



Effectiveness of Edge Line Audible Pavement Striping in Preventing Roadway Departure

Requested by
May Alsheikh, Caltrans District 11

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Executive Summary

Background

An edge line audible stripe pavement marking has raised segments that generate a noise when motorists drive over them. Previous iterations of the California Department of Transportation (Caltrans) Authorized Material List included methyl methacrylate and thermoplastic edge line audible striping products from various vendors.

An ongoing evaluation by Caltrans District 11 is considering the use of profiled or raised edge line audible striping systems as a roadway departure countermeasure. Before recommending that this pavement marking system be included as a countermeasure in agency guidance and standards, Caltrans is seeking research findings and the experience of other state transportation agencies that consider this pavement marking system's effectiveness in reducing roadway departure incidents, the long-term maintenance required for these installations, and the system's retroreflectivity and cost. Of particular interest is how edge line audible stripes fare compared to ground-in rumble strips or stripes.

To assist Caltrans with its review, CTC & Associates surveyed other state departments of transportation (DOTs) to learn more about agency use of profiled or raised edge line audible pavement striping systems. Results of a literature search supplemented the survey findings.

Summary of Findings

Survey of Practice

A national survey of state DOT members of the American Association of State Highway and Transportation Officials (AASHTO) Committee on Maintenance sought information about agency practices for the use of profiled or raised edge line audible pavement striping. The survey received responses from 17 state DOTs. Of these, four agencies reported on current or previous use of this edge line pavement marking system.

Survey questions are provided in [Appendix A](#). Survey findings are highlighted below in two topic areas:

- Users of profiled or raised edge line audible striping.
- Nonusers of profiled or raised edge line audible striping.

Users of Profiled or Raised Edge Line Audible Striping

Case studies describe current or previous use of profiled or raised edge line audible pavement markings in four states:

- *Arizona, Georgia and Oregon*: These states responded to the survey and reported on current use of this pavement marking system.
- *South Carolina*: The survey respondent described previous use of profiled or raised edge line audible pavement markings.

Tables ES1 through ES4 highlight selected elements of these case studies:

- Installation practices.
- Maintenance practices.
- Performance and safety outcomes.
- Challenges.

Table ES1. Installation Practices

State	Installation Practice
Arizona	<ul style="list-style-type: none"> • Marking installed when pavement condition does not permit the installation of ground-in rumble strips. • Installation locations: <ul style="list-style-type: none"> ○ Asphalt in poor condition. ○ Road segments with narrow shoulders of less than 1 foot. ○ Places where snowplow activity is not common, generally in locations below 3,000 feet.
Georgia	<ul style="list-style-type: none"> • Placement based on functional classification of roadway. • Marking installed on segments with shoulders that are 2 feet or wider. • Installation locations: <ul style="list-style-type: none"> ○ Bridges. ○ Concrete roadways. ○ Roadways that have not been resurfaced in more than three years. ○ Off-system roadways.
Oregon	<ul style="list-style-type: none"> • Marking predominantly used in urban areas for enhanced visibility. • No special requirements for installation. • Not used for audible benefits or as a roadway departure countermeasure.
South Carolina	<ul style="list-style-type: none"> • Acceptable alternative only if rumble strips were not feasible due to structural insufficiencies of a paved shoulder where ground-in rumble strips may damage the surface or shoulders. • Characteristics of previous installation locations: <ul style="list-style-type: none"> ○ Roadways classified as rural. ○ Average daily traffic of 500 vehicles per day or greater. ○ Posted speed limit of 45 mph or greater. ○ Existing roadway width of 20 feet or greater.

Table ES2. Maintenance Practices

State	Maintenance Practice
Arizona	<ul style="list-style-type: none"> • No regularly scheduled maintenance.
Georgia	<ul style="list-style-type: none"> • Profiled rumble strips occasionally removed during winter maintenance operations in north Georgia and require replacement.
Oregon	<ul style="list-style-type: none"> • No special maintenance required. The typical maintenance cycle is every one to three years. • Frequency of maintenance by in-house crews or contracted vendors dependent on location and material used. • More frequent maintenance required for profiled rumble strips compared to ground-in rumble strips (every one to three years versus life of the pavement or after two to three chip seals, respectively).

State	Maintenance Practice
South Carolina	Maintenance challenges highlighted in a 2018 Federal Highway Administration report: Their use is limited due to the short life cycle and comparable cost to milled-in rumble strips. We are not necessarily a snow state, but any snow removal or shoulder leveling would practically remove the markings.

Table ES3. Performance and Safety Outcomes

State	Performance and/or Safety Outcome
Arizona	<ul style="list-style-type: none"> • Service life: 10 years or more. • Safety outcomes: Unknown.
Georgia	<ul style="list-style-type: none"> • Service life: “Can be lower” than service life of ground-in rumble strips. • Safety outcomes: Reduction in crashes, particularly fatal and serious injury crashes resulting from roadway and lane departure.
Oregon	<ul style="list-style-type: none"> • No data are available to permit comparison of estimated service life.
South Carolina	<ul style="list-style-type: none"> • Although profiled edge line striping “can be beneficial in the appropriate location,” ground-in rumble strips preferred because of lower maintenance required.

Table ES4. Challenges

State	Challenge
Arizona	<ul style="list-style-type: none"> • Funding installation. • Limited number of contractors approved for installation.
Georgia	<ul style="list-style-type: none"> • Noise complaints. • Lack of understanding of the safety benefits.
Oregon, South Carolina	<ul style="list-style-type: none"> • Profiled striping removed by winter maintenance operations.

Recommendations

Agencies considering the use of profiled or raised edge line pavement markings should:

- Conduct outreach and develop communication materials for stakeholders (*Georgia*).
- Consider conditions for installation, including winter weather experienced in the area, available lane and shoulder width, and condition of the roadway surface (*South Carolina*).
- Develop policies, standard specifications or other guidance (*Arizona, Georgia*).
- Track before-and-after data for crashes, retroreflectivity and maintenance (*Arizona*).
- Understand and demonstrate benefits (*Georgia*).

Ongoing Efforts: Arizona Department of Transportation

Arizona DOT is developing an experiment to determine the effectiveness of profiled thermoplastic pavement markings for reducing lane departure crashes. The agency is also modifying its rumble strip specifications to include additional guidance on when and where to use profiled rumble strips.

Other Agency Experience: Florida Department of Transportation

While Florida DOT did not participate in the survey, publicly available literature was used to inform a description of the agency's practices, including an October 2022 agency bulletin that advises using audible and vibratory treatment for edge lines and centerlines:

- Use on flush-shoulder roadways with a posted speed of 50 mph or greater.
- Do not exclude sections of the project where advisory speeds are used due to restricted horizontal or vertical geometry.
- Do not place audible and vibratory treatments within the limits of crosswalks.
- Use sinusoidal ground-in rumble strips on flexible pavements.
- Use profiled thermoplastic on rigid pavements.
- Obtain approval from the state roadway design engineer for these project types:
 - Resurfacing, restoration and rehabilitation.
 - Permits.
 - Push-button safety.
 - Restriping.

Nonusers of Profiled or Raised Edge Line Audible Striping

Thirteen of the 17 responding agencies reported limited or no experience with a profiled or raised edge line audible pavement marking system.

Mississippi DOT makes limited use of a profiled pavement marking system as an alternative installation on roadways where shoulder width is insufficient to place ground-in rumble strips or stripes.

Respondents that are not using this system cited snowplowing concerns and other issues:

- Awaiting further studies (*Alabama, Nevada*).
- Lack of equipment (*Kansas, Michigan*).
- Lack of familiarity with product or technology (*New Hampshire, West Virginia*).
- Snowplowing impacts (*Connecticut, Michigan, Nebraska, Nevada, New Hampshire, Rhode Island, South Dakota, Utah*).
- Success with other rumble strips (*Michigan, Pennsylvania*).

To change an agency's assessment of this type of pavement marking system and encourage future use, agencies require:

- Continued evaluation of safety impacts and ongoing maintenance.
- Ease of application.
- Equipment availability.
- Evidence of long-term performance in winter climates.
- Product evaluation, including test or study results on cost, durability and effectiveness, particularly when compared to ground-in rumble strips.

Related Research and Resources

A literature search of publicly available domestic research and related resources identified a sampling of publications that are organized into two categories:

- National research and guidance.
- State research and guidance.

Tables ES5 and ES6, which begin on page 9, summarize these publications, providing the publication or resource title, the year of publication, the publication's category, if applicable, and a brief description of the resource. More information about each resource can be found in the **Detailed Findings** section of this report.

Gaps in Findings

A 2018 National Cooperative Highway Research Program (NCHRP) synthesis (*NCHRP Synthesis 515*; see **Related Research and Resources**, page 27, for the citation) highlighted the experiences of seven states that reported using profiled or raised edge line audible striping “often” at the time of the synthesis report's publication. Four of these states responded to the current Caltrans survey. However, these respondents were not able to respond to follow-up communication to provide clarifying or additional information to supplement survey responses. Additional feedback from these agencies and other agencies not responding to the current Caltrans survey may yield additional information that may be helpful to Caltrans.

Next Steps

Moving forward, Caltrans could consider:

- Following up with one or more of the four state DOTs reporting current or previous experience with profiled or raised edge line audible striping:
 - *Arizona*. The agency is developing an experiment to determine the effectiveness of profiled thermoplastic markings for reducing lane departure crashes. Also in development are revisions to agency specifications to provide additional guidance on when and where to use profiled rumble strips.

