Rumble Strips Installation on Thin Pavement Overlays

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16. Abstract

The purpose of this project was to establish a synthesis of best practices from various state and other transportation agency stakeholders regarding the installation and re-installation of rumble strips on pavements treated with a thin pavement overlay. This was completed based on a review of existing literature and a state transportation agency outreach effort. The best practices are intended to provide a standardized, cost-effective process for the Pennsylvania Department of Transportation to effectively utilize rumble strips in conjunction with thin pavement overlays. These include three rumble strip types (centerline, edge line, and shoulder), two standard rumble strip depths (3/8-inch and ½-inch), and three thin overlay types (hot-mix asphalt, microsurfacing, and seal coat).

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INTRODUCTION

Rumble strips are milled, rolled, formed, or raised patterns in the pavement surface that produce auditory and tactile vibration to inattentive or drowsy drivers when departing the traveled way. The most common applications of rumble strips are on highway shoulders or edge lines (referred to as shoulder or edge line rumble strips) or on the centerline of undivided highways (referred to as centerline rumble strips). Research has shown that shoulder rumble strips are an effective safety countermeasure on urban and rural freeways, rural two-lane highways, and rural multi-lane divided highways. Similarly, centerline rumble strips have been shown to improve safety on urban and rural two-lane highways (Torbic et al., 2009). In 1995, the Pennsylvania Department of Transportation (PennDOT) began using shoulder rumble strips on multi-lane highways in the Commonwealth, and has since installed thousands of miles of shoulder and edge line rumble strips throughout the state on a variety of roadway types. Figure 1 shows that the number of run-off-road fatalities in Pennsylvania has decreased as the mileage of edge line rumble strips has increased. Additionally, more than 4,600 miles of centerline rumble strips have been installed on undivided highways in Pennsylvania since 2001. Figure 2 shows that the number of head-on fatalities in Pennsylvania on undivided highways has decreased as the mileage of centerline rumble strips has increased.

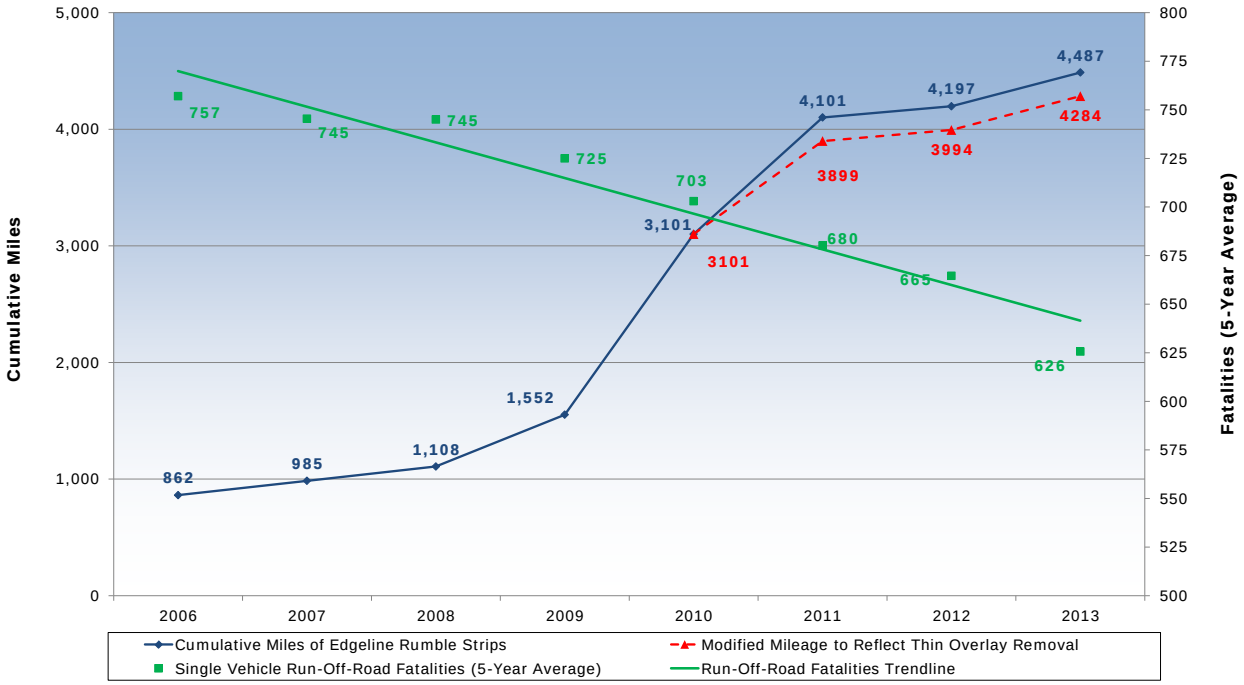

Figure 1. Edge Line Rumble Strip Mileage versus Run-off-Road Fatalities.

