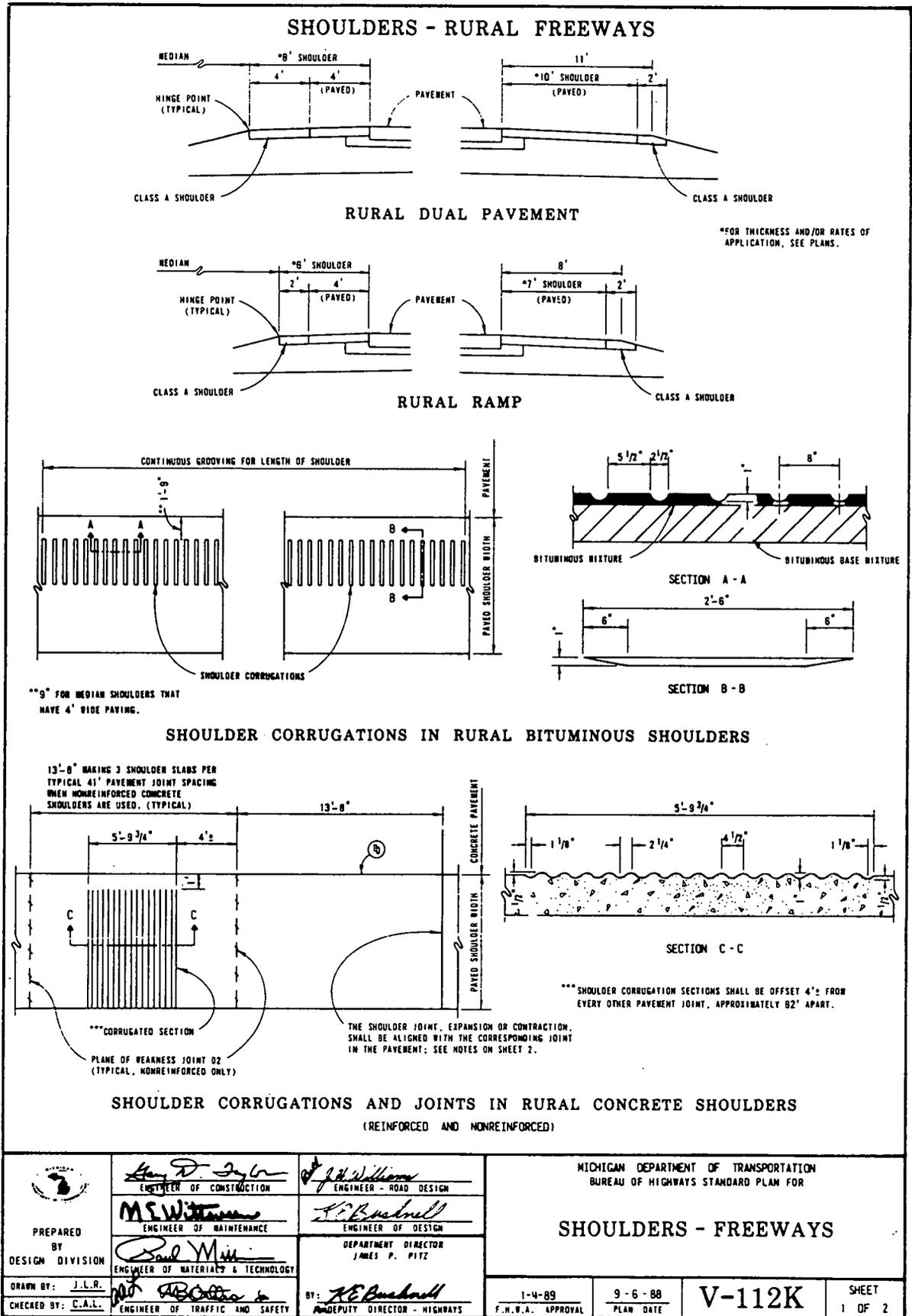
ASPHALTIC SHOULDER RUMBLE STRIPS	
STATE OF WISCONSIN DEPARTMENT OF TRANSPORTATION	
APPROVED 2/8/79 DATE	<i>[Signature]</i> STATE DESIGN ENGINEER FOR HWYS
FMSB	

S.D.D. 13 A 4-3

S.D.D. 13 A 4-3

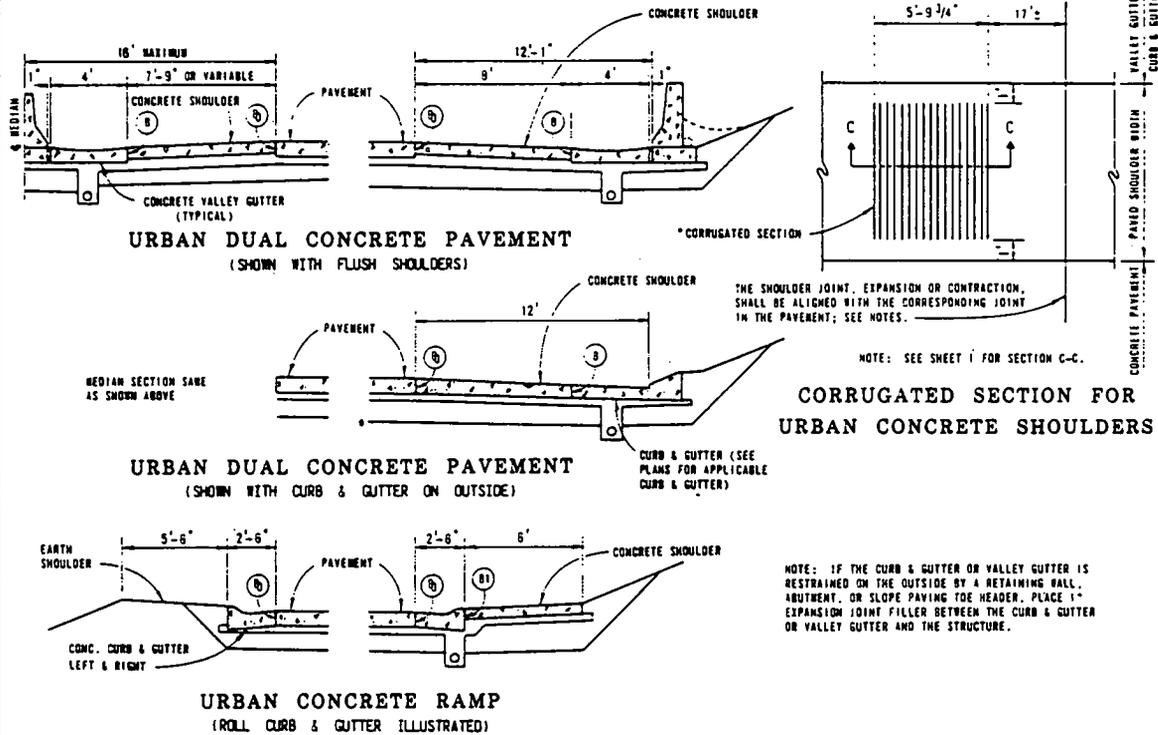
APPENDIX D

TYPICAL SPECIFICATIONS AND STANDARDS FOR RUMBLE STRIPS PLACED ON PORTLAND CEMENT CONCRETE SHOULDERS



<p>PREPARED BY DESIGN DIVISION</p> <p>DRAWN BY: J.L.R.</p> <p>CHECKED BY: C.A.L.</p>	<p><i>Henry D. Taylor</i> ENGINEER OF CONSTRUCTION</p>	<p><i>J. Williams</i> ENGINEER - ROAD DESIGN</p>	<p>MICHIGAN DEPARTMENT OF TRANSPORTATION BUREAU OF HIGHWAYS STANDARD PLAN FOR</p> <p>SHOULDERS - FREEWAYS</p>				
	<p><i>M.S. Williams</i> ENGINEER OF MAINTENANCE</p>	<p><i>T.E. Bushnell</i> ENGINEER OF DESIGN</p>				<p>SHOULDERS - FREEWAYS</p>	
	<p><i>Rand Miller</i> ENGINEER OF MATERIALS & TECHNOLOGY</p>	<p>DEPARTMENT DIRECTOR JAMES P. PITZ</p>		<p>1-4-89</p>	<p>9-6-88</p>		
	<p><i>ABC</i> ENGINEER OF TRAFFIC AND SAFETY</p>	<p>BY: <i>T.E. Bushnell</i> DEPUTY DIRECTOR - HIGHWAYS</p>		<p>F.N.B.A. APPROVAL</p>	<p>PLAN DATE</p>		

SHOULDERS - URBAN FREEWAYS



NOTES:

THIS SHOULDER STANDARD FOR FREEWAYS SHOWS CORRUGATIONS, SETS GUIDELINES FOR SHOULDER WIDTHS, AND ILLUSTRATES THE RELATIONSHIP OF SHOULDERS TO THE REST OF THE ROADWAY SECTION. THE ACTUAL DESIGN AND MATERIALS USED TO CONSTRUCT THE COMPLETE ROADWAY SECTION, WHICH INCLUDES THE SHOULDERS, WILL BE IN ACCORDANCE WITH THE PLANS AND CURRENT SPECIFICATIONS.