Caltrans may also wish to query the agency on why current use of this pavement marking system is now characterized as “rarely” when it was often used in 2018.
 - *Georgia*. Following up with the survey respondent to learn more about references to safety data and internal analyses of crash reduction may provide context for Caltrans' evaluation of the effectiveness of profiled or raised edge line audible striping as a roadway departure countermeasure.
 - *Oregon*. Engaging with this respondent could yield more information about the differences in maintenance frequency for profiled versus ground-in rumble strips.
 - *South Carolina*. Outreach to this respondent might include questions about the life cycle and cost of profiled rumble strips compared to ground-in rumble strips. The respondent may also offer additional context regarding the agency's decision to no longer make frequent use of this pavement marking system.

- Reaching out to three state DOTs not responding to the Caltrans survey that are known to have relevant experience to share. These agencies — Florida, Texas and Washington State DOTs — were mentioned in publications describing agency use of profiled or raised edge line audible striping.
- Reviewing existing research, installation guidance and other specifications cited in this Preliminary Investigation to inform Caltrans' continued examination of profiled or raised edge line audible striping.
- Initiating a pilot in selected Caltrans districts to assess profiled or raised edge line audible striping products, including safety benefits (before-and-after installation roadway departure incidents, and impacts on cyclists and motorcyclists), retroreflectivity, long-term maintenance, audibility and cost compared to ground-in rumble strips.

Table ES5. National Research and Guidance

Publication or Resource (Year)	Excerpt from Abstract or Description of Resource
Rural Roadway Departure Countermeasure Pocket Guide (2021)	Suggests countermeasures for reducing roadway departure crashes. Addresses edge line markings and mentions thermoplastic material having a longer life than paint, thus reducing maintenance, and raised pavement markers increasing nighttime visibility.
Safety Evaluation of Profiled Thermoplastic Pavement Markings (2018)	Evaluates the effect of profiled (raised or inverted) thermoplastic pavement markings on many different crash types. A literature review found no published research evaluating the effects on crashes of installing profiled thermoplastic pavement markings. An examination of road geometry and crash and traffic data from two-lane and multilane roads in Florida and South Carolina found only nighttime wet road crashes experienced a material change.
Safety Evaluation of Profiled Thermoplastic Pavement Markings (2017)	Provides a brief technical summary of the research described in the citation above.
CMF/CRF Details: Install Profiled Thermoplastic Pavement Markings (2018)	Provides a crash modification factor (CMF) for profiled thermoplastic pavement markings, which consist of thermoplastic material with raised thermoplastic bumps creating a raised profile marking. The publication notes that “[t]hese markings are designed to provide an improved level of vision to drivers, particularly during wet-road surface conditions. The profiled nature also provides a rumble effect for errant vehicles.”
NCHRP Synthesis 515: Practices for Preventing Roadway Departures (2018)	Summarizes various state practices for preventing roadway departure crashes and identifies advantages and disadvantages of these practices. Notes that there had not been any published research evaluating the effect of profiled pavement markings on crashes until Federal Highway Administration’s 2018 study was completed (<i>Safety Evaluation of Profiled Thermoplastic Pavement Markings</i> , cited above) and provides responses from a survey of state DOTs. Of particular interest are responses addressing states’ practices for use of raised thermoplastic markings.
State of the Practice for Shoulder and Center Line Rumble Strip Implementation on Non-Freeway Facilities (2017)	Notes that while research suggests that milled rumble strips are the most effective application type, raised rumble strips (or rumble stripes) have been applied in states with warmer climates or where milled rumble strips cannot be installed. Locations without snowplowing activities may use profiled thermoplastic pavement markings or other raised rumble strips; however, milled rumble strips are preferred. Raised rumble strips may be considered in areas where milled rumble strips are not practical, such as bridge decks or on thin surface courses (e.g., chip seals).
Decision Support Guide for the Installation of Shoulder and Center Line Rumble Strips on Non-Freeways (2016)	Describes methods for identifying appropriate locations for installation of center line and shoulder rumble strips, assessing the potential crash reductions and benefit-cost ratio, and developing performance metrics for safety.

Publication or Resource (Year)	Excerpt from Abstract or Description of Resource
Low-Cost Treatments for Horizontal Curve Safety 2016 (2016)	Notes that profiled markings are particularly beneficial under wet nighttime conditions, when the retroreflectivity of flat markings is obscured. While thermoplastic markings will last approximately twice as long as paint-based markings, thermoplastic markings are more expensive to install.
Rumble Strip Implementation Guide: Addressing Noise Issues on Two-Lane Roads (2015)	Provides information about potential noise issues related to rumble strips and describes raised edge line rumble strips as an “alternative or experimental design.” States that raised edge line striping reduces external noise but does not provide the same level of internal noise and vibration as typical milled rumble strips.
Rumble Strip Implementation Fact Sheet: Noise (2015)	Distills the guidance above, recommending outreach that invites public comment and encourages public agencies to address the public’s questions and concerns directly and emphasize road use safety.

Table ES6. State Research and Guidance

Publication or Resource (Year)	State	Excerpt from Abstract or Description of Resource
Pavement Markings Manual for Designers and Construction Services (2022)	Louisiana	Describes the selection, design, maintenance and installation of pavement markings. Provides a description, uses, advantages and disadvantages of audible thermoplastic, profiled thermoplastic and methyl methacrylate markings.
Edge-Line Pavement Markings on Two-Lane, Two-Way Local Roads (2020)	Pennsylvania	Examines requirements and applications of edge lines on two-lane roads. As the information sheet notes, “These treatments are countermeasures for safety problems, and their use should be based on an engineering study.”
Special Provision Regarding Profiled Thermoplastic Pavement Marking Audible System (2023)	Tennessee	Provides guidance for the placement of a raised or inverted profiled thermoplastic pavement marking audible system.
Evaluation of Audible Lane Departure Warning Treatments for Seal Coat Road Surfaces (2019)	Texas	Evaluates audible lane departure warning treatments with regard to the following: <ul style="list-style-type: none"> • What are the safety benefits? • What is the delivered performance (noise, vibration, visibility)? • What are the costs? • What is(are) the best design(s)? • When and where should audible lane departure warning treatments be implemented? • What level of performance remains after the treatments are seal coated over?

Publication or Resource (Year)	State	Excerpt from Abstract or Description of Resource
Project Summary 0-6888: Audible Lane Departure Warning Treatments for Seal Coat Road Surfaces (2019)	Texas	Summarizes findings from the report cited above: Audible markings and rumble bars are viable alternative lane departure warning treatments from a noise and vibration performance standpoint, from a crash reduction standpoint, and from a benefit-cost ratio (at least 11:1) standpoint. These treatments should be considered when traffic volumes, speeds and crash history indicate a need for increased attention to reduce single-vehicle run-off-the-road and two-lane two-way crossover crashes.
Safety Evaluation of Alternative Audible Lane Departure Warning Treatments in Reducing Traffic Crashes: An Empirical Bayes Observational Before–After Study (2018)	Texas	Examines the safety effect of installing profiled pavement markings and preformed rumble bars. Describes CMFs for these treatments that quantify the effectiveness in reducing single-vehicle-run-off-road and opposite-direction crashes.
Guidance for and Effectiveness of Low-Cost Delineation Treatments (2022)	Virginia	Examines treatments that include curve warning signs, edge lines, centerlines, post-mounted delineators at 20- and 40-foot spacing, and plastic inlaid markers. Researchers developed a Microsoft Excel-based tool for evaluating benefit-cost ratios based on a range of input variables such as type of facility, annual average daily traffic and treatment considerations.

Detailed Findings

Background

The raised segments of a profiled or raised edge line audible striping pavement marking generate noise and vibration when motorists drive over them. California Department of Transportation (Caltrans) District 11 previously installed this pavement marking system using methyl methacrylate and thermoplastic edge line audible striping products from vendors listed on the Caltrans Authorized Material List. The district's Division of Traffic Safety and Operations is currently assessing the effectiveness of this pavement marking system, seeking research to support the continued use of profiled or raised edge line striping and to potentially add this pavement marking system as a roadway departure countermeasure, along with ground-in rumble strips and stripes, to the district's guidance and standards.

To assist with this effort, CTC & Associates surveyed other state transportation agencies about their experience with profiled or raised edge line audible striping systems. A literature search that examined domestic research and state practices supplemented the survey findings.

Survey of Practice

An online survey was distributed to state department of transportation (DOT) members of the American Association of State Highway and Transportation Officials (AASHTO) Committee on Maintenance. This committee's membership includes all 50 state DOTs and the District of Columbia.

Respondents were asked to provide information about their agencies' experience with profiled or raised edge line audible pavement markings, including how this type of installation compares to ground-in rumble strips and stripes. Survey questions are provided in [Appendix A](#).

The survey received responses from 17 state DOTs:

- Alabama
- Arizona
- Connecticut
- Georgia
- Kansas
- Michigan
- Mississippi
- Nebraska
- Nevada
- New Hampshire
- Oregon
- Pennsylvania
- Rhode Island
- South Carolina
- South Dakota
- Utah
- West Virginia

Survey results are summarized below in two topic areas:

- *Users of profiled or raised edge line audible striping.* Four responding agencies reported on current or previous use of profiled edge line striping. Practices of another agency user — Florida DOT — are also highlighted. (*Note:* Florida DOT did not respond to the current Caltrans survey.) Presentation of these survey findings begins on page 13.
- *Nonusers of profiled or raised edge line audible striping.* Thirteen of the responding agencies reported limited or no experience with this type of edge line marking system. Presentation of these survey findings begins on page 23.