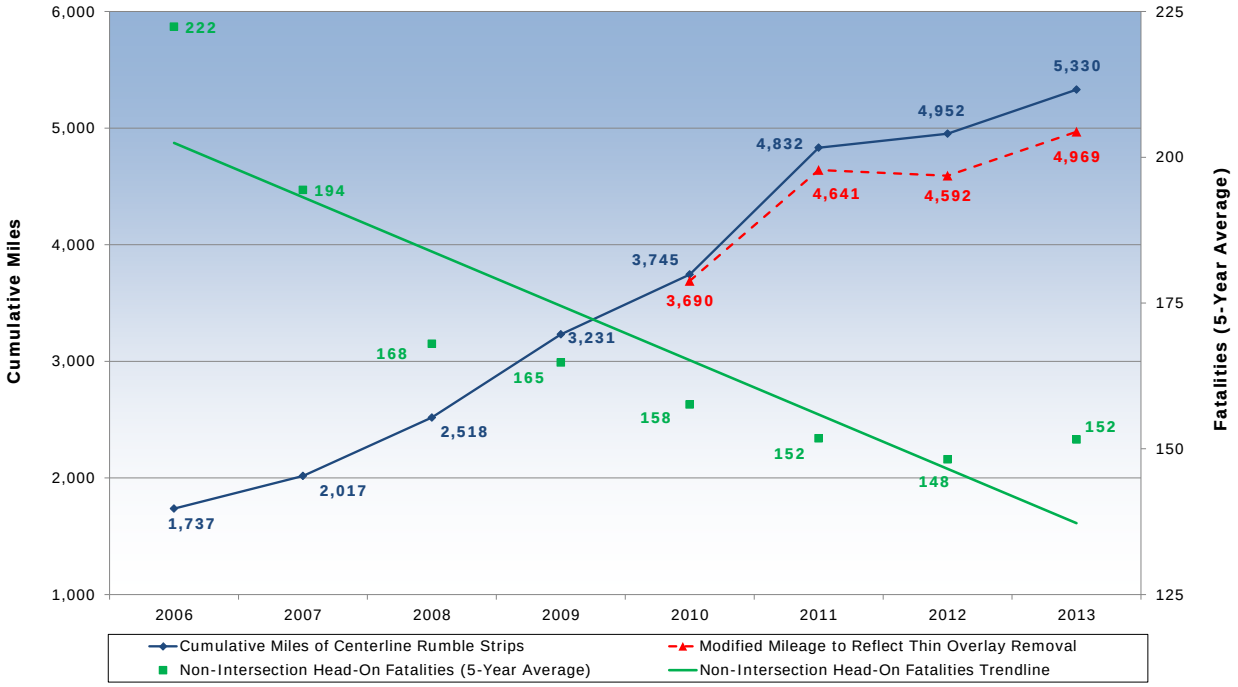

Figure 2. Centerline Rumble Strip Mileage versus Head-on Fatalities in Pennsylvania.

The milled pattern is used in Pennsylvania to construct rumble strips in accordance with *Publication 408: Highway Construction Specifications* (PennDOT, 2011). The dimensions for shoulder rumble strips are as follows:

- 16-inches long, 5-inches wide, and 3/8-inch deep, with 12-inch center-to-center spacing on undivided non-Interstate and non-expressway roads with posted speed limits of 55 miles per hour (mph) or greater (referred to as bicycle-tolerable pattern);
- 16-inches long, 5-inches wide, and 3/8-inch deep, with 11-inch center-to-center spacing on undivided non-Interstate and non-expressway roads with posted speed limits less than 55 mph (referred to as bicycle-tolerable pattern);

The dimensions for centerline rumble strips used in Pennsylvania are 14- to 18-inches long, 7-inches wide, and ½-inch deep, with 2- or 4-foot center-to-center spacing, depending on the lane width and paved shoulder width. Edge line rumble strips are 6-inches long, 5-inches wide, and 3/8-inch deep, with 12-inch center-to-center spacing.