WHEN SHOULDERS FOR FREEWAYS ARE DESIGNATED "FREEWAY SHOULDERS", THE CONTRACTOR WILL HAVE THE OPTION OF A BITUMINOUS OR NONREINFORCED CONCRETE SHOULDER AS DETAILED ON PLANS.

SHOULDER WIDTHS FOR TWO-LANE RURAL FREEWAYS ARE SHOWN. FOR THREE OR MORE LANES, THE INSIDE SHOULDER WIDTH IS INCREASED TO 10' PAVED (11' TO THE HINGE POINT). WHEN TRUCK VOLUMES EXCEED 250 VEHICLES PER HOUR, THE OUTSIDE SHOULDER MAY BE WIDENED TO 12' PAVED (13' TO THE HINGE POINT). SHOULDER WIDTHS SHOWN ON THE TYPICAL CROSS-SECTION SHEET IN THE PLANS WILL GOVERN.

NORMAL SHOULDER SLOPE IS 0.04' PER FOOT FOR ALL SECTIONS.

SHOULDER CORRUGATION CROSS-SECTIONS AND LOCATION SHALL BE AS DETAILED ON THIS PLAN. CORRUGATIONS SHALL BE USED IN CONCRETE AND BITUMINOUS SHOULDERS PAVED 4 FEET OR WIDER OR WHERE THE SHOULDER LIES BETWEEN THE PAVEMENT AND VALLEY GUTTER OR CURB AND GUTTER. CORRUGATIONS WILL NOT BE USED IN RAMP SHOULDERS OR WHERE SHOULDERS ARE SEPARATED FROM THE PAVEMENT BY CURB AND GUTTER.

WHEN BITUMINOUS SHOULDERS ARE USED, THE CONTRACTOR MAY SUBMIT TO THE ENGINEER OF TRAFFIC AND SAFETY, FOR APPROVAL, ALTERNATE DIMENSIONS OR CONFIGURATIONS FOR RUMBLE STRIPS WHICH WILL PROVIDE AN EQUIVALENT "RUMBLE" EFFECT. THE CONTRACTOR WILL HAVE THE OPTION OF FORMING OR CUTTING THE GROOVES IN THE SHOULDER TO FORM THE RUMBLE STRIP. IF SAWING OR COLD-BILLING IS USED TO CONSTRUCT CORRUGATIONS, THE CONTRACTOR MUST WAIT A MINIMUM OF 72 HOURS AFTER THE BITUMINOUS MAT IS PLACED. THE CORRUGATED SECTIONS WILL NOT BE USED ON SHOULDERS SURFACED WITH OPEN-GRADED FRICTION COURSE.

WHEN RAMP SHOULDERS ARE CONSTRUCTED INTEGRALLY WITH THE RAMP PAVEMENT, THE PAVEMENT CROSS-SLOPE MAY BE INCREASED TO 0.018' PER FOOT AND THE NORMAL SHOULDER SLOPE MAY BE REDUCED TO 0.018' PER FOOT. WHEN THE RAMP IS SUPERELEVATED, THE SHOULDERS MAY BE SLOPED AT THE SAME RATE AS THE RAMP PAVEMENT.

WHEN CONCRETE SHOULDERS ARE CAST SEPARATELY FROM REINFORCED CONCRETE PAVEMENT, A KEYWAY MAY BE USED TO FACILITATE THE PLACING OF LAME TIES. WHEN A FEMALE KEYWAY IS USED, IT SHALL BE CONTINUOUS AND UNIFORM.

WHEN STEEL REINFORCEMENT IS USED IN SHOULDERS, IT SHALL MEET THE REQUIREMENTS SHOWN ON STANDARD PLAN II-45 SERIES.

TRANSVERSE JOINTS IN CONCRETE SHOULDERS SHALL BE AS SHOWN ON STANDARD PLAN II-42 SERIES. CORRESPONDING TRANSVERSE JOINTS IN REINFORCED CONCRETE SHOULDERS TIED TO REINFORCED CONCRETE PAVEMENT SHALL BE (C3) SHOULDER WITH (C) PAVEMENT, (C4) SHOULDER WITH (C2) PAVEMENT, (E4) SHOULDER WITH (E2) PAVEMENT, AND (E3) BEING THE SAME IN BOTH SHOULDER AND PAVEMENT. CORRESPONDING TRANSVERSE JOINTS IN NONREINFORCED CONCRETE SHOULDERS TIED TO CONCRETE PAVEMENT SHALL BE THE SAME AS THOSE FOR REINFORCED SHOULDERS WITH ADDITIONAL (O2) JOINTS SPACED BETWEEN THE CORRESPONDING TRANSVERSE JOINTS AS SHOWN ON THIS STANDARD AND AS CALLED FOR ON STANDARD PLAN II-42 SERIES.

SEE STANDARD PLAN II-38 SERIES FOR DETAILS OF TRANSVERSE PAVEMENT JOINTS.

FOR CONCRETE SHOULDERS ADJACENT TO CONTINUOUSLY REINFORCED CONCRETE PAVEMENT, SEE SPECIAL DETAILS.

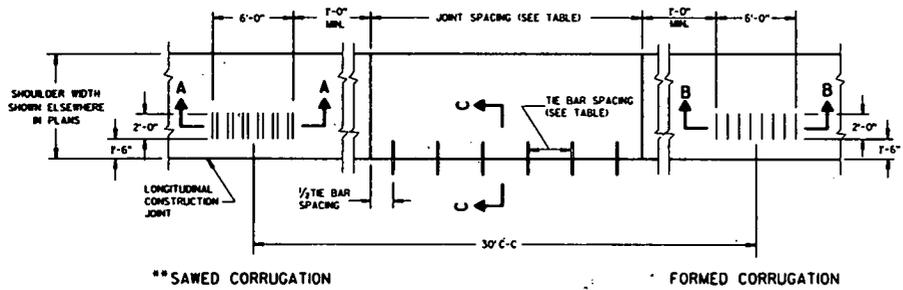
ALL CONCRETE SHOULDER SLABS ADJACENT TO BRIDGE STRUCTURES SHALL BE REINFORCED AS SHOWN ON STANDARD PLAN II-45 SERIES.

 PREPARED BY DESIGN DIVISION	<i>H. P. Taylor</i> ENGINEER OF CONSTRUCTION	<i>C. L. Williams</i> ENGINEER - ROAD DESIGN	MICHIGAN DEPARTMENT OF TRANSPORTATION BUREAU OF HIGHWAYS STANDARD PLAN FOR		
	<i>M. W. Williams</i> ENGINEER OF MAINTENANCE	<i>J. C. Bushnell</i> ENGINEER OF DESIGN	SHOULDERS - FREEWAYS		
	<i>Paul W. ...</i> ENGINEER OF MATERIALS & TECHNOLOGY	DEPARTMENT DIRECTOR JAMES P. PITZ		SHEET 2 OF 2	
DRAWN BY: <i>J.L.R.</i> CHECKED BY: <i>C.A.L.</i>	<i>W. B. ...</i> ENGINEER OF TRAFFIC AND SAFETY	BY: <i>J.C. Bushnell</i> DEPUTY DIRECTOR - HIGHWAYS	1-4-89 F.H.V.A. APPROVAL	9-6-88 PLAN DATE	V-112K

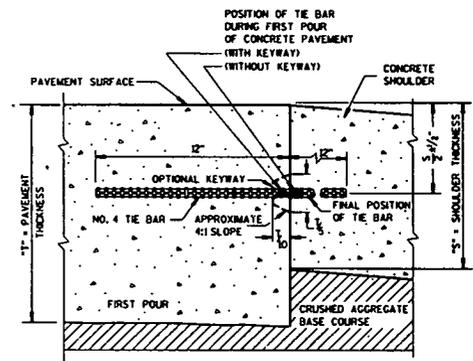
PAVEMENT TYPE OF TRAFFIC LANES	TI E BAR SPACING	SHOULDER JOINT SPACING
NON-REINFORCED	30"	MATCH JOINT SPACING OF ADJACENT TRAFFIC LANE
REINFORCED	30"	20' AND MATCH JOINT SPACING OF ADJACENT TRAFFIC LANE
CONTINUOUSLY REINFORCED	30"	15' FOR 6' TO 10' WIDE SHOULDERS
CONTINUOUSLY REINFORCED	36"	12' FOR 3' WIDE SHOULDERS