Users of Profiled or Raised Edge Line Audible Striping

Note: NCHRP Synthesis 515: Practices for Preventing Roadway Departures (2018) presents survey results from state DOTs about the use of various roadway departure countermeasures, including the raised thermoplastic markings that Caltrans is evaluating. At the time of the NCHRP report’s publication, seven state DOTs used these pavement markings “often”:

- Arizona
- Florida
- Georgia
- Oregon
- South Carolina
- Texas
- Washington

Four of these agencies (Arizona, Georgia, Oregon and South Carolina) responded to the current Caltrans survey, and their responses are highlighted below in brief case studies. While Florida DOT did not respond to the survey, agency practices identified through relevant literature are summarized after the case studies.

Three responding state DOTs (Arizona, Georgia and Oregon) currently use profiled or raised edge line audible pavement markings to some degree. Table 1 provides general information about the audible striping products these agencies use. *Note:* Unless noted in the table below, respondents did not provide a year when citing product cost.

Table 1. Description of Respondents’ Profiled or Raised Edge Line Audible Striping Products

State	Material/Vendor	Retroreflectivity	Cost
Arizona	No material noted AQUALITE Ennis-Flint, Inc.	Same as other thermoplastic: <ul style="list-style-type: none"> • White: 350 millicandela (mcd). • Yellow: 200 mcd. 	Varies; generally more than double for profiled installations. Approximately \$3/linear foot (in 2011).
Georgia	Thermoplastic No vendor noted	Application of glass sphere and/or reflective composite optics as recommended by manufacturer: <ul style="list-style-type: none"> • White: 300 mcd/lux/m². • Yellow: 250 mcd/lux/m². 	Approximately \$1/linear foot.
Oregon	Methyl methacrylate and thermoplastic Ennis-Flint, Inc. SWARCO	Initial retroreflectance: <ul style="list-style-type: none"> • White: 250 mcd. • Yellow: 200 mcd. 	\$1.65 to \$5/linear foot.

The case studies below describe current or previous practices for the use of profiled or raised edge line audible pavement markings by four state DOTs:

- Arizona

- Georgia
- Oregon
- South Carolina

Arizona Department of Transportation

At the time of publication of the 2018 *NCHRP Synthesis 515*, Arizona DOT used profiled edge line striping systems “often.” The survey respondent characterized current use as “rarely.”

Installation

Arizona DOT’s installation guidance refers to “pavement condition such that ground-in rumble strips cannot be installed.” The agency has interpreted this to mean asphalt in poor condition and roads with narrow shoulders (less than 1 foot). The agency will only install profiled pavement markings in places where snowplow activity is not common, generally in locations below 3,000 feet. Other factors, such as speed or roadway type, are not part of an installation decision. The agency is not using this pavement marking system to increase retroreflectivity and does not conduct before-and-after tests to compare performance to other enhanced wet-night thermoplastic striping systems.

Currently, the most significant limitation for use is the presence of snow — profiled marking systems are not recommended for areas with snowplow activity.

Maintenance

District engineers and the regional traffic engineering office monitor profiled pavement marking installations along with other roadway signing and striping. The agency does not conduct regularly scheduled maintenance on the markers. The respondent noted that the markers “do wear out eventually” and are replaced.

Water Ponding and Settling

With each rain in Arizona, water collects in ground-in rumble strips along with silt and debris. Water often then seeps into the asphalt, eventually degrading the surface material.

Performance and Safety Outcomes

Arizona DOT’s profiled rumble strip applications have a service life of 10 years or more. The agency has not compared this service life with ground-in rumble strips and has not received public complaints about noise generated by the profiled markers.

The respondent noted that the pavement marking system’s safety outcomes are “[u]nknown, but in theory, the benefit should be similar to ground-in [rumble strips] since there are no alternative treatments in areas with poor pavement or no shoulder.”

Challenges

The respondent noted that there is “[n]o easy way to fund installation of profile rumbles through maintenance, and only one contractor [is] currently approved to install.”

Recommendations

Below are Arizona DOT's recommendations to other transportation agencies that are considering the use of profiled or raised edge line audible pavement markings:

- *Develop standard specifications.* Include in agency specifications for spacing, thickness and reflectivity of profiled pavement markings.
- *Develop guidance.* Ensure that documented guidance addresses appropriate installation locations, including places with no shoulder or poor pavement condition and in high lane departure segments near residential areas where ground-in rumble strips might be too noisy.
- *Track the data.* Gather before-and-after data for crashes, retroreflectivity and maintenance.

Ongoing Evaluation

Arizona DOT is developing an experiment to determine the effectiveness of profiled thermoplastic pavement markings for reducing lane departure crashes. The agency is also modifying its rumble strip specifications to include additional guidance on when and where to use profiled rumble strips.

Related Resources

"Section 480, Longitudinal Rumble Strips," *ADOT Traffic Engineering Guidelines and Processes*, Arizona Department of Transportation, January 2018.

<https://azdot.gov/sites/default/files/2019/05/tgp0480-2018-01.pdf>

This standard specification allows use of profiled edge line striping as an alternative to traditional rumble strips. *From 480.1, Introduction and General Considerations:*

The purpose of this guidance is to define when and where longitudinal rumble strips may be applied on the state highway system.

....

Longitudinal rumble strips may be constructed through a number of different techniques and patterns (e.g., formed rumble strip, raised pavement markers such as ceramic buttons, or profile pavement markings). This guidance is not intended to restrict or prohibit the use of any of these other alternatives. If an alternative technique is shown to offer an advantage over the ground-in rumble strip, then its use may be considered. Raised treatments may not be suitable for locations subject to snow plow activity, or in other areas subject to frequent use of blade-on-pavement activities such as debris or rock clearance.

From 480.2, Shoulder Rumble Strips:

The effective clear shoulder width is important for the following reasons:

- (a) Constructibility — To allow for installation equipment, i.e., grinding, a minimum effective clear shoulder width of two (2) feet is needed from the outside edge of the rumble strip groove to the front face of the barrier or guardrail. If the barrier is on a higher-degree horizontal curve, additional width may be needed. This constructibility issue applies to all shoulders and all types of highways.
- (b) Bicycle Traffic — A minimum effective clear shoulder width of four (4) feet should be provided from the outside edge of the rumble strip pattern to the edge of pavement or front face of the barrier or guardrail. If this clear area can not be maintained, then a change of configuration and/or deletion of the rumble strip should be considered.

If these minimum clear shoulder width dimension criteria can not be maintained, then there are four possible solutions that may be considered. These possible solutions should be considered in the order that they are presented here.

1. Use a narrower strip width (6 inch) installed under the edge line (see Standard Drawing M-22).
2. Re-evaluate lane widths; if the lanes are wider than 12 feet it may be permissible to reduce their width.
3. If on a roadway not subject to routine snow plow activity, consider using an alternative rumble strip treatment such as profile pavement markings and/or raised pavement markers. Note that neither a ground-in rumble strip nor a raised pavement marker pattern should be considered as “bicycle-friendly,” as these have negative impacts on bicyclists by causing significant vertical oscillations that can be very uncomfortable or potentially affect stability.
4. Omit the use of the longitudinal rumble strip.

See page 5 of the PDF for Exhibit 480-A, Shoulder Rumble Strip Evaluation Checklist.

Miscellaneous Work (Profile Thermoplastic) (White), Project: SR71 – JCT SR 95 to South of Bouse, Arizona Department of Transportation, February 2011.

(This publication has been provided to Caltrans separately.)

This 2011 specification, provided by the respondent, describes the pattern and spacing of profiled rumble strips for a specific project.

Georgia Department of Transportation

At the time of publication of the 2018 *NCHRP Synthesis 515*, Georgia DOT used profiled edge line striping systems “often.” The survey respondent characterized current use as “occasionally.”

Installation

Profiled or raised edge line audible striping is most commonly placed on bridges, concrete roadways, roadways that have not been resurfaced in more than three years, and off-system roadways. The agency installs profiled or raised edge line audible pavement markings on segments with shoulders that are 2 feet or wider.

Georgia DOT is the only agency among the case study agencies to describe other factors that determine placement. Functional classification of the roadway is part of the placement decision. For example, profiled or raised edge pavement markings are placed on rural roadway shoulders where the design speed is greater than or equal to 40 mph and lane width is 11 feet or greater.

Georgia DOT is also the only agency among the agency case studies to receive public complaints about the noise generated by the profiled pavement markers. The agency has not made any changes to the materials or installation practices in response to these complaints.

Maintenance

Snow removal is the only type of maintenance performed by in-house maintenance crews in connection with the profiled rumble strips. Occasionally, winter maintenance operations in north Georgia remove the profiled rumble strips, and they must be replaced.

Water Ponding and Settling

In Georgia, water ponding is mostly related to poor installation in the midjoint. The respondent did not comment on how ponding has impacted the integrity of the shoulder structure.

Performance and Safety Outcomes

Georgia DOT has not compared the retroreflectivity of profiled or raised edge line audible pavement markings with enhanced wet-night thermoplastic striping systems. The service life of profiled edge line markings “can be lower” than the service life of ground-in rumble strips.