Many Pennsylvania roadways that contain rumble strips have either been resurfaced with a thin pavement overlay, or are planned for a thin pavement overlay. Similarly, new rumble strips may be planned for application on roadways that already have a thin pavement overlay. PennDOT uses hot-mix asphalt, seal coat, and microsurfacing treatments for thin overlays. A study by Amjadi et al. (2014) found that thin hot-mix asphalt overlays (without rumble strips) are expected to reduce wet road crashes on multilane highways, but may increase wet and dry road crashes on two-lane highways. This same study found that a chip seal thin pavement overlay may reduce wet road crashes on multilane highways, but may increase dry road crashes on these

same roadway types. Microsurfacing treatments were found to reduce wet road crashes on two-lane and multilane highways, but may increase dry road crashes on two-lane highways. The installation or re-installation of rumble strips will either provide further safety benefits, or help mitigate the safety disbenefits, of thin pavement overlays. In order to maintain the level of noise and vibration produced by the rumble strip patterns in Pennsylvania, and to ensure that rumble strips produce the expected safety benefits on thin pavement overlays, PennDOT seeks information about how transportation agencies prepare the roadway surface prior to the application of the overlay. Additionally, information about how agencies treat the rumble strip pattern after a thin pavement overlay is also sought by PennDOT.

Project Objectives

The purpose of this project was to establish a synthesis of best practices from various state and other transportation agency stakeholders regarding the installation and re-installation of rumble strips on pavements treated with a thin pavement overlay. The best practices will provide a standardized, cost-effective process for PennDOT to effectively utilize rumble strips in conjunction with thin pavement overlays. These include three rumble strip types (centerline, edge line, and shoulder), two standard rumble strip depths (3/8-inch and ½-inch), and three thin overlay types (hot-mix asphalt, microsurfacing, and seal coat).

Organization of Report

This report is organized into two subsequent sections. The first is a brief description of the methodology used to collect the information employed to develop guidance concerning the installation or re-installation of rumble strips on roadways treated with a thin pavement overlay. The second section presents the narrative guidance that was developed from the information gathering process, as well as design-decision tables that were created based on the narrative guidance.

DATA COLLECTION METHODOLOGY

The data collected and subsequently used to develop the design guidance in this report were from a literature review and state transportation agency survey. The literature review was undertaken to identify and synthesize the range of practices associated with installing and re-installing rumble strips on thin pavement overlays with or without existing rumble strips. Appendix A is a summary of the extant literature related to the installation or reinstallation of rumble strips on thin pavement overlays.

The state transportation agency (STA) survey was distributed to all 50 agencies in the United States. The survey instrument is shown in Appendix B while each STA response is shown in tabular form in Appendix C. A modified version of the STA survey was distributed to each PennDOT engineering district. In many instances, follow-up telephone calls were made to clarify agency responses to survey questions. A narrative summary of the survey results is provided in Appendix D of this report.

Appendix E of this report includes a tabular summary of rumble strip construction data (i.e., dimensions and placement) as well as a brief summary of the guidance offered by STAs in relation to treatment rumble strip grooves that are on roadways planned for thin pavement overlays. The information included in Appendices A through E of this report was used collectively to develop the design guidance included in the following section. The field performance of rumble strips on thin pavement overlays reported by Boisvert (2010) in New Hampshire provided the primary objective data used to develop the guidance.

DESIGN GUIDANCE

This section of the report includes background information concerning PennDOT's current guidelines for installing rumble strips on structural pavements. These guidelines should continue to be followed when implementing rumble strips on pavements that are not planned for, or have not been treated with, a thin pavement overlay.

This section of the report contains guidance for the re-installation of rumble strips, as well as installation of new rumble strips, on thin pavement overlays. The guidance that is proposed for the installation or re-installation of rumble strips on thin pavement overlays is based principally on the literature review summary found in Appendix A of this report, and state transportation agency outreach findings, which are synthesized in Appendix C. This section of the report concludes with recommendations for monitoring the performance of rumble strips that were installed or re-installed at locations with thin pavement overlays.

Rumble Strips on Structural Pavements

PennDOT's *District Highway Safety Guidance Manual* (2014) recommends centerline rumble strips on two-lane roads with pavement widths of 20 feet or greater, or on multi-lane undivided roads. Candidate sections are also identified based on the following criteria:

- Average annual daily traffic (AADT) of 1,500 vehicles per day or greater.
- Highways with AADT less than 1,500 vehicles per day with three or more head-on or opposite-direction sideswipe crashes over a 15,000-foot section in the previous five years.
- New pavement less than 1 year old, having a minimum depth of 1.5 inches.