GENERAL NOTES

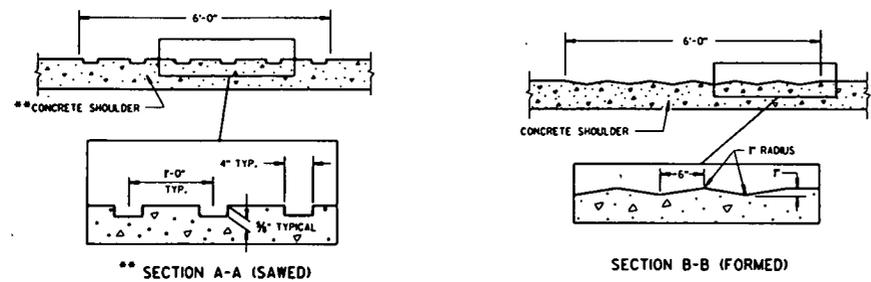
DETAILS OF CONSTRUCTION, MATERIALS AND WORKMANSHIP NOT SHOWN ON THIS DRAWING SHALL CONFORM TO THE PERTINENT REQUIREMENTS OF THE STANDARD SPECIFICATIONS AND THE APPLICABLE SPECIAL PROVISIONS.
 CORRUGATIONS SHALL BE PERPENDICULAR TO THE PAVEMENT EDGE.
 TRANSVERSE JOINT DETAILS ARE SHOWN ELSEWHERE IN THE PLAN.
 THE SHOULDER PAVEMENT SHALL RECEIVE A FROSH WITH AN ARTIFICIAL TURF DRAG IN CONFORMANCE WITH SUBSECTION 415.3.9.6.2 OF THE STANDARD SPECIFICATIONS
 TI E BARS SHALL BE EPOXY COATED IN CONFORMANCE WITH SUBSECTION 505.2.4 OF THE STANDARD SPECIFICATIONS.
 **SAWED CORRUGATIONS SHALL NOT BE USED UNLESS SPECIFIED ELSEWHERE IN THIS CONTRACT.



PLAN VIEW OF CONCRETE SHOULDER



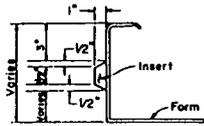
SECTION C-C
 LONGITUDINAL CONSTRUCTION JOINT



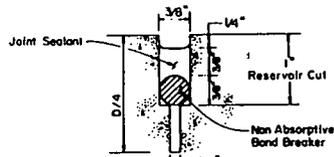
CORRUGATION DETAIL

CONCRETE SHOULDERS	
STATE OF WISCONSIN DEPARTMENT OF TRANSPORTATION	
APPROVED <i>[Signature]</i> DATE	STATE DESIGN ENGINEER FOR HWYS FWSA

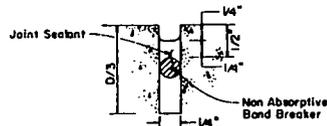
S.D.D. 13 A 3-3



DETAIL OF METAL OR WOODEN INSERT TO BE PLACED ON FORM



TRANSVERSE WEAKENED PLANE JOINT DOUBLE SAW CUT

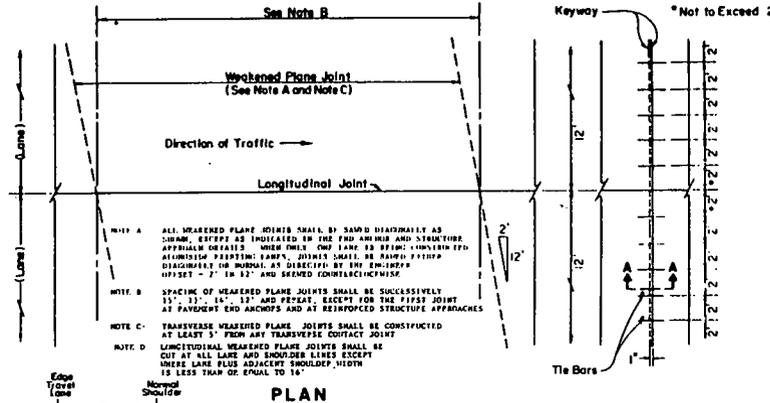


LONGITUDINAL WEAKENED PLANE JOINT SINGLE SAW CUT



PAVEMENT END ANCHOR DETAIL

NOTE: PAVEMENT END ANCHORS SHALL BE CONSTRUCTED AS THE TERMINAL PART OF ALL PAVEMENT NOT ADJOINING EXISTING PAVEMENTS OR STRUCTURES, AND ELEVATION IS CHECKED BY THE ENGINEER.

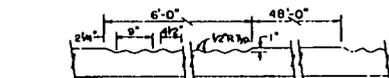


PLAN

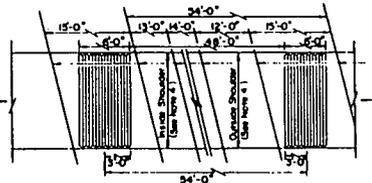


PLAN

SECTION D-D
RUMBLE STRIPS ON ASPHALT SHOULDERS

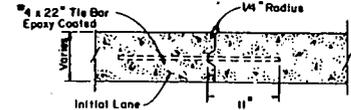


SECTION C-C



RUMBLE STRIPS ON CONCRETE SHOULDERS

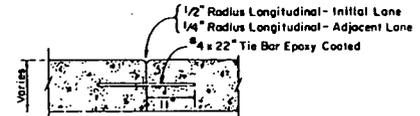
(THIS DESIGN SHALL NOT BE USED IN URBAN AREAS)



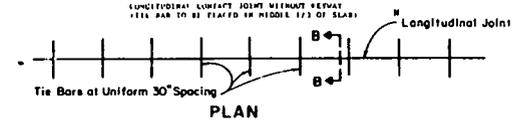
SECTION A-A (TIE BAR)

TRANSVERSE CONTACT JOINT WITH KEYWAY AND TIE BARS

NOTE: TRANSVERSE CONTACT JOINTS WITH REINBAR AND TIE BARS SHALL BE USED AT ALL CONSTRUCTION JOINTS, AND EVERYWHERE IT IS CHECKED BY THE ENGINEER. TIE BARS TO BE PLACED IN THE MIDDLE 1/3 OF THE SLAB THICKNESS.



SECTION B-B



PLAN TIE BAR DETAIL

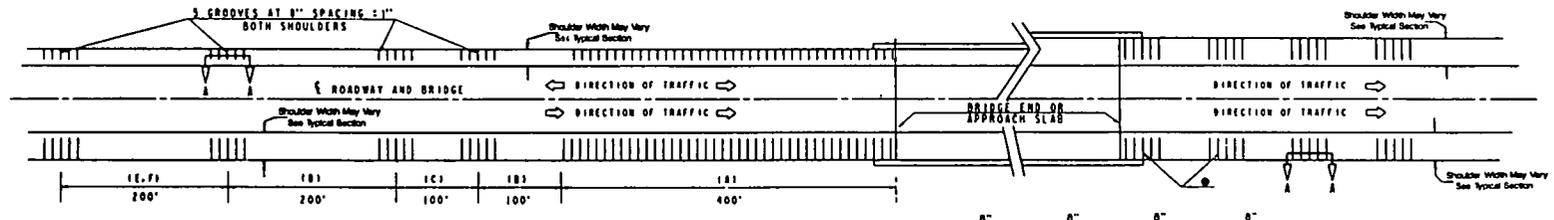
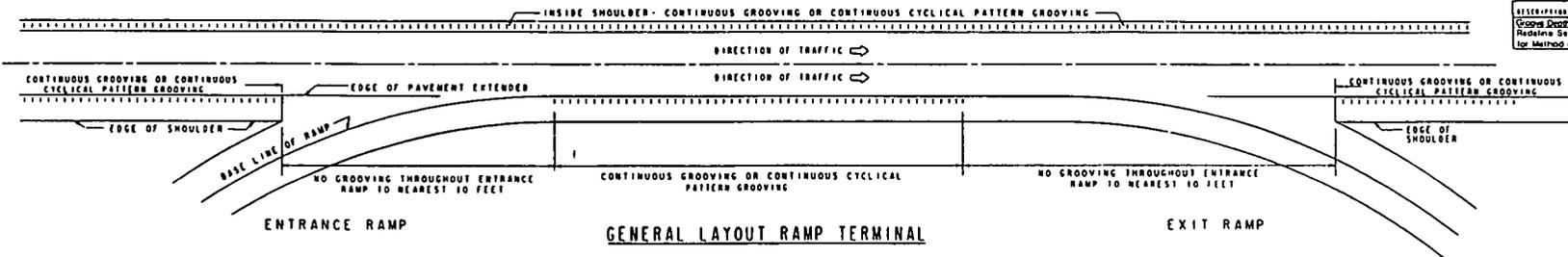
- 1. DO NOT SHOW SHIP DECELERATION AND ACCELERATION AREAS OR ROAD AND TAPERED APPROACHES. DO NOT SHOW ALGOSSE RAMP APPROACHES.
- 2. SHOULDERS TRANSVERSE JOINTS SHALL BE THE SAND PATTERN AS SHOWN HEREON.
- 3. RUMBLE STRIPS SHALL BE SPACED BETWEEN THE 1/3 DECAIMENTS SAND TRANSPORT JOINTS.
- 4. SET TYPICAL PATTERN FOR WIDTH OF SHOULDER.