Safety outcomes of profiled or raised edge line audible markings include a reduction in crashes, particularly fatal and serious injury crashes resulting from roadway and lane departure. The respondent further noted that “[s]afety data shows they are close in terms of the crash reduction for the analysis we have done.” The respondent was not able to respond to follow-up queries about this analysis.

Challenges

The agency’s most significant challenges are noise complaints and the lack of understanding of the safety benefits.

Recommendations

Below are Georgia DOT’s recommendations to other transportation agencies that are considering the use of profiled or raised edge line markings:

- Conduct outreach and develop communication pieces for stakeholders.
- Develop policies that describe agency practices.
- Understand and be able to demonstrate the benefits of these pavement markings.

Related Resources

Design Policy Manual, Revision 7.3, Georgia Department of Transportation, October 2024.

<https://www.dot.ga.gov/partnersmart/designmanuals/designpolicy/gdot-dpm.pdf>

Section 6.5.1, Rumble Strips (beginning on page 146 of the PDF) presents a brief discussion of rumble strip use in cross-section elements, including a table summarizing the criteria for standard placement of rumble strips. In addition, agency policy on placing audible profiled thermoplastic stripes in 3R (resurfacing, restoration or rehabilitation) and pavement reconstruction projects begins on page 279 of the PDF.

Construction Detail, Audible Profiled Thermoplastic Details, T-37, 2025 Construction Standards and Details, Georgia Department of Transportation, July 2024.

http://mydocs.dot.ga.gov/info/gdotpubs/ConstructionStandardsAndDetails/00-2025%20CSD%20BOOK_00-2025.pdf

See page 381 of the PDF for the construction detail of Georgia DOT’s profiled edge line striping.

Section 653, Thermoplastic Traffic Stripe, Supplemental Specification, Georgia Department of Transportation, October 31, 2018.

https://www.dot.ga.gov/PartnerSmart/Business/Source/special_provisions/2016%20Supplemental%20Specifications/Not%20Published/SS%20653%20-%20Thermoplastic%20Traffic%20Stripe.pdf

This specification describes the materials and installation requirements for profiled edge line striping.

Oregon Department of Transportation

At the time of publication of the 2018 *NCHRP Synthesis 515*, Oregon DOT used profiled edge line striping systems “often.” The survey respondent characterized current use as “occasionally.”

Installation

Oregon DOT is not using profiled or raised edge line audible pavement markings for their audible benefits or as a roadway departure countermeasure. Instead these markings are predominantly used in urban areas to enhance visibility. The agency has no special requirements for installation and has not received public complaints about the noise generated from them.

Maintenance

No special maintenance is required for the agency’s installations. The typical maintenance cycle is every one to three years; the frequency of maintenance by in-house crews or contracted vendors depends on location and the material used.

Water Ponding and Settling

In Oregon, water ponding is a “common occurrence.” The agency has no data on how ponding impacts shoulder structure.

Performance and Safety Outcomes

Profiled rumble strips require more frequent maintenance than ground-in rumble strips (every one to three years versus life of the pavement or after two to three chip seals, respectively). No data are available to permit comparison of estimated service life.

As previously noted, profiled rumble strips are not used as a roadway departure countermeasure. When profiled rumble strips are used to improve visibility for nighttime and wet road driving, the agency applies a 9% crash reduction factor (CRF). Ground-in rumble strips are used as a roadway departure countermeasure; the agency applies a 22% CRF for run-off-road crashes.

Challenges

Oregon DOT’s most significant challenge is related to snow removal: The profiled rumble strips “may get plowed off.”

Related Resource

Standard Drawing TM520, Durable Pavement Markings Method “A” and Method “D” Surface Installed Profiled, TM520. Oregon Standard Drawings, Oregon Department of Transportation, 2024.

<https://www.oregon.gov/odot/engineering/202407/TM520.pdf>

This standard drawing illustrates installation of Oregon DOT’s profiled edge line striping.

South Carolina Department of Transportation

At the time of publication of the 2018 *NCHRP Synthesis 515*, South Carolina DOT used profiled edge line striping systems “often.” The agency no longer makes frequent use of this pavement marking system. The respondent noted that profiled edge line striping “can be beneficial in the appropriate location,” but the agency prefers the lower maintenance associated with ground-in rumble strips.

Appendix B to the March 2018 Federal Highway Administration (FHWA) report, *Safety Evaluation of Profiled Thermoplastic Pavement Markings* (see **Related Research and Resources**, page 26, for the citation) included additional installation details for South Carolina DOT. At that time, the agency’s criteria for identifying roads to receive profiled thermoplastic markings included the following:

- Roadway is classified as rural.
- Average daily traffic is 500 vehicles per day or greater.
- Posted speed limit is 45 mph or greater.
- Existing roadway width is 20 feet or greater.

Thermoplastic profiled markings were an acceptable alternative only if rumble strips were not feasible due to structural insufficiencies of a paved shoulder where ground-in rumble strips may damage the surface or shoulders.

The March 2018 FHWA guidance also noted the following about maintenance challenges that South Carolina DOT identified for profiled markings:

Their use is limited due to the short life cycle and comparable cost to milled in rumble strips. We are not necessarily a snow state, but any snow removal or shoulder leveling would practically remove the markings.

For the current Caltrans survey, the South Carolina DOT respondent described previous use of this type of pavement marking system, as summarized below:

<u>Topic</u>	<u>Description</u>
Previous use	Locations where the width of paved shoulders is insufficient to install ground-in rumble strips.
Reason for discontinuing use	Installations were difficult to maintain. As the respondent noted, “We do not have a lot of snow and ice, but if you do have to plow, the domes are gone.”
Potential for future use	The pavement marking system will remain in the agency’s pavement marking toolbox “should a specific situation arise [for which] they would be beneficial.”
Recommendations to other agencies	Other agencies are advised to consider: <ul style="list-style-type: none">• Existing condition of the roadway surface.• Winter weather experienced in the area.• Available lane and shoulder width.

Florida Department of Transportation

At the time of publication of the 2018 *NCHRP Synthesis 515*, Florida DOT used profiled edge line striping systems “often.” While the agency did not respond to the current Caltrans survey, a review of literature informed the following summary of agency practices.

Historical Perspective

Appendix A to the March 2018 FHWA report, *Safety Evaluation of Profiled Thermoplastic Pavement Markings* (see **Related Research and Resources**, page 26, for the citation), included selected installation details for Florida DOT, including:

- **Average installation costs per lane-mile.** Average cost for a 6-inch 100 mil above-surface thickness extruded with bump material could average somewhere between \$3,275 to \$3,900 per gross lane mile.
- **Estimated service life.** Service life as required by specification is three years.

A 2018 Florida DOT presentation, *Audible and Vibratory Treatment: Arterials and Collectors* (see **Related Resources**, page 22, for the citation), described the agency’s use of profiled thermoplastic striping as appropriate under these conditions:

- Rigid pavement.
- Requirements for installing ground-in rumble strips cannot be met.
- Paved shoulder width prevents the construction phasing required for installation of ground-in rumble strips.
- Restriping projects where the district maintenance engineer has determined ground-in rumble strips are not cost-effective based on the remaining service life of the pavement.
- Edge lines for bridges with narrow shoulders as a countermeasure for barrier impacts.

The 2018 Florida DOT presentation also noted other circumstances that call for use of profiled thermoplastic striping:

- Paved shoulders of 1 foot or less (for durability of pavement and constructability). May be used with ground-in rumble strips on outside shoulder.
- Use with residences nearby and for paved shoulders greater than 1 foot and less than 5 feet. Residences are considered nearby when located within a minimum of a 650-foot radius. (The minimum 650-foot radius is guidance only; the district may choose to increase this distance.)

Below are examples of existing conditions where profiled thermoplastic striping should be installed for an entire project:

Example 1

- Divided, multilane roadway.
- Outside paved shoulders that are 5 feet.
- Sporadic subdivisions along the length of the project with a significant risk for noise complaints.

Example 2

- Divided, multilane roadway.
- Paved shoulders that are 4 to 5 feet.
- Residences adjacent to the roadway.

Current Installation Practices

An October 2022 Florida DOT Roadway Design Bulletin (see **Related Resources**, page 22, for the citation) provides the following recommendations for using audible and vibratory treatment on edge lines and centerlines:

- Use on flush-shoulder roadways with a posted speed of 50 mph or greater.
- Do not exclude sections of the project where advisory speeds are used due to restricted horizontal or vertical geometry.
- Do not place audible and vibratory treatments within the limits of crosswalks.
- Use sinusoidal ground-in rumble strips on flexible pavements.
- Use profiled thermoplastic on rigid pavements. Otherwise, use of profiled thermoplastic for any project including 3R (resurfacing, restoration and rehabilitation), permits, push-button safety and restriping projects must be approved by the state roadway design engineer.

As the bulletin highlights in its commentary and background, through testing and evaluation of options, Florida DOT has selected sinusoidal ground-in rumble strips for all audible and vibratory treatments on arterials and collectors with flexible pavement.