With regard to the pavement, a bituminous wearing course and bituminous concrete base course (BCBC) or better must be present. The District Pavement Engineer should confirm that the pavement condition is adequate to accept the rumble strip groove-milling process without raveling or deterioration. On pavements that are more than 3 years old, PennDOT recommends that a crack seal or seal coat be placed prior to milling the centerline rumble strip groove pattern on an existing pavement.

Candidate locations for shoulder and edge line rumble strips include rural highways with paved shoulders 4 feet or greater in width and five or more run-off-road crashes within a 3,000-foot length over a 5-year period. Application of shoulder and edge line rumble strips also requires a bituminous wearing course surface with a BCBC or better base course. Application of milled

shoulder rumble strips requires that the shoulder pavement surface be able to adequately accept the milled groove pattern without deterioration or raveling. Further, the paved shoulder should be the same smoothness as the roadway when considering application of shoulder rumble strips.

Once rumble strips are planned for an existing structural pavement, the construction standards found in PennDOT *Publication 72M, Roadway Construction Standard* (RC)-22M, "Rumble Strips," should be consulted.

Re-installing Rumble Strips on Thin Pavement Overlays

No guidance currently exists in Pennsylvania concerning the installation or re-installation of rumble strips on thin pavement overlays. In this guidance, a thin pavement overlay includes seal coat, hot-mix asphalt, or microsurfacing. Two rumble strip depths (1/2- or 3/8-inch) are considered. The guidance includes centerline, shoulder, and edge line rumble strips. When applying the guidance, it is important to consider the roadway type (divided or undivided) as well as the type and location of the existing or planned rumble strip pattern. As such, the guidance is organized by roadway and rumble strip type.

<u>On Highways with Edge Line or Shoulder Rumble Strips Only</u>

There are two possible thin pavement overlay scenarios in this case. First, the travel lanes may be the only section of the roadway that is programmed for an overlay. This overlay can be applied to the travel lane of the existing pavement after crack sealing or patching, or the thin pavement overlay can be applied after the travel lanes are milled. This overlay will not affect the shoulder rumble strips because PennDOT guidance stipulates that shoulder rumble strips be offset 6 to 18 inches from the edge line (see Appendix E). When applying a thin pavement overlay to only the travel lanes without milling, the overlay may be tapered between the edge line and shoulder rumble strip pattern to gradually transition the elevation difference between the thin pavement overlay and shoulder. If edge line rumble strips are present, a thin pavement overlay will affect the groove pattern. In this case, an overlay on the travel lanes will create an elevation difference between the travel lanes and shoulder. In this scenario, a scratch layer should be applied to fill and level the edge line rumble strip depressions, followed by a tack coat and thin hot-mix asphalt overlay, and then the rumble strip pattern should be re-milled into the pavement surface. In case the existing pavement is milled and then the thin overlay applied, the shoulder and thin overlay surface should have the same elevation.

In the second case, where the entire paved roadway (travel lanes and shoulders) is programmed for a thin pavement overlay, the following guidelines are recommended:

- For <u>hot-mix asphalt overlays</u>, mill the existing rumble strip pattern (20-inches wide and at least 1/2-inch deep for shoulder rumble strips, or 12-inches long and at least 1/2-inch deep for edge line rumble strips), or the entire roadway surface (if a complete mill and overlay project is planned due to poor pavement surface conditions), then inlay the milled area with a properly designed asphalt mix. The inlay material should be compacted in accordance with PennDOT *Publication 408: Highway Construction Specifications*. A tack coat should be applied to the milled surface to assist with sealing and bonding the

thin pavement overlay of hot-mix asphalt, which should be at least 7/8-inch thick. Once the hot-mix asphalt overlay is applied, re-mill the edge line or shoulder rumble strip pattern in accordance with the standard specifications for highway construction. The new rumble strip should be 3/8-inch deep if the overlay is between 7/8- and 1-inch thick. The rumble strip could be 3/8- or ½-inch deep if the overlay thickness exceeds 1 inch. The rumble strip's length, width, and center-to-center spacing should be installed in accordance with PennDOT Publication 72M, RC-22M, "Rumble Strips."