Sawed Transverse Joints

*ALL TRANSVERSE AND LONGITUDINAL CONTACT JOINTS SHALL BE SAVED AND JOINT SEALANT USED PER SECTION 11.01.01, THIS WEAKENED PLANE JOINT DETAIL.

STATE OF NEVADA DEPARTMENT OF TRANSPORTATION	
CONCRETE & ASPHALT PAVEMENT DETAILS	
<i>Richard O. Hall</i> CHIEF ROAD & SIGN ENGR.	R-10.1.1 (409) ADOPTED - 8/69 REVISION 11-1016

CLASSIFICATION: REVISIONS
 (Specify Dist./Sec. A-A) LDC 7/83
 Redline Sec. A-A & BA Tables, Notes
 for Method BA & Basis of Pay LOC 5/90



BRIDGE APPROACH - (BA)
 Two Lane - One Way
 Two Lane - Two Way

DESIGN SPEED TABLES

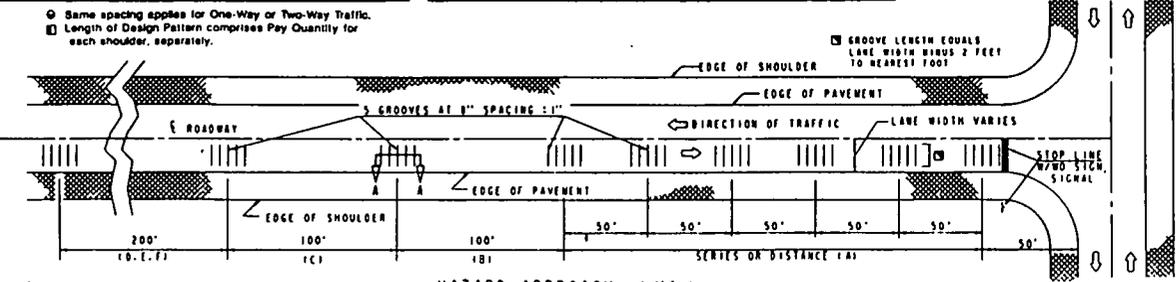
BRIDGE APPROACH SPACING FOR PATTERNS IN SHOULDER

DES. NO.	MPH	DIST. A	B	C	D	E	F	TOTAL (L.F.)
1	40	FIRST 300'	100'	100'	200'			700
2	45	FIRST 300'	100'	100'	200'			700
3	50	FIRST 350'	100'	100'	200'			750
4	55	FIRST 400'	100'	100'	200'			800
5	60	FIRST 400'	100'	100'	200'	200'		1000
6	65	FIRST 400'	100'	100'	200'	200'	200'	1200
7	70	FIRST 400'	100'	100'	200'	200'	200'	1200

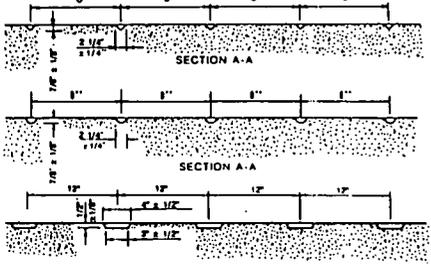
HAZARD APPROACH SPACING FOR PATTERNS IN PAVING LANE

DES. NO.	MPH	DIST. SERIES A	B	C	D	E	F	TOTAL (L.F.)
1	40	6 SPACES @ 50 C/C	100'	100'	200'			700
2	45	6 SPACES @ 50 C/C	100'	100'	200'			700
3	50	7 SPACES @ 50 C/C	100'	100'	200'			750
4	55	8 SPACES @ 50 C/C	100'	100'	200'			800
5	60	8 SPACES @ 50 C/C	100'	100'	200'	200'		1000
6	65	8 SPACES @ 50 C/C	100'	100'	200'	200'	200'	1200
7	70	8 SPACES @ 50 C/C	100'	100'	200'	200'	200'	1200

Same spacing applies for One-Way or Two-Way Traffic.
 Length of Design Pattern comprises Pay Quantity for each shoulder, separately.



HAZARD APPROACH - (HA)



GENERAL NOTES

ALL CONSTRUCTION AND MATERIAL REQUIREMENTS SHALL BE IN ACCORDANCE WITH THE STANDARD SPECIFICATIONS AND SPECIAL PROVISIONS.
 STANDARD RUMBLE STRIP TREATMENT SHALL BE USED IN THE SHOULDERS AT THE APPROACH AND LEAVE 10' OF THE BRIDGE FORE WAY ON TWO WAY TRAFFIC, AS SHOWN ON THE SPACING AND PLACEMENT DETAILS.

BASIS OF PAYMENT		
ITEM NO.	ITEM	UNIT
413.061A	RUMBLE STRIP-METHOD AC-CO2	S.F.
413.061B	RUMBLE STRIP-METHOD AC-CYC (PER GROUP)	EA
413.061C	RUMBLE STRIP-METHOD PCC-C1C1	S.F.
413.061D	RUMBLE STRIP-METHOD PCC-C1C2	S.F.
413.061E	RUMBLE STRIP-METHOD SG-CYC (PER GROOVE)	EA
413.061F	RUMBLE STRIP-METHOD BA 108S, ▲ 1	S.F.
413.061G	RUMBLE STRIP-METHOD HA 108S, ▲ 1	S.F.

Design Number specifies pattern, spacing & overall length (L.F.) based on 5 MPH increments

APPROVED BY

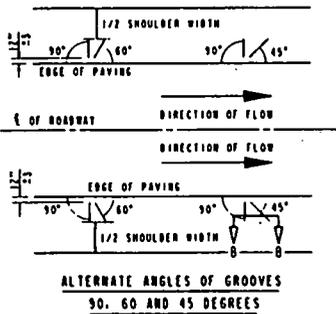
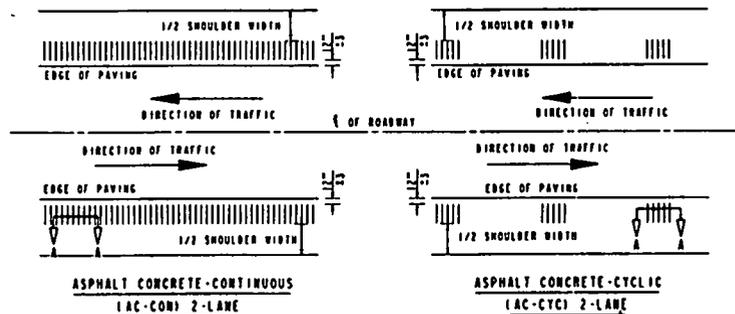
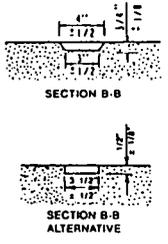
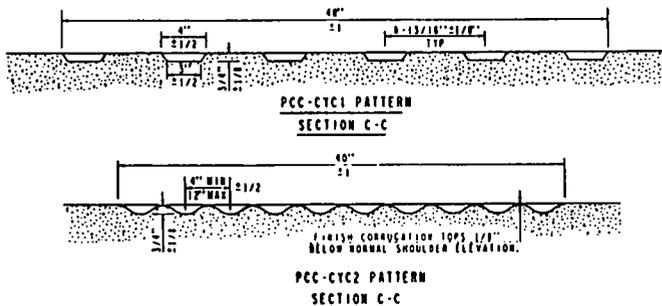
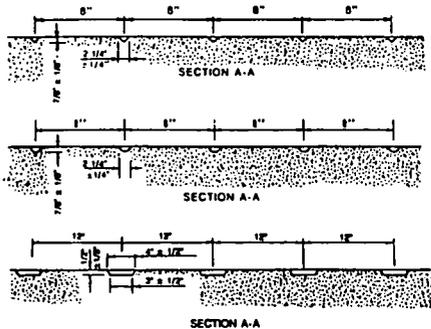
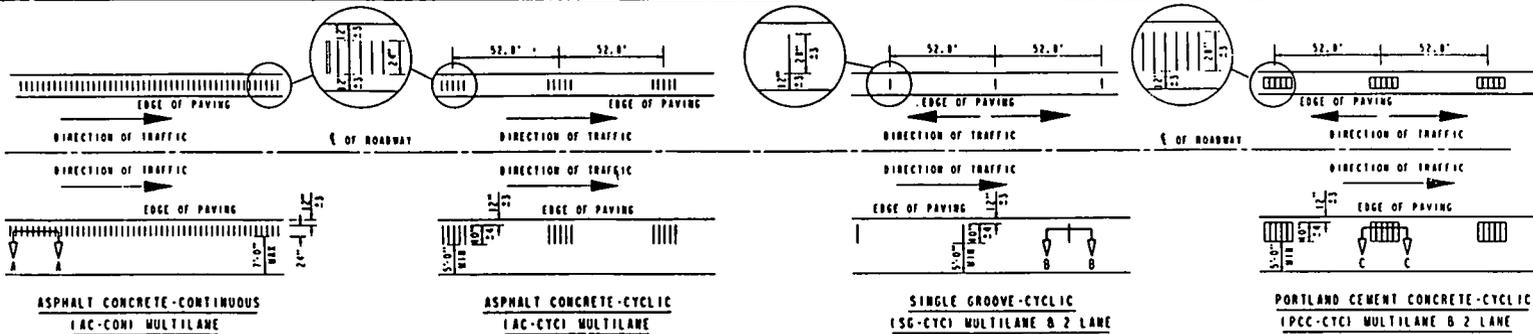
OKLAHOMA DEPT. OF TRANSPORTATION STANDARD