Installation specifications provided in *Section 701, Profiled Thermoplastic Pavement Markings* (see **Related Resources**, page 22, for the citation) address the following:

- **Thickness:** Apply flat base lines having a minimum thickness of 0.100 inches or 100 mils and not exceeding a thickness of 0.150 inches or 150 mils, exclusive of the bumps, when measured above the pavement surface.
- **Dimensions of raised bumps:** Apply the raised bumps with a profile such that the leading and trailing edges are sloped at a sufficient angle to create an audible and vibratory warning. Bumps on edge line and centerline markings shall be at least 0.45 inches at the highest point of the bump, above the pavement surface, including the base line. The height shall be measured after application of drop-on retroreflective elements or glass spheres. Bumps shall have a minimum baseline coverage dimension of 2.5 inches in both transverse and longitudinal directions. The bumps may have a drainage channel; the width of each drainage channel will not exceed 1/4 inch at the bottom of the channel. The longitudinal distance between bumps shall be approximately 30 inches.
- **Retroreflectivity:** Apply white and yellow profiled thermoplastic markings that will attain an initial retroreflectance of not less than 300 mcd/m²/lx and not less than 250 mcd/m²/lx, respectively.

For limited access facilities, the January 2025 FDOT Design Manual specifies using profiled thermoplastic “for inside and outside edge line pavement markings on roadways with rigid pavement shoulders” (see **Related Resources**, page 22, for the citation).

Related Resources

Section 701, Profiled Thermoplastic Pavement Markings, Standard Specifications for Road and Bridge Construction, FY 2024-2025, Florida Department of Transportation, 2024.

https://fdotwww.blob.core.windows.net/sitefinity/docs/default-source/programmanagement/implemented/specbooks/fy-2024-25/fy2024-25ebookfinalcomp-revised3-4-24.pdf?sfvrsn=16ab03d_1

Section 701, which begins on page 954 of the manual (page 962 of the PDF), describes the equipment, materials and installation practices for “profiled thermoplastic pavement markings [that] consist of thermoplastic material with raised thermoplastic bumps creating a raised profile marking.”

2025 FDOT Design Manual, Florida Department of Transportation, January 2025.

https://fdotwww.blob.core.windows.net/sitefinity/docs/default-source/roadway/fdm/2025/2025-fdm-complete.pdf?sfvrsn=624b0e74_7

See Section 210.4.6, Audible and Vibratory Treatment (beginning on page 428 of the PDF) and Section 211.4.4, Audible and Vibratory Treatment (beginning on page 480 of the PDF).

Audible and Vibratory Treatments for Arterials and Collectors, Roadway Design Bulletin 22-05, October 11, 2022.

<https://fdotwww.blob.core.windows.net/sitefinity/docs/default-source/roadway/fdm/review/2023-avt-draft-bulletin-chief-brief.pdf?>

From the bulletin: This Bulletin introduces revisions to the FDOT Design Manual (FDM) and FDOT Standard Plans for Road and Bridge Construction (Standard Plans) to streamline and improve the Department’s criteria and construction details for Audible and Vibratory Treatments (AVTs) on arterials and collectors.

“Effect of Rumble Strip Profiles on Noise Levels,” Guangming Wang and Edward Offei, *Journal of Transportation Engineering, Part B: Pavements*, Vol. 146, Issue 2, 2020.

Citation at <https://ascelibrary.org/doi/10.1061/JPEODX.0000166>

From the abstract: In this study, the effect of different shoulder rumble strip profiles, including cylindrical, sinusoidal and raised audible rumble strips, on the tire–pavement interface noise, internal noise (inside the vehicle) and wayside noise were evaluated. The results show that the tire–pavement interface noise level based on the Florida Department of Transportation (FDOT) onboard sound intensity (OBSI) noise trailer, the internal noise in the cab and wayside noise increase with the depth of rumble strips for all cylindrical rumble strips. Both sinusoidal rumble strips and raised audible rumble strips made a noticeable increase in the internal noise in the cab but little discernible increase on external noise in terms of OBSI noise measurements and wayside noise measurements. Using 5 and 10 dB(A) as the lower and upper bounds of effective noise increase levels, results of this study also indicate that (1) cylindrical rumble strips deeper than 6.4 mm (0.25 in.) may produce excessive noise to the surrounding environment; and (2) both raised audible strips and sinusoidal rumble strips may best strike a balance between roadway safety and community noise concerns.

“Audible and Vibratory Treatment: Arterials and Collectors,” Gevin McDaniel and Ed Cashman, Florida Department of Transportation, 2018.

<https://www.fdot.gov/docs/default-source/roadway/Training/Webinar18/1-1.pdf>

Topics addressed in this webinar are:

- Standard plans process.
- Terminology.
- Overview of results from the developmental phase.
- Roadway Design Bulletin 18-03 (*Note:* See Roadway Design Bulletin 22-05, cited above, for an update to this guidance.)
 - Standard plans.
 - FDOT Design Manual.
 - Basis of estimates (pay items).
- Typical scenario renderings.
- Project-specific examples.

Nonusers of Profiled or Raised Edge Line Audible Striping

Thirteen of the 17 responding state DOTs reported limited or no experience with a profiled or raised edge line audible pavement marking system:

- Alabama
- Connecticut
- Kansas
- Michigan
- Mississippi*
- Nebraska
- Nevada
- New Hampshire
- Pennsylvania
- Rhode Island
- South Dakota
- Utah
- West Virginia

* See **Limited Use** on page 24.

Reasons for Nonuse

Responding agencies reported a range of reasons for choosing not to use profiled or raised edge line audible striping, mainly relating to the impacts of snowplowing. Other factors include lack of equipment, lack of familiarity with the product and effective programs that employ other types of rumble strips. The Alabama and Nevada DOT respondents noted that future use depends on study results or an independent agency evaluation.

Table 2 summarizes survey responses.

Table 2. Reasons for Nonuse of Profiled or Raised Edge Line Audible Striping

Reason for Nonuse	State	Additional Comments
Lack of Equipment	Kansas, Michigan	<i>Kansas.</i> No equipment available in the region to test these products. <i>Michigan.</i> Agency contractors do not currently possess the necessary equipment.
Lack of Familiarity with Product or Technology	New Hampshire, West Virginia	None provided.
Other Rumble Strips	Michigan, Pennsylvania	<i>Michigan.</i> The agency already has an extensive network of rumble strips in place. <i>Pennsylvania.</i> The agency has had “[s]uccess with recessed rumble strips.”
Pending Evaluation of Use	Alabama, Nevada	<i>Alabama.</i> The agency is waiting for study results to determine the benefits of profiled edge line installations compared to current edge line striping systems that place a ground-in rumble strip beside the edge line stripe. <i>Nevada.</i> The agency has not yet evaluated the use of profiled pavement marking systems.

Reason for Nonuse	State	Additional Comments
Snowplowing Impacts	Connecticut, Michigan, Nebraska, Nevada, New Hampshire, Rhode Island, South Dakota, Utah	<p><i>Connecticut.</i> Currently, the agency recesses its pavement markings to protect retroreflective elements. The respondent questioned the longevity of profiled markings in snow states.</p> <p><i>Michigan.</i> The agency “[t]ends to avoid raised markings due to snowplowing in the winter months.”</p> <p><i>Nevada.</i> Operation and maintenance of profiled markings in northern Nevada is incompatible with snow removal operations.</p> <p><i>New Hampshire.</i> The DOT tends to bypass marking elements with any vertical profile due to snow removal concerns.</p> <p><i>Rhode Island.</i> The agency employs aggressive plowing practices in which the plow blade sits on the pavement. Recessed rumble strips are used in appropriate locations.</p> <p><i>Utah.</i> The respondent noted that snowplowing “tears up anything not flush with [the] pavement.”</p>

Limited Use

Mississippi DOT makes limited use of profiled or raised edge line audible striping. The agency recommends these marking systems as an alternative treatment on specific roadways that lack adequate shoulder width to place a rumble stripe, which is prescribed on all routes. The agency has considered specifying audible striping along centerlines in lieu of ground-in rumble strips given this area’s susceptibility to raveling failure.

Potential for Future Use

Nine responding transportation agencies reported a range of factors that would contribute to future use of this pavement marking system, most frequently citing a product evaluation and demonstrated long-term performance in winter climates.

Four state DOTs are unlikely to adopt this pavement marking treatment:

- *Michigan.* The state does not typically place extruded thermoplastic longline striping and has ceased working with methyl methacrylate.
- *Nebraska.* The respondent noted that “as long as we plow snow, we won’t use this type of pavement marking.”
- *Nevada.* The agency is unlikely to adopt profiled or raised edge line audible stripe pavement marking systems in the state anywhere other than southern Nevada. Such use would be contingent on an assessment of the pavement marking system.
- *South Dakota.* The agency is unlikely to permit use of profiled or raised edge line audible striping. Ground-in edge line rumble strips are installed on most state highways that work well and improve safety.

Table 3 summarizes survey responses.

Table 3. Factors Contributing to Future Use of Profiled or Raised Edge Line Audible Striping

Factor	State	Description
Product Evaluation	Alabama, Connecticut, Nevada, Rhode Island, West Virginia	<p><i>Alabama.</i> Require results of other states’ evaluations that indicate a higher safety improvement as compared to ground-in rumble strips.</p> <p><i>Connecticut.</i> Desire a study of the countermeasure’s useful life and impacts of maintenance operations.</p> <p><i>Nevada.</i> Require a positive benefit-cost ratio, verified safety improvement data (i.e., proven safety countermeasure), construction compatibility with existing equipment, and a general agency desire to establish standards that are geographically applicable.</p> <p><i>Rhode Island.</i> Need cost information and studies showing effectiveness compared to rumble strips.</p> <p><i>West Virginia.</i> Require more information on the treatment, include the results of testing or studies on cost, durability and effectiveness.</p>
Long-Term Performance in Winter Climates	Michigan, New Hampshire, Rhode Island, Utah	<p><i>Michigan.</i> Require proof of durability against harsh plowing.</p> <p><i>New Hampshire.</i> Need evidence of long-term performance in a snow environment.</p> <p><i>Rhode Island.</i> Desire indications that the pavement marking system can withstand plowing and has a “long life-cycle in Northeast states.”</p> <p><i>Utah.</i> May not work in areas of the state where it snows.</p>
Availability	Kansas	None provided.
Ease of Application	Michigan	None provided.