- For chip seal applications, up to one seal coat can be applied on existing rumble strips, and the milled rumble strip pattern may remain "as is." However, because the Department requires a rumble strip groove depth of either 3/8- or ½-inch, the groove depth should be checked in the field after applying a seal coat to ensure that adequate depth has been maintained. Rather than check the groove depth recommendation after completing an entire seal coat project, it is recommended that a 100-foot test location be checked first. If the minimum groove depth requirement cannot be maintained when applying the prescribed seal coat, the existing rumble strip pattern should be milled and inlayed using a dense-graded hot-mix asphalt, before applying the seal coat. The inlay material should be compacted in accordance with PennDOT *Publication 408: Highway Construction Specifications*. Once the seal coat is applied, the rumble strip pattern should be re-milled into the seal coat. If, after the first seal coat application, the rumble strip pattern remained "as is," the second seal coat application will likely fill the existing rumble strip grooves. As such, for a second seal coat application, the existing rumble strips should be milled and inlayed prior to applying the second seal coat. After applying the second coat overlay, the rumble strip grooves should be re-milled. The rumble strips should be installed in accordance with PennDOT Publication 72M, RC-22M, "Rumble Strips."
- For microsurfacing applications, if the existing rumble strip is deep enough, and the microsurfacing material leaves a minimum depth rumble strip groove of 3/8-inch after placement of the microsurfacing, then it is not necessary to mill the existing rumble strips. Evaluation of such could be included in a 100-foot test location if needed. If placement of the microsurfacing on existing rumble strips will not provide a minimum rumble strip groove depth of 3/8-inch, then one of two options should be followed: (1) either a scratch layer must be applied to fill the rumble depression before applying the microsurfacing material, or (2) the existing rumble strips must be milled in a manner consistent with the guidance provided above. In either case, tacking the surface of the scratch layer or the milled surface is necessary before application of the microsurfacing. The new rumble strip must be at least 3/8-inch deep. The rumble strip's length, width, and center-to-center spacing should be installed in accordance with PennDOT Publication 72M, RC-22M, "Rumble Strips." If the mill and inlay option is chosen, the inlay material should be compacted in accordance with PennDOT *Publication 408: Highway Construction Specifications*.

In cases where an existing rumble strip pattern is temporarily removed as a result of milling or a thin pavement overlay, the pattern should be re-installed as soon as possible as part of the ongoing project. Table 1 is a design-decision matrix that shows the narrative guidance provided above. In Table 1, the guidance applies for existing shoulder or edge line rumble strips that

programmed for a thin pavement overlay of the entire roadway surface (travel lanes and shoulders).

Table 1. Highways with Edge Line or Shoulder Rumble Strips Only
(Travel Lanes and Shoulders are Programmed for Thin Pavement Overlay)

<table>
<tr><th rowspan="2">Thin Overlay Type</th><th rowspan="2">Overlay Depth</th><th colspan="5">Existing Rumble Strip Treatment Process</th></tr>
<tr><th>Mill</th><th colspan="2">Mill Dimensions</th><th>Inlay Materials</th><th>Re-milled Rumble Strip Depth</th></tr>
<tr><td rowspan="2">Hot-mix Asphalt</td><td>7/8- to 1-inch</td><td rowspan="2">Yes*</td><td>SRS</td><td>20-inches wide
> ½-inch deep</td><td rowspan="2">Tack coat on milled surface and apply dense-graded hot-mix asphalt that is level with existing pavement surface</td><td>3/8-inch</td></tr>
<tr><td>> 1-inch</td><td>ERS</td><td>12-inches wide
> ½-inch deep</td><td>3/8- or 1/2-inch</td></tr>
<tr><td rowspan="3">Seal Coat</td><td>1st seal coat</td><td>No, if material does not fill rumble strip groove</td><td colspan="4">Maintain ≥ 3/8-inch existing groove depth**</td></tr>
<tr><td rowspan="2">2nd seal coat</td><td rowspan="2">Yes*</td><td>SRS</td><td>20-inches wide
> ½-inch deep</td><td>Tack coat on milled surface</td><td>3/8-inch</td></tr>
<tr><td>ERS</td><td>12-inches wide
> ½-inch deep</td><td>Dense-graded hot-mix asphalt that is level with surface of 1st seal coat</td><td>3/8- or 1/2-inch</td></tr>
<tr><td rowspan="5">Microsurfacing</td><td rowspan="5">Varies</td><td>No, if material will not fill rumble strip groove</td><td colspan="4">Maintain ≥ 3/8-inch existing groove depth**</td></tr>
<tr><td>No, if material will fill existing rumble strip groove</td><td colspan="3">Fill existing grooves with scratch layer and then tack coat surface</td><td>3/8- or ½-inch</td></tr>
<tr><td rowspan="3">Yes*</td><td>SRS</td><td>20-inches wide
> ½-inch deep</td><td>Tack coat on milled surface</td><td>3/8- or ½-inch</td></tr>
<tr><td>ERS</td><td>12-inches wide
> ½-inch deep</td><td>Dense-graded hot-mix asphalt that is level with surface existing pavement surface</td><td>3/8- or ½-inch</td></tr>
<tr><td colspan="6">*If the entire roadway surface (travel lanes and shoulders) will be overlaid because of poor pavement conditions, the entire roadway surface should be milled at least as deep as the depth shown in the “Mill Dimensions” column.