RUMBLE STRIP

RS2 - 1 - 2

106

DESCRIPTION	REVISIONS	DATE
Ground Dist. Sec. 4	1	10/2/78
Revised Sec. 4 - A & B & C P. Notes	1/2	1/2/80



GENERAL NOTES

ALL CONSTRUCTION AND MATERIAL REQUIREMENTS SHALL BE IN ACCORDANCE WITH THE STANDARD SPECIFICATIONS.
 Length of Design Pattern comprises Pay Quantity for each shoulder, separately. See Standard RS2-1

BASIS OF PAYMENT		
ITEM NO.	ITEM	UNIT
413.061A2	RUMBLE STRIP-METHOD AC-CON	L.F.
413.061B1	RUMBLE STRIP-METHOD AC-CYC (PER GROUP)	EACH
413.061C1	RUMBLE STRIP-METHOD PCC-CYC1	S.F.
413.061D1	RUMBLE STRIP-METHOD PCC-CYC2	S.F.
413.061E1	RUMBLE STRIP-METHOD SG-CYC (PER GROOVE)	EACH
413.061F1	RUMBLE STRIP-METHOD BA (RES. Δ 1)	L.F.
413.061G1	RUMBLE STRIP-METHOD BA (RES. Δ 2)	L.F.

Δ Design Number specifies pattern, spacing & overall length (L.F.) based on 5 MPH increments. See Standard RS2-1

APPROVED BY: *[Signature]*

DESIGN: *[Signature]*

CHECKER: *[Signature]*

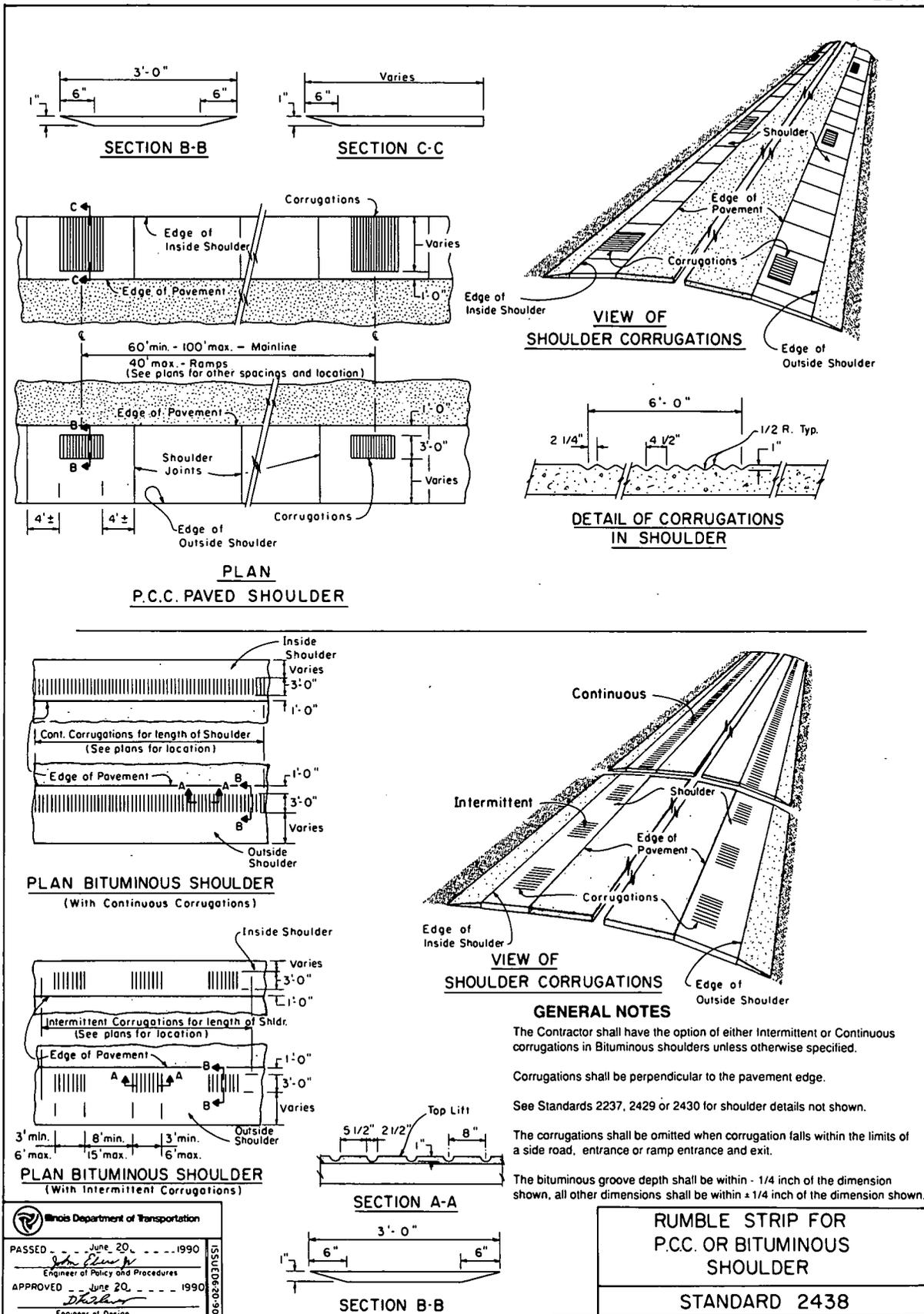
SOB: *[Signature]*

DRAWN: *[Signature]*

DATE: 1/2/80

OKLAHOMA DEPT. OF TRANSPORTATION
STANDARD
RUMBLE STRIP

RS1-1-2



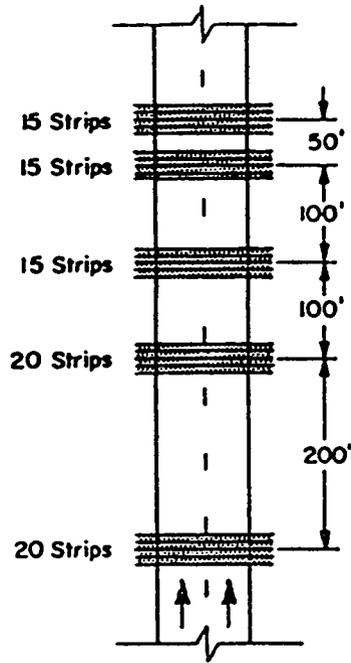
Illinois Department of Transportation

PASSED - June 20, 1990
 Engineer of Policy and Procedures

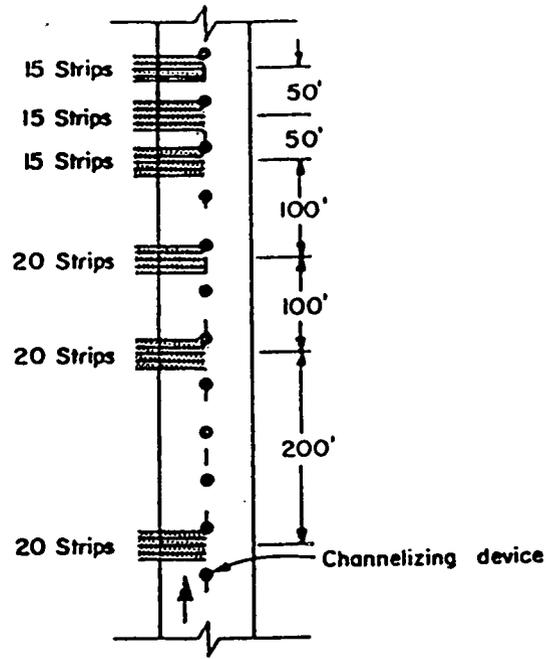
APPROVED - June 20, 1990
 Engineer of Design