Related Research and Resources

Results of a literature search of in-progress and published research are presented below in the following categories:

- National research and guidance.
- State research and guidance.

Additional state-specific resources are included in the case studies beginning on page 13 that highlight use of profiled or raised edge line audible striping in five states: Arizona, Florida, Georgia, Oregon and South Carolina.

National Research and Guidance

Rural Roadway Departure Countermeasure Pocket Guide, Federal Highway Administration, September 2021.

<https://safety.fhwa.dot.gov/FoRRRwD/RwDPocketGuide.pdf>

This quick reference guide suggests countermeasures for reducing roadway departure crashes. The document includes edge line markings and notes that thermoplastic material has a longer life than paint, thus reducing maintenance, and raised pavement markers increase nighttime visibility.

Safety Evaluation of Profiled Thermoplastic Pavement Markings, Craig Lyon, Bhagwant Persaud and Kimberly Eccles, Federal Highway Administration, March 2018.

<https://www.fhwa.dot.gov/publications/research/safety/17075/17075.pdf>

FHWA's Development of Crash Modification Factors (CMF) program, which provides benefit-to-cost ratios for safety treatments, evaluated the effect of profiled (raised or inverted) thermoplastic pavement markings on different crash types. A literature review found no published research evaluating the effects of installing profiled thermoplastic pavement markings on crashes.

In this study, an examination of road geometry and crash and traffic data from two-lane and multilane roads in Florida and South Carolina found only nighttime wet road crashes experienced a material change. An estimated CMF of 0.908 "was based on a small sample of crashes and was not statistically significant at the 95-percent confidence level," however "it was consistent between the two states, which suggests that its use might be justifiable." Combining the CMF with an economic analysis using conservative assumptions on cost, service life and the value of a statistical life, the benefit-to-cost ratio with U.S. DOT sensitivity analysis applied ranged from 2.01:1 to 5.04:1, suggesting that the treatment "can be applied cost-effectively despite the relatively low crash effects."

Related Resources:

Safety Evaluation of Profiled Thermoplastic Pavement Markings, TechBrief, Federal Highway Administration, December 2017.

<https://www.fhwa.dot.gov/publications/research/safety/17076/17076.pdf>

This brief summarizes the 2018 study described above.

CMF/CRF Details: Install Profiled Thermoplastic Pavement Markings, Crash Modification Factors Clearinghouse, Federal Highway Administration, October 27, 2018.

<https://cmfclearinghouse.fhwa.dot.gov/detail.php?facid=9798>

This Crash Modification Factors Clearinghouse link for profiled thermoplastic pavement markings was added after the 2018 study described above. *From the description:*

Profiled thermoplastic pavement markings consist of thermoplastic material with raised thermoplastic bumps creating a raised profile marking. These markings are designed to provide an improved level of vision to drivers, particularly during wet-road surface conditions. The profiled nature also provides a rumble effect for errant vehicles.

NCHRP Synthesis 515: Practices for Preventing Roadway Departures, Hugh W. McGee, Sr., 2018. Publication available at <https://nap.nationalacademies.org/catalog/25165/practices-for-preventing-roadway-departures>

This synthesis summarizes state practices for preventing roadway departure crashes and identifies advantages and disadvantages of these practices. The report notes that there had not been any published research evaluating the effect of profiled pavement markings on crashes until FHWA's 2018 study was completed (see the citation above) and provides responses from a survey of state DOTs.

From page 24 of the report, page 31 of the PDF:

Raised (Profiled) Pavement Marking (Question 14)

Description

A raised (also known as profiled) thermoplastic pavement marking is a less costly but less effective treatment to produce the same result from that of a centerline or edge-line rumble strip. As illustrated by Figure 13, it is a pavement marking line composed of a thicker-than-usual thermoplastic with ridges added at a prescribed spacing. This design and material increase its visibility and produce a vibration, albeit less than that of a rumble strip, to alert motorists. It is not used in states where there is snow because it is easily damaged by snowplowing operations.

....

Literature Findings

While this device has been used by some states for many years, there had not been any published research evaluating its effect on crashes until an FHWA-sponsored study was completed. The study used data from two-lane and multilane roads in two states — Florida and South Carolina — to examine the effects for specific crash types, including total, fatal plus injury, run-off-road, head-on, sideswipe-opposite-direction, sideswipe-same-direction, wet-road, nighttime and nighttime wet-road crashes. Only nighttime wet-road crashes, the principal target crash type, experienced a material change in yielding a CMF of 0.908, which was not unexpected since this was the primary target crash type. Although the estimated CMF was based on a small sample of crashes and was not statistically significant at the 95% confidence level, it was consistent between the two states, which suggests the use of this device may be justifiable.

State Practices

The responses for all 40 states that responded are shown in Table B14 in Appendix B, and Table 9 shows the tally for frequency of use.

Sixteen of the states reported that they used this device, and nearly 44 percent (seven states) of those said they did so often. While various reasons were given for not using this device, the most prominent response was maintenance concerns — specifically that they are scraped off by snowplows. However, in states where this is not an issue, the thicker thermoplastic material provides a longer service life than that of standard pavement markings.

Related Resource:

Appendices A through F, NCHRP Synthesis 515: Practices for Preventing Roadway Departures, Hugh W. McGee, Sr., 2018.

https://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_syn_515appendicesA-F.pdf

Table B14, States' Practices for Use of Raised Thermoplastic Markings, which begins on page 51 of the PDF, provides responses to a survey question regarding the use of raised pavement markings. Highlighted below are the agencies not using raised thermoplastic markings at the time of the 2018 synthesis and the reasons for nonuse:

- Not aware of method (*Idaho, Maryland*).
- Method not proven cost-effective (*Ohio*).
- Insufficient funding (*Colorado, Connecticut, New Hampshire, Virginia*).
- Maintenance concerns (*Arkansas, Colorado, Delaware, Kansas, Kentucky, Massachusetts, Michigan, Minnesota, Montana, Nebraska, New Hampshire, South Dakota, Virginia, Wisconsin, West Virginia*).
- Concerns with snowplows damaging or removing (*Maine, Utah, Wisconsin*).
- Not using and was testing at the time to replace bot dots but they didn't seem to be as effective as MRS [milled rumble strips] (*Hawaii*).
- Not using with no reasoning stated (*New York*).

State of the Practice for Shoulder and Center Line Rumble Strip Implementation on Non-Freeway Facilities, Scott Himes, Hugh McGee, Skye Levin and Yuying Zhou, Federal Highway Administration, March 2017.

<https://www.fhwa.dot.gov/publications/research/safety/17026/17026.pdf>

This study developed a rumble strip decision support guide for both center line and shoulder rumble strips. A literature review summarizes previous research related to rumble strip design, noise and vibration testing methods and findings, impacts on bicyclists and motorcyclists, pavement condition impacts, pavement marking visibility, and operational and safety effectiveness. Researchers also reviewed the current state of the practice, identified knowledge gaps and recommended future research. Profiled thermoplastic pavement markings were among the types of rumble strips reviewed. *From page 7 of the report (page 17 of the PDF):*

Although research suggests that milled rumble strips are the most effective application type, raised rumble strips (or rumble stripes) have been applied in [s]tates with warmer climates or where milled rumble strips cannot be installed. Raised rumble strips include side-by-side raised pavement markers, rumble bars or plastic inserts within thermoplastic pavement markings. Profiled thermoplastic pavement markings have been developed to help with nighttime wet pavement visibility and may have some very limited rumble characteristics. ... Locations without snowplowing activities may use profiled thermoplastic pavement markings or other raised rumble strips; however, milled rumble strips are preferred. Raised rumble strips may be considered in areas where milled rumble strips are not practical, such as bridge decks or on thin surface courses (e.g., chip seals).

Decision Support Guide for the Installation of Shoulder and Center Line Rumble Strips on Non-Freeways, Scott Himes and Hugh McGee, Office of Safety, Federal Highway Administration, August 2016.

<https://highways.dot.gov/sites/fhwa.dot.gov/files/2022-06/fhwasa16115.pdf>

From page 10 of the guide: The purpose of this guide is to inform agencies on center line and shoulder rumble strip installation. It describes methods for identifying appropriate locations for installation,

assessing the potential crash reductions and [benefit-cost] ratio, and developing performance metrics for safety. Additionally, this guide discusses special considerations for rumble strip installations, identifies variability in current practices, and provides a decision-support framework for installing rumble strip.