** Groove depth of existing rumble strip pattern should be checked along 100-foot test section within the limit of the seal coat or microsurfacing overlay project. If a rumble strip groove depth ≥ 3/8-inch is maintained, no milling is recommended. If the average groove depth, measured in at least 5 locations within the test section, is less than 3/8-inch, the existing rumble strip pattern should be milled and inlayed in accordance with the hot-mix asphalt guidelines presented here.</td></tr>
</table>

On Undivided Highways, with Centerline Rumble Strips Only

In this case, the thin pavement overlay will affect the rumble strip pattern, thus the following guidance is recommended:

- For hot-mix asphalt overlays, mill the existing rumble strip pattern (20-inches wide and at least 1/2-inch deep), or the entire roadway surface (if a complete mill and overlay project is planned due to poor pavement surface conditions), then inlay the milled area with dense-graded hot-mix asphalt. The inlay material should be compacted in accordance with PennDOT *Publication 408: Highway Construction Specifications*. A tack coat should be applied to the milled surface to assist with sealing and bonding the thin pavement overlay of hot-mix asphalt, which should be at least 7/8-inch thick. Once the hot-mix asphalt overlay is applied, re-mill the centerline rumble strip pattern in accordance with the standard specifications for highway construction. The new rumble strip should be 3/8-inch deep if the overlay is between 7/8- and 1-inch thick. The rumble strip could be 3/8- or ½-inch deep if the overlay thickness exceeds 1 inch. The rumble strip's length, width, and center-to-center spacing should be installed in accordance with PennDOT Publication 72M, RC-22M, "Rumble Strips."
- Up to one seal coat can be applied on existing rumble strips, and the milled rumble strip pattern may remain "as is." However, because the Department requires a rumble strip groove depth of either 3/8- or ½-inch thick, the groove depth should be checked in the field after applying a seal coat to ensure that adequate depth has been maintained. Rather than check the groove depth recommendation after completing an entire seal coat project, it is recommended that a 100-foot test location be checked first. If the minimum groove depth requirement cannot be maintained when applying the prescribed seal coat, the existing rumble strip pattern should be milled and inlayed using a dense-graded hot-mix asphalt, before applying the seal coat. The inlay material should be compacted in accordance with PennDOT *Publication 408: Highway Construction Specifications*. Once the seal coat is applied, the rumble strip pattern should be re-milled into the seal coat. If, after the first seal, the rumble strip pattern remained "as is," the second seal coat application will likely fill the existing rumble strip grooves. As such, when a second seal coat application is planned, the existing rumble strips should be milled and inlayed prior to applying the second seal coat. After applying the second coat overlay, the rumble strip grooves should be re-milled. The rumble strips should be installed in accordance with PennDOT Publication 72M, RC-22M, "Rumble Strips."
- For microsurfacing projects, if the existing rumble strip is deep enough, and the microsurfacing material leaves a minimum depth of 3/8-inch after placement of the microsurfacing, then it is not necessary to mill the existing rumble strips. Evaluation of such could be included in a 100-foot test location if needed. If placement of the microsurfacing on existing rumble strips will not generate a minimum depth of 3/8-inch, then one of two options must be followed: (1) either a scratch layer must be applied to fill the rumble depression before applying the microsurfacing material, or (2) the existing rumble strips must be milled in a manner consistent with the guidance provided above. In either case, tacking the surface of the scratch layer or the milled surface is necessary before application of the microsurfacing. The new rumble strip must be 3/8- or ½-inch deep. The rumble strip's length, width, and center-to-center spacing should be installed

in accordance with PennDOT Publication 72M, RC-22M, "Rumble Strips." If the mill and inlay option is chosen, the inlay material should be compacted in accordance with PennDOT *Publication 408: Highway Construction Specifications*.