APPENDIX E

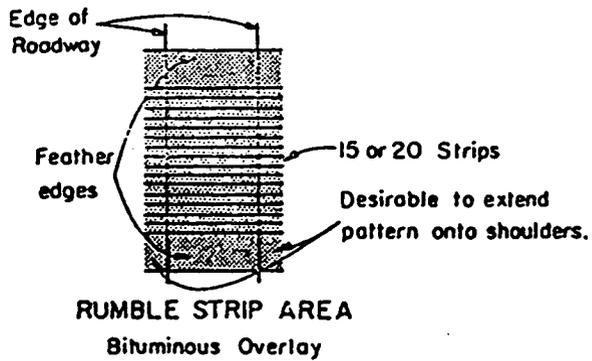
EXAMPLES OF RUMBLE STRIPS PLACED IN THE TRAVELED WAY IN WORK ZONES



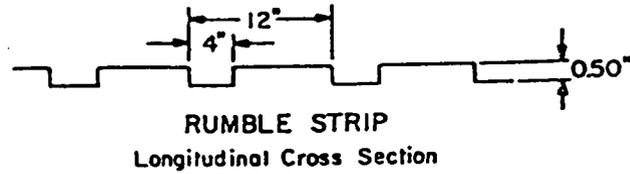
RUMBLE STRIP PATTERN A



RUMBLE STRIP PATTERN B



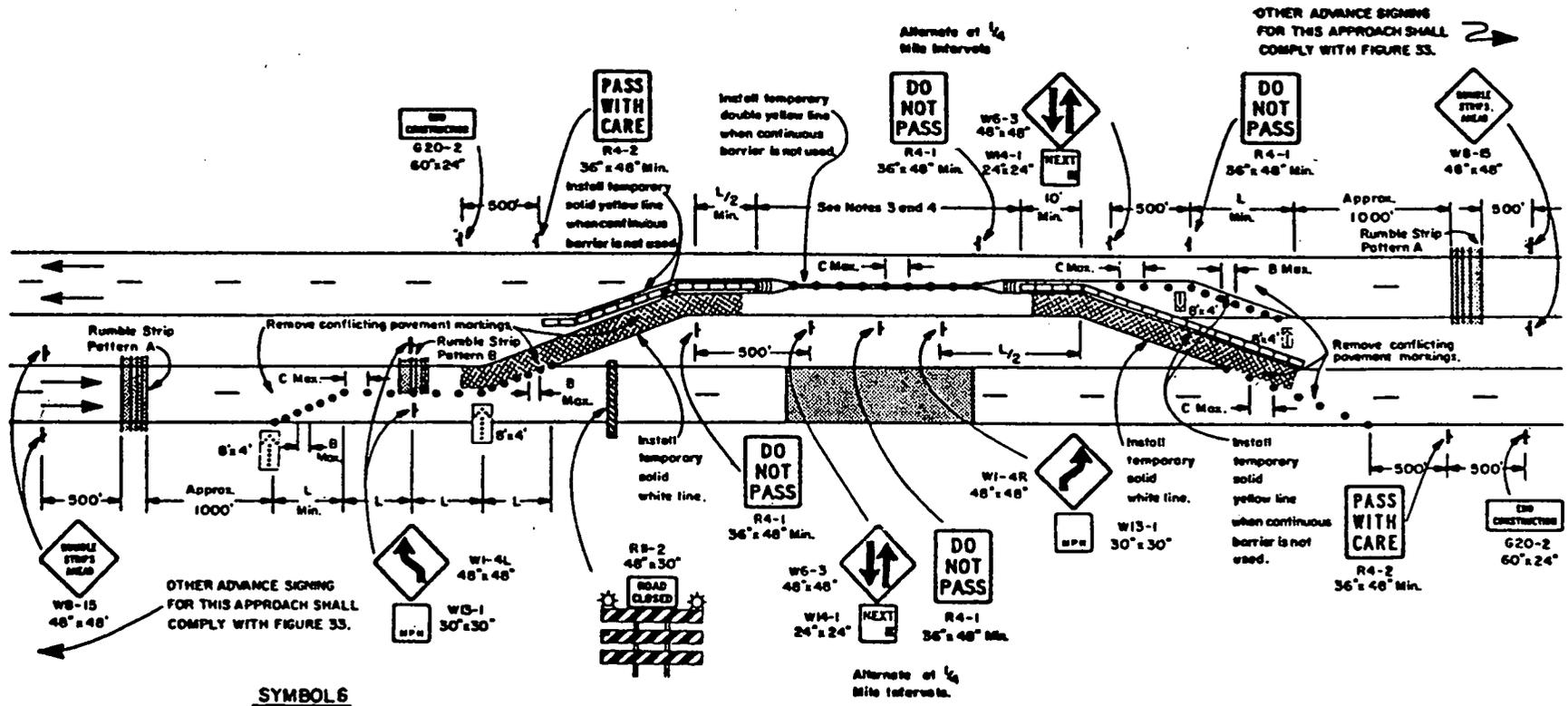
RUMBLE STRIP AREA
Bituminous Overlay



RUMBLE STRIP
Longitudinal Cross Section

INSTALLATION $\frac{1}{2}$ " x 4" plywood strips nailed in place at 12" spacing to form grooves.
INSTRUCTIONS Apply bituminous overlay, then remove plywood strips.

Figure E-1. Pennsylvania's Rumble Strip Patterns. Source: (31)



OTHER ADVANCE SIGNING FOR THIS APPROACH SHALL COMPLY WITH FIGURE 33.

SYMBOLS

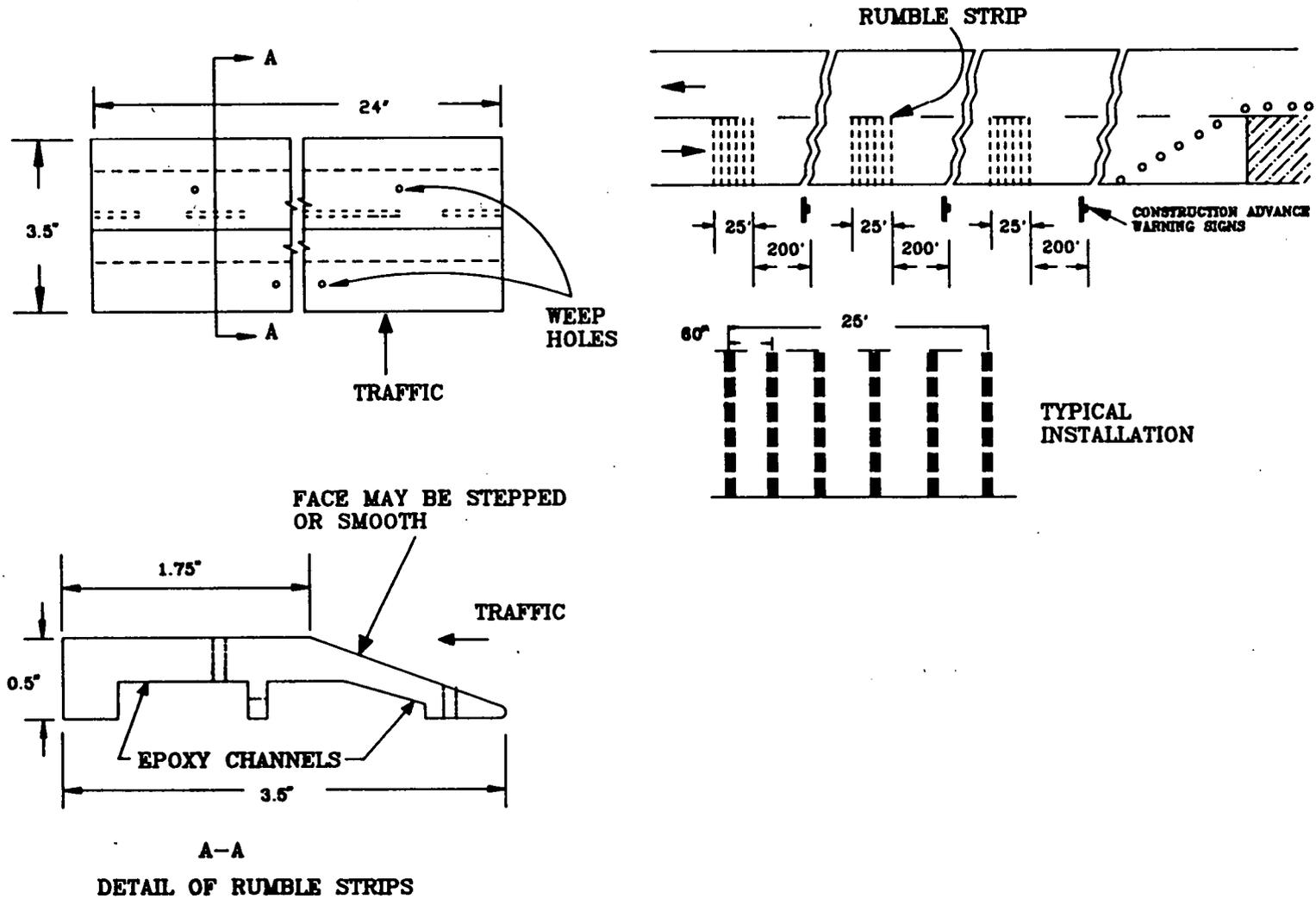
- Work area
- Sign
- Channelizing device
- Type B light
- Arrow board
- See Table 3
- Temporary concrete median barrier (See § 203.61)
- Approved temporary impact attenuator (See § 203.61)
- Temporary bituminous rumble stripe (See § 203.102 and Figure 30a)
- Temporary bituminous overlay
- Normal speed limit