Low-Cost Treatments for Horizontal Curve Safety 2016, Richard Albin, Victoria Brinkly, Joseph Cheung, Frank Julian, Cathy Satterfield, William Stein, Eric Donnell, Hugh McGee, Ann Holzem, Matthew Albee, Jonathan Wood and Fred Hanscom, Office of Safety, Federal Highway Administration, January 2016.

https://highways.dot.gov/sites/fhwa.dot.gov/files/2022-06/fhwasa15084rev011720_508_FINAL.pdf

This publication updates a 2006 guide to provide guidance for local transportation agencies selecting safety countermeasures for lower volume two-lane roads. *From page 20 of the report, page 32 of the PDF:*

These markings are particularly beneficial under wet nighttime conditions, where the retroreflectivity of the normal, flat markings is obscured. Note that the *MUTCD [Manual on Uniform Traffic Control Devices]* recommends against use of RPMs [raised pavement markers] either as a substitute or supplement to the edge line. The rationale is that under wet night conditions when only the RPMs are visible, edge line RPMs can confuse drivers who could misinterpret them as marking the lane line.

Rumble Strip Implementation Guide: Addressing Noise Issues on Two-Lane Roads, Federal Highway Administration, April 2015.

https://safety.fhwa.dot.gov/roadway_dept/pavement/rumble_strips/media/RumbleStripGuide_Noise/noise_bpg.pdf

This guidance provides information about potential noise issues related to rumble strips and describes raised edge line rumble strips as an “alternative or experimental design.” These rumble strips “reduce external noise but do not provide the same level of internal noise and vibration as typical milled rumble strips.”

Related Resource:

Rumble Strip Implementation Fact Sheet: Noise, Federal Highway Administration, 2015.

https://highways.dot.gov/sites/fhwa.dot.gov/files/2022-06/noise_fs.pdf

This two-page fact sheet distills the 2015 guidance described above and covers noise facts, rumble strip placement issues and solutions, design considerations and suggestions for outreach to the general public. Among the recommendations for outreach:

- Inviting the public to comment, and addressing their questions and concerns directly.
- Emphasizing road use safety first and foremost.
- Seeking to understand the specific concerns of each community member and being willing to modify the design and placement of rumble strips on an as-needed basis.
- Educating the public on options.

State Research and Guidance

Publications from five states — Louisiana, Pennsylvania, Tennessee, Texas and Virginia — are highlighted below.

Louisiana

Pavement Markings Manual for Designers and Construction Services, Traffic Engineering Division, Louisiana Department of Transportation and Development, March 2022.

http://wwwsp.dotd.la.gov/Inside_LaDOTD/Divisions/Engineering/Traffic_Engineering/ManualsPublications/Documents1/Pavement%20Marking%20Manual.pdf

This manual describes the selection, design, maintenance and installation of pavement markings. Topic areas include the following:

- Referencing Specification (“Spec. Book”) Sections 732 and 1015 of the report address thermoplastic pavement markings in general.
- Raised, or profiled, thermoplastic markings are discussed in Specialty Pavement Markings (page 12 of the manual) and require special approval.

From page 12 of the manual:

*The following materials are for experimental use only. Traffic Engineering Division Administrator must approve use and location. Approved project locations may serve as a test location for evaluation and study.

***AUDIBLE THERMOPLASTIC MARKINGS**

Description: Flat line thermoplastic that has evenly spaced out raised bumps (inverted profiled) that produces an audible noise and positive feedback to the driver when driven over by the vehicle.

Uses: Currently under study. To be used for asphalt pavement that is too old or narrow for ground-in rumble strips or for concrete pavement without cast-in rumbles [i.e., bridge decks].

Pros: Able to provide wet reflectance during heavy rains as the audible bump is above the water runoff.

Cons: Higher cost than typical thermoplastic markings and ground-in rumble strips. Requires more maintenance than ground-in rumble strips.

***PROFILED THERMOPLASTIC MARKINGS**

Description: Profiled pavement markings are thermoplastic that is an inverted profile to produce a slight humming sound and a little positive feedback to the driver. This alerts the driver that the vehicle is encroaching over the centerline or edge line. Typically, these markings use a higher refractive index glass bead or wet reflective bead.

Uses: A substitute for edge and centerlines (lane lines) in areas where visibility may be hindered from water runoff and/or fog.

Pros: Provides better visibility in rain or fog than traditional flat line markings.

Cons: Higher cost than [typical] thermoplastic markings and ground-in rumble strips.

Pennsylvania

Edge-Line Pavement Markings on Two-Lane, Two-Way Local Roads, Technical information Sheet #201, Pennsylvania Department of Transportation Local Technical Assistance Program, Fall 2020.

https://gis.penndot.gov/BPR_PDF_FILES/Documents/LTAP/TechSheets/TS_201_color.pdf

This technical information sheet examines requirements and applications of edge lines on two-lane roads. *From the publication:*

In special situations, the edge lines can be supplemented with raised pavement markers (RPMs) or edge-line rumble strips. These treatments are countermeasures for safety problems, and their use should be based on an engineering study. Both measures can be helpful to provide motorists with additional guidance around curves and to reduce run-off-the-road crashes, according to the Federal Highway Administration in its publication, *Low-Cost Treatments for Horizontal Curve Safety* (FHWA-SA-07-002, 2006).

Tennessee

Special Provision Regarding Profiled Thermoplastic Pavement Marking Audible System, State of Tennessee, February 13, 2023.

<https://www.tn.gov/content/dam/tn/tdot/construction/special-provisions/Const-716PTA.pdf>

This Special Provision provides guidance for the placement of a raised or inverted profiled thermoplastic pavement marking audible system.

Texas

Evaluation of Audible Lane Departure Warning Treatments for Seal Coat Road Surfaces, Adam M. Pike, Bryan T. Wilson, Eun Sug Park, Srinivas R. Geedipally and Lingtao Wu, Texas Department of Transportation, February 2019.

<https://static.tti.tamu.edu/tti.tamu.edu/documents/0-6888-R1.pdf>

From the abstract: In an effort to reduce the number of single vehicle run-off-road and two-lane two-way crossover crashes, TxDOT [Texas DOT] has implemented various audible lane departure warning systems on seal coat road surfaces. This 20-month research project explored the effectiveness of these various treatments using several performance metrics and provided recommendations on implementation of these types of treatments. The researchers conducted performance evaluations at 24 unique field sites that had 51 treatments and at a test deck that had 12 different variations of audible markings. The field sites consisted of varying designs and spacing of audible markings, rumble bars, and milled rumble strips. A crash study was conducted that considered 77 treatment sites and appropriate comparison sites.

From the overview: The researchers evaluated the following aspects of audible lane departure warning treatments to meet the project goals:

- What are the safety benefits?
- What is the delivered performance (noise, vibration, visibility)?
- What are the costs?
- What is(are) the best design(s)?
- When and where should audible lane departure warning treatments be implemented?
- What level of performance remains after the treatments are seal coated over?

Related Resource:

Project Summary 0-6888: Audible Lane Departure Warning Treatments for Seal Coat Road Surfaces, Texas Department of Transportation, 2019.

<https://static.tti.tamu.edu/tti.tamu.edu/documents/0-6888-PSR.pdf>

From the project summary:

What This Means

Audible markings and rumble bars are viable alternative lane departure warning treatments from a noise and vibration performance standpoint, from a crash reduction standpoint, and from a benefit-cost ratio (at least 11:1) standpoint. These treatments should be considered when traffic volumes, speeds and crash history indicate a need for increased attention to reduce single-vehicle run-off-the-road and two-lane two-way crossover crashes.

The research team recommends requiring retroreflectivity performance on profiled pavement markings. To increase consistency in performance, the research team recommends TxDOT consider including noise performance levels in the specifications. A minimum of a 6-dBA change in the interior noise should be required for audible lane departure warning treatments. The report provides recommendations for updating the specifications and plans for profile pavement markings and rumble bars.

“Safety Evaluation of Alternative Audible Lane Departure Warning Treatments in Reducing Traffic Crashes: An Empirical Bayes Observational Before–After Study,” Lingtao Wu, Srinivas Reddy Geedipally and Adam M. Pike, *Transportation Research Record 2672*, Issue 21, pages 30-40, 2018.

Citation at <http://dx.doi.org/10.1177/0361198118776481>

From the abstract: The main purpose of this paper is to examine the safety effect of installing profile pavement markings and preformed rumble bars. Specifically, this study developed crash modification factors for these treatments that quantify the effectiveness in reducing single-vehicle-run-off-road (SVROR) and opposite-direction (OD) crashes. Traffic, roadway and crash data at the treated sites on 189 miles of rural two-lane highways in Texas were analyzed using an empirical Bayes (EB) before–after analysis method. Safety performance functions from the *Highway Safety Manual* and Texas Highway Safety Design Workbook were used in the EB analysis. The results revealed a 21.3 [percent] reduction in all SVROR and OD crashes, and 32.5 [percent] to 39.9 [percent] reduction in fatal and injury SVROR and OD crashes after installing profile pavement marking and preformed rumble bars.

Virginia

Guidance for and Effectiveness of Low-Cost Delineation Treatments, Alejandra Medina Flintsch, Ronald Gibbons, Yingfeng (Eric) Li, Brian Williams, Andrew Kassing and Bradley Myers, Virginia Department of Transportation and Federal Highway Administration, November 2022.