In cases where an existing rumble strip pattern is temporarily removed as a result of milling or a thin pavement overlay, the pattern should be re-installed as soon as possible as part of the ongoing project. Table 2 is a design-decision matrix that provides a tabular summary of the narrative design guidance above. In the case of a microsurfacing overlay, milling is the most costly alternative. The microsurfacing guidance included in Table 1 for edge line or shoulder rumble strips is repeated in Table 2, in the case of centerline rumble strips on undivided highways.

On Undivided Highways, with Centerline Rumble and Edge Line or Shoulder Rumble Strips

In this case, the entire roadway surface should be programmed for a thin pavement overlay. The following guidance is recommended:

- For hot-mix asphalt overlays, mill the existing roadway (travel lanes and shoulders), apply a tack coat, and then apply the prescribed hot-mix asphalt overlay. Once the hot-mix asphalt overlay is applied, re-mill all rumble strip patterns in accordance with the standard specifications for highway construction. The new rumble strip should be 3/8-deep if the overlay is between 7/8- and 1-inch thick. The rumble strip could be 3/8- or ½-inch deep if the overlay thickness exceeds 1-inch. The rumble strip's length, width, and center-to-center spacing should be installed in accordance with PennDOT Publication 72M, RC-22M, "Rumble Strips."
- Only a single seal coat may be applied on existing rumble strips, if the milled rumble strip pattern is planned to remain "as is." However, because the Department requires a rumble strip groove depth of either 3/8- or ½-inch thick, the groove depth should be checked in the field after applying a seal coat to ensure that adequate depth has been maintained. Rather than check the groove depth recommendation after completing an entire seal coat project, it is recommended that a 100-foot test location be checked first. If the minimum groove depth requirement cannot be maintained when applying the prescribed seal coat, the entire roadway (travel lanes and shoulders) should be milled, a tack coat applied, and then the seal coat applied. Once the seal coat is applied, the rumble strip pattern should be re-milled into the seal coat. The rumble strips should be installed in accordance with PennDOT Publication 72M, RC-22M, "Rumble Strips."
- For microsurfacing projects, if the existing rumble strip is deep enough, and the microsurfacing material leaves a minimum depth of 3/8-inch after placement of the microsurfacing, then it is not necessary to mill the existing rumble strips. Evaluation of such could be included in a 100-foot test location if needed. If placement of the microsurfacing on existing rumble strips will not generate a minimum depth of 3/8-inch, then one of two options must be followed: (1) either a scratch layer must be applied to fill the rumble depression before applying the microsurfacing material, or (2) the existing rumble strips must be milled in a manner consistent with the guidance provided above. In either case, tacking the surface of the scratch layer or the milled surface is necessary before application of the microsurfacing. The new rumble strip must be 3/8- or ½-inch

deep. The rumble strip's length, width, and center-to-center spacing should be installed in accordance with PennDOT Publication 72M, RC-22M, "Rumble Strips."

In cases where an existing rumble strip pattern is temporarily removed as a result of milling or a thin pavement overlay, the pattern should be re-installed as soon as possible as part of the ongoing project. Table 3 is a design-decision matrix based on the narrative guidance offered above. In the case of a microsurfacing overlay, milling is the most costly alternative. The microsurfacing guidance contained in Tables 1 and 2 is repeated in Table 3 for roadways with both centerline and edge line or shoulder rumble strips.