S	B	C
(MPH)	(FT)	(FT)
25	25	50
30	30	60
35	35	70
40	40	80
45	45	90
50	50	100
55	55	110

NOTES

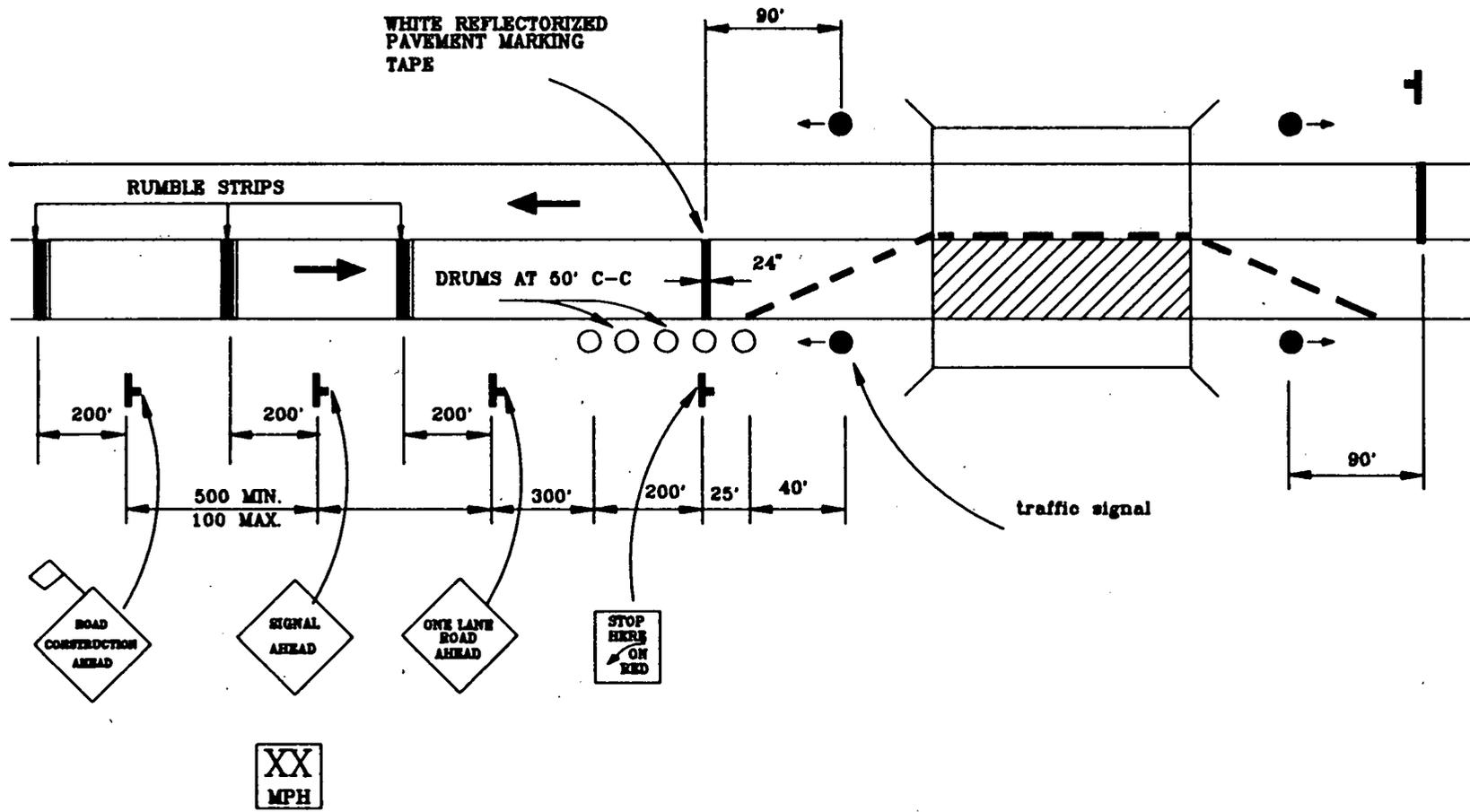
1. All distances may be adjusted slightly to fit field conditions.
2. During hours of darkness, all signs shall be reflectorized or illuminated.
3. Continuous temporary concrete median barrier, or other channelizing devices in conjunction with temporary concrete median barrier of each transition, shall be used between opposing traffic except in the following situations:
 - a. Where the opposing traffic is located on an urban-type street or arterial where operating speeds are low.
 - b. Where drivers entering the section with opposing traffic can see the transition back to normal one-way operation on each roadway.
 - c. Where removal of these operation devices is approved in advance, based on unusual circumstances:
 - (i) By the FHWA on all federal-aid projects,
 - (ii) By the Department's Engineering District on non-federal-aid projects on State-designated highways, or
 - (iii) By the local authority's engineer on non-federal-aid projects on highways under its jurisdiction.
4. The maximum length of temporary one-lane operation, including transitions, should not exceed approximately 3 miles. Temporary one-lane operation longer than approximately 3 miles shall only be permitted if justified by an engineering analysis of crossover locations, traffic operations, safety, and other related factors.
5. When continuous temporary concrete median barrier is used between opposing traffic, Do Not Pass (R4-7), Pass With Care (R4-2), and Two-Way Traffic (W6-3) Signs are not required. Two-Way Traffic Signs (W6-3) with appropriate Advisory Mile Signs (W4-1) shall be used at a maximum spacing of 1/2 mile where continuous temporary concrete median barrier is not used between opposing traffic.
6. Crossovers should be designed for speeds not more than 10 mph below S, but definitely shall not be designed for speeds more than 20 mph below S.
7. For existing concrete pavements, temporary bituminous overlays should be used as shown to cover misfitting pavement joints.
8. The use of rumble strips and associated W6-15 Signs is optional.

Figure E-2. Pennsylvania's Standard Drawing of Rumble Strip Application.