<https://vtrc.virginia.gov/media/vtrc/vtrc-pdf/vtrc-pdf/23-R8.pdf>

From the purpose and scope:

To facilitate countermeasure selection and maximize the benefits of limited resources, it is important to develop guidelines for countermeasure selection that consider all of the above factors [roadway classification, traffic, environment, roadway geometry, horizontal and vertical curvature, number of lanes, speed limit, the presence of other countermeasures, installation and maintenance practices, crash type, cost, maintenance and visibility]. The specific objectives of this research project were to:

1. Evaluate the likely safety effects of different low-cost delineation and marking strategies with regard to preventing RDCs [roadway departure crashes]; and

2. Determine the life cycle costs of different effective countermeasures identified under the first objective.

The original scope of this project focused on edge lines with different widths and materials, post-mounted delineators (PMDs) with different materials and spacings, and raised pavement markers (RPMs). During the project, however, additional delineation treatments were included based on input from both the Virginia Department of Transportation (VDOT) project technical review panel (TRP) and VDOT district officials. The types of treatments included in each task of this project are described in more detail in the Methods section.

Beginning on page 69 of the report (page 76 of the PDF), the authors examine the costs and service lives of RPMs based on a literature review.

Contacts

CTC engaged with the people below to gather information for this investigation.

State Agencies

Alabama

Jason Daniels
State Traffic Engineer, Maintenance Bureau
Alabama Department of Transportation
334-242-6275, danielsja@dot.state.al.us

Arizona

Kerry Wilcoxon
State Traffic Engineer
Arizona Department of Transportation
602-712-2060, kwilcoxon@azdot.gov

Connecticut

Matthew Blume
Transportation Division Chief, Traffic Engineering
Connecticut Department of Transportation
860-594-2248, matthew.blume@ct.gov

Georgia

Sam Harris
Assistant State Traffic Engineer
Georgia Department of Transportation
404-858-1933, sharris@dot.ga.gov

Kansas

Robert Allen Fuller
Chief, Bureau of Maintenance
Kansas Department of Transportation
785-296-7130, robert.fuller@ks.gov

Michigan

Mary Bramble
Pavement Marking and Delineation Engineer
Michigan Department of Transportation
517-582-0211, bramblem1@michigan.gov

Mississippi

Heath Patterson
State Maintenance Engineer
Mississippi Department of Transportation
601-359-7113, hpatterson@mdot.ms.gov

Nebraska

Matt Neemann
Traffic Engineer, Traffic Engineering Division
Nebraska Department of Transportation
402-479-4594, matt.neemann@nebraska.gov

Nevada

Frederick Tydeman
Principal Engineer, Signs, Striping and Traffic
Control
Nevada Department of Transportation
775-888-7556, ftydeman@dot.nv.gov

New Hampshire

Bill Lambert
State Safety Engineer, Highway Design
New Hampshire Department of Transportation
603-271-2604, william.r.lambert@dot.nh.gov

Oregon

Rebecca Burrow
Maintenance and Operations Branch
Oregon Department of Transportation
503-951-9333, rebecca.burrow@odot.oregon.gov

Pennsylvania

Douglas Tomlinson
Chief, Highway Safety and Traffic Operations
Pennsylvania Department of Transportation
717-787-3657, dtomlinson@pa.gov

Rhode Island

Sean Raymond
Managing Engineer
Rhode Island Department of Transportation
401-563-4204, sean.raymond@dot.ri.gov

South Carolina

Duncan Smith
State Traffic Safety Engineer
South Carolina Department of Transportation
803-737-1418, smithd@scdot.org

South Dakota

Christina Bennett
Construction and Maintenance Engineer
South Dakota Department of Transportation
605-280-9665, christina.bennett@state.sd.us

Utah

Ryan Ferrin
Statewide Maintenance Engineer
Utah Department of Transportation
801-910-2562, rferrin@utah.gov

West Virginia

Ted Whitmore
Director, Traffic Engineering
West Virginia Department of Transportation
304-414-7373, ted.j.whitmore@wv.gov

Appendix A: Survey Questions

An online survey was distributed to state transportation agency members of the American Association of State Highway and Transportation Officials (AASHTO) Committee on Maintenance.

Caltrans Survey on the Use of Edge Line Audible Stripe Pavement Marking Systems

An edge line audible stripe is a pavement marking system with raised segments that provide an audible and vibratory response to motorists when they drive over them. This type of marking system may be referred to as a *profiled* or *raised pavement marking*, and is distinguished from ground-in rumble strips and stripes. Profiled or raised pavement markings that provide an audible and vibratory response may be used to enhance drivers' vision when roadways are wet, particularly at night.

Caltrans is assessing the effectiveness of this edge line pavement marking system as a roadway departure countermeasure to add to agency guidance and standards. Before doing so, Caltrans is gathering information from other state transportation agencies with experience using this type of edge line audible striping system.

The survey below inquires about your agency's experience with profiled or raised edge line audible pavement markings. We estimate the survey will take 15 to 20 minutes to complete. We would appreciate receiving your responses by **Friday, September 6**.

The final report for this project, which will include a summary of the responses received from all survey participants, will be available on the [Caltrans website](#).

If you have questions about completing the survey, please contact Dan Kleinmaier at dan.kleinmaier@ctcandassociates.com. If you have questions about Caltrans' interest in this issue, please contact Tori Kanzler at tori.kanzler@dot.ca.gov.

Thanks very much for your participation.

(Required) Please provide your contact information.

Name:

Agency:

Title/Division:

Email Address:

Phone Number:

Note: Responses to the question below determined how respondents were directed through the survey.

(Required) Does your agency currently use a profiled or raised edge line audible stripe pavement marking system?

- Yes (Skipped the respondent to **Current Users of Profiled or Raised Edge Line Audible Striping and Wrap-Up.**)

- No, but we previously used edge line audible striping. (Skipped the respondent to **Previous Users of Profiled or Raised Edge Line Audible Striping and Wrap-Up.**)
- No, we have never used this type of pavement marking system. (Skipped the respondent to **No Experience with Profiled or Raised Edge Line Audible Striping and Wrap-Up.**)

Current Users of Profiled or Raised Edge Line Audible Striping

Material Description

Please describe the profiled or raised edge line audible striping pavement marking system(s) your agency uses.

Material(s):

Vendor(s):

Retroreflectivity:

Cost:

Frequency of use:

- Very frequently
- Frequently
- Occasionally
- Rarely
- Very rarely

Installation and Maintenance

1. Please indicate any shoulder width requirements for the installation of this type of edge line audible striping.
2. Does your agency consider speed, roadway type or any other factors when deciding to install profiled or raised edge line audible striping?
 - No
 - Yes (Please describe how these factors impact installation decisions.)
3. Has your agency received public complaints about noise generated by the pavement marking system?
 - No
 - Yes
4. Has your agency implemented any changes to the material or installation practices to reduce public noise impacts?
 - Not applicable
 - No
 - Yes (Please describe these changes and their impact.)
5. How does the retroreflectivity of profiled or raised edge line audible striping systems fare over time as compared to enhanced wet-night thermoplastic striping systems?
6. Please describe the long-term maintenance required for profiled or raised edge line audible striping systems.
 - Type of maintenance:
 - Frequency of maintenance:
 - Other (Please describe other aspects of long-term maintenance.)

7. Who is responsible for maintaining your agency's profiled or raised edge line audible striping systems? Please select all that apply.
 - In-house maintenance crews
 - Contracted vendors
 - Other (Please describe the other parties responsible for maintaining your agency's profiled or raised edge line audible striping systems.)
8. Has your agency developed a standard plan, specification or special provision for the profiled or raised edge line audible striping system?
 - No
 - Yes (Please provide a link to the standard plan, specification or special provision. Send any files not available online to dan.kleinmaier@ctcandassociates.com.)

Comparison with Ground-In Rumble Strips and Stripes

1. Generally, when is a profiled or raised edge line audible striping system preferred over a ground-in rumble strip or stripe?
2. Has your agency experienced water ponding or settling in ground-in rumble strips and stripes?
 - No
 - Yes (Please describe the frequency of this issue and how it has impacted the integrity of the shoulder structure.)
3. How does the long-term maintenance for profiled or raised edge line audible striping systems compare with ground-in rumble strips and stripes?
4. How does the estimated service life of profiled or raised edge line audible striping installations compare with ground-in rumble strips and stripes?
5. Please describe the effectiveness of profiled or raised edge line audible striping systems in preventing roadway departure incidents as compared with ground-in rumble strips and stripes.

Assessment

1. Please describe the safety outcomes of your agency's use of profiled or raised edge line audible striping, including its use as a roadway departure countermeasure.
2. What are the most significant challenges your agency has encountered when using this pavement marking system?
3. Please identify your agency's top three recommendations for another agency preparing to use profiled or raised edge line audible striping as a standard countermeasure for roadway departure.
 - Recommendation 1:
 - Recommendation 2:
 - Recommendation 3:
4. Has your agency conducted or been associated with research on profiled or raised edge line audible striping?
 - No
 - Yes (Please describe this research and provide links to publications associated with it. Send any files not available online to dan.kleinmaier@ctcandassociates.com.)

Previous Users of Profiled or Raised Edge Line Audible Striping

1. Please describe your agency's previous use of profiled or raised edge line audible striping.
2. Why does your agency no longer use this pavement marking system?

3. Do you anticipate your agency will begin using profiled or raised edge line audible striping at some future date?
 - No
 - Yes (Please describe how and when you may use this pavement marking system.)
4. What recommendations do you have for an agency considering the use of profiled or raised edge line audible striping?
 - Recommendation 1:
 - Recommendation 2:
 - Recommendation 3:

No Experience with Profiled or Raised Edge Line Audible Striping

1. Why has your agency elected not to use profiled or raised edge line audible striping?
2. What might change your assessment of this type of pavement marking system and permit its use?

Wrap-Up

Please use this space to provide any comments or additional information about your previous responses.