Source: Report Part VI of the Illinois MUTCD, 1987 (32)

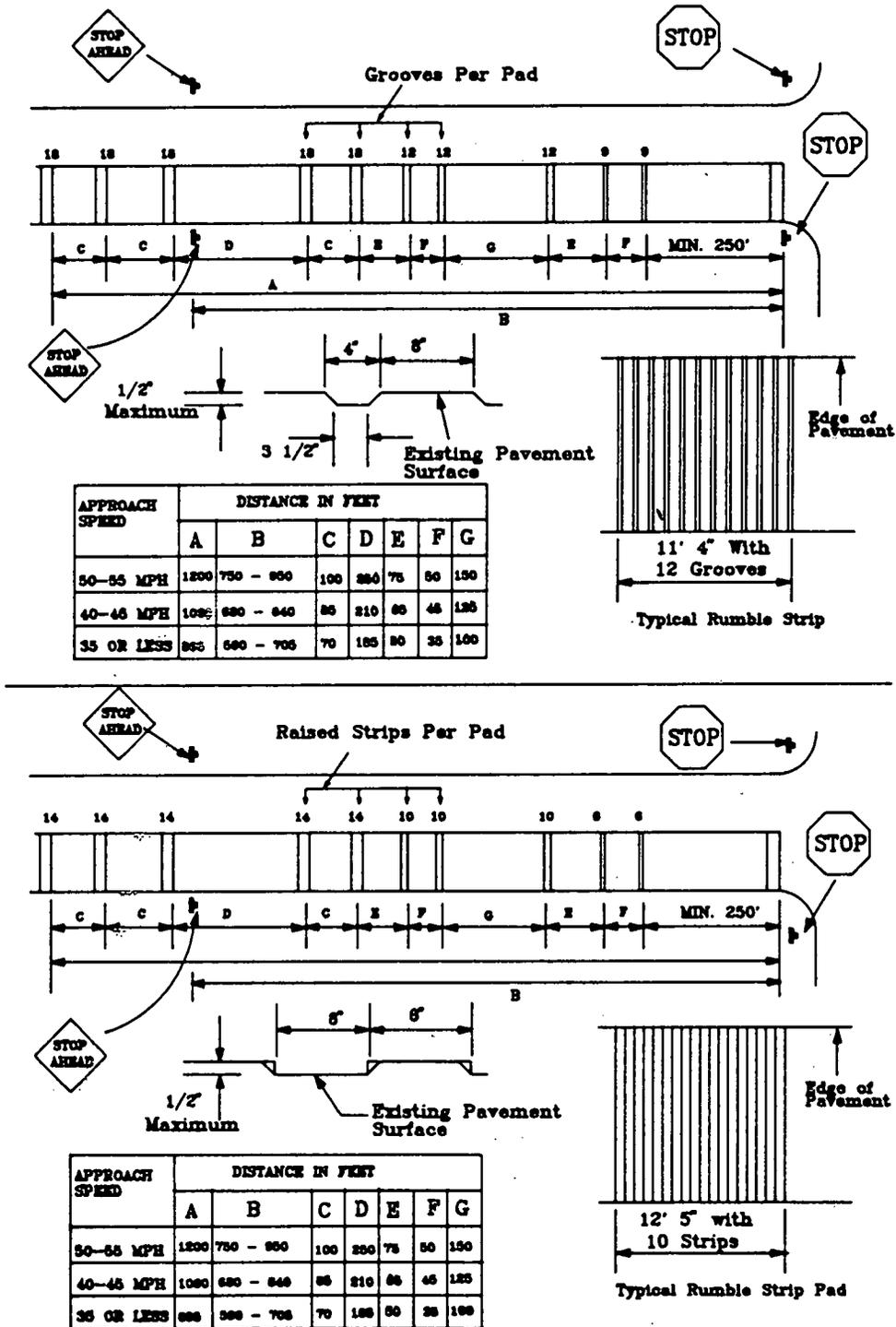
Figure E-3. Temporary Rumble strips Used in Illinois.



Note: Rumble Strips and other control devices are applied to both approaches of the bridge in the schematic.

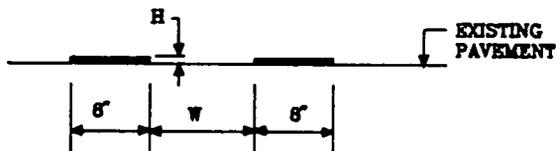
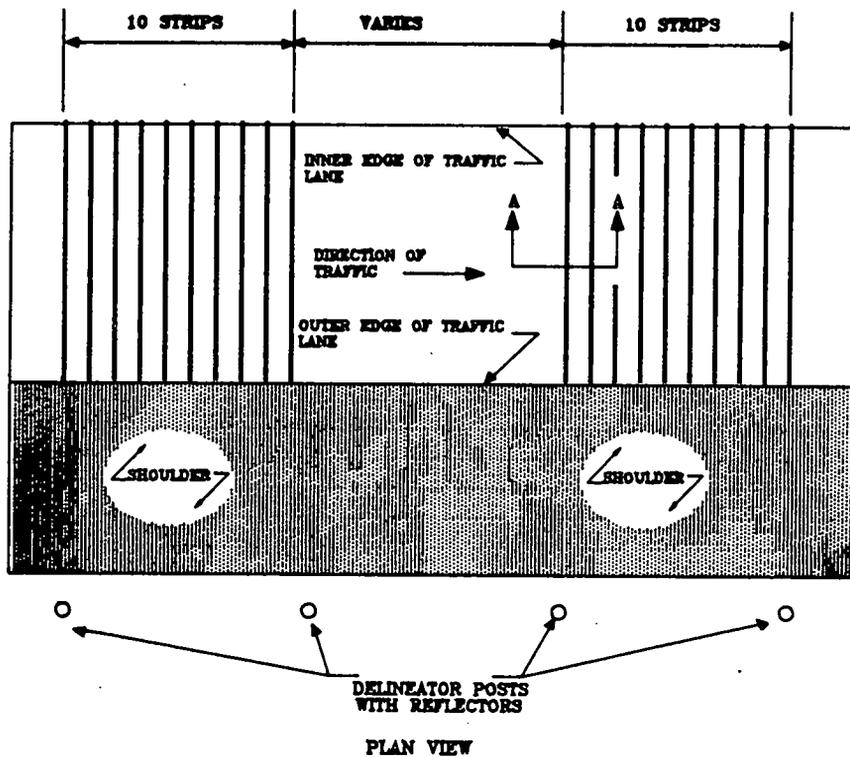
Source: (32)

Figure E-4. Schematic of Illinois' Application of Rumble Strips.



Source (34)

Figure E-5. Rumble Strip Patterns and Applications Used in Ohio.



PART-SECTION A-A

TYPE	M.P.H	H	W
1	0 - 45	1/4" - 3/8"	12"
2	OVER 45	3/8" - 1/2"	24"

Source: (35)

Figure E-6. Traveled Way Rumble Strips Used in Kentucky.

THE TRANSPORTATION RESEARCH BOARD is a unit of the National Research Council, which serves the National Academy of Sciences and the National Academy of Engineering. It evolved in 1974 from the Highway Research Board, which was established in 1920. The TRB incorporates all former HRB activities and also performs additional functions under a broader scope involving all modes of transportation and the interactions of transportation with society. The Board's purpose is to stimulate research concerning the nature and performance of transportation systems, to disseminate information that the research produces, and to encourage the application of appropriate research findings. The Board's program is carried out by more than 270 committees, task forces, and panels composed of more than 3,300 administrators, engineers, social scientists, attorneys, educators, and others concerned with transportation; they serve without compensation. The program is supported by state transportation and highway departments, the modal administrations of the U.S. Department of Transportation, the Association of American Railroads, the National Highway Traffic Safety Administration, and other organizations and individuals interested in the development of transportation.

The National Academy of Sciences is a private, nonprofit, self-perpetuating society of distinguished scholars engaged in scientific and engineering research, dedicated to the furtherance of science and technology and to their use for the general welfare. Upon the authority of the charter granted to it by the Congress in 1863, the Academy has a mandate that requires it to advise the federal government on scientific and technical matters. Dr. Bruce Alberts is president of the National Academy of Sciences.

The National Academy of Engineering was established in 1964, under the charter of the National Academy of Sciences, as a parallel organization of outstanding engineers. It is autonomous in its administration and in the selection of its members, sharing with the National Academy of Sciences the responsibility for advising the federal government. The National Academy of Engineering also sponsors engineering programs aimed at meeting national needs, encourages education and research, and recognizes the superior achievements of engineers. Dr. Robert M. White is president of the National Academy of Engineering.

The Institute of Medicine was established in 1970 by the National Academy of Sciences to secure the services of eminent members of appropriate professions in the examination of policy matters pertaining to the health of the public. The Institute acts under the responsibility given to the National Academy of Sciences by its congressional charter to be an adviser to the federal government and, upon its own initiative, to identify issues of medical care, research, and education. Dr. Kenneth I. Shine is president of the Institute of Medicine.

The National Research Council was organized by the National Academy of Sciences in 1916 to associate the broad community of science and technology with the Academy's purposes of furthering knowledge and advising the federal government. Functioning in accordance with general policies determined by the Academy, the Council has become the principal operating agency of both the National Academy of Sciences and the National Academy of Engineering in providing services to the government, the public, and the scientific and engineering communities. The Council is administered jointly by both Academies and the Institute of Medicine. Dr. Bruce Alberts and Dr. Robert M. White are chairman and vice chairman, respectively, of the National Research Council.

Transportation Research Board
National Research Council
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