Installing New Rumble Strips on Thin Pavement Overlays

When rumble strips do not exist on a roadway that has a thin pavement overlay, the following guidance is offered, based on the results of the state transportation agency survey and literature review:

- For hot-mix asphalt overlays, the surface should be in good condition and a crack seal should be applied before milling the centerline, shoulder, or edge line groove pattern. The hot-mix asphalt surface should be at least 1.25-inches deep to mill the ½-inch pattern, while a 1-inch hot-mix asphalt surface should be present to mill the 3/8-inch rumble strip groove. The rumble strip's length, width, and center-to-center spacing should be installed in accordance with PennDOT Publication 72M, RC-22M, "Rumble Strips."
- Rumble strips should not be applied on pavements with only a single seal coat as the only surface layer. After a second seal coat is applied, however, centerline, shoulder, or edge line rumble strips may be milled into the pavement surface. The rumble strips should be re-milled in accordance with the Department's standard specifications for highway construction, Publication 72M, RC-22M, "Rumble Strips."
- For microsurfacing projects, 3/8-inch deep rumble strips may be milled into the roadway if the depth of the material is 7/8- to 1-inch deep. If the material is at least 1-inch deep, a ½-inch rumble strip pattern may be milled into the roadway. The rumble strip's length, width, and center-to-center spacing should be installed in accordance with PennDOT Publication 72M, RC-22M, "Rumble Strips."

Table 4 presents the narrative design guidance in a design-decision matrix.

Table 2. Undivided Highway with Centerline Rumble Strips Only

<table>
<tr><th rowspan="2">Thin Overlay Type</th><th rowspan="2">Overlay Depth</th><th colspan="4">Existing Rumble Strip Treatment Process</th></tr>
<tr><th>Mill</th><th>Mill Dimensions</th><th>Inlay Materials</th><th>Re-milled Rumble Strip Depth</th></tr>
<tr><td rowspan="2">Hot-mix Asphalt</td><td>7/8- to 1-inch</td><td rowspan="2">Yes*</td><td rowspan="2">20-inches wide
> ½-inch deep</td><td>Tack coat on milled surface</td><td>3/8-inch</td></tr>
<tr><td>> 1-inch</td><td>Dense-graded hot-mix asphalt</td><td>3/8- or 1/2-inch</td></tr>
<tr><td rowspan="3">Seal Coat</td><td>1st seal coat</td><td>No, if material does not fill rumble strip groove</td><td colspan="3">Maintain ≥ 3/8-inch existing groove depth**</td></tr>
<tr><td rowspan="2">2nd seal coat</td><td rowspan="2">Yes*</td><td rowspan="2">20-inches wide
> ½-inch deep</td><td>Tack coat on milled surface</td><td rowspan="2">3/8- or 1/2-inch</td></tr>
<tr><td>Dense-graded hot-mix asphalt that is level with surface of 1st seal coat</td></tr>
<tr><td rowspan="4">Microsurfacing</td><td rowspan="4">Varies</td><td>No, if material will not fill rumble strip groove</td><td colspan="3">Maintain ≥ 3/8-inch existing groove depth**</td></tr>
<tr><td>No, if material will fill existing rumble strip groove</td><td colspan="2">Fill existing grooves with scratch layer and then tack coat surface</td><td>3/8- or ½-inch</td></tr>
<tr><td rowspan="2">Yes*</td><td rowspan="2">20-inches wide
> ½-inch deep</td><td>Tack coat on milled surface</td><td>3/8- or ½-inch</td></tr>
<tr><td>Dense-graded hot-mix asphalt that is level with surface of 1st seal coat</td><td>3/8- or ½-inch</td></tr>
</table>

*If the entire roadway surface (travel lanes only or travel lanes and shoulders) will be overlaid because of poor pavement conditions, the affected roadway surface should be milled at least as deep as the depth shown in the "Mill Dimensions" column.

** Groove depth of existing rumble strip pattern should be checked along 100-foot test section within the limit of the seal coat or microsurfacing overlay project. If a rumble strip groove depth ≥ 3/8-inch is maintained, no milling is recommended. If the average groove depth, measured in at least 5 locations within the test section, is less than 3/8-inch, the existing rumble strip pattern should be milled and inlayed in accordance with the hot-mix asphalt guidelines presented here.

Table 3. Undivided Highway with Centerline and Edge Line or Shoulder Rumble Strips

Thin Overlay Type	Overlay Depth	Existing Rumble Strip Treatment Process			
		Mill	**Mill Dimensions**	**Post-milling Materials**	**Re-milled Rumble Strip Depth**
Hot-mix Asphalt	7/8- to 1-inch	Yes	Full roadway (travel lanes and shoulders)	Tack coat on milled surface	3/8-inch
	> 1-inch				3/8- or 1/2-inch
Seal Coat	1st seal coat	No, if material will not fill rumble strip groove	Maintain ≥ 3/8-inch existing groove depth*		
	2nd seal coat	Yes	Full roadway (travel lanes and shoulders)	Tack coat on milled surface	3/8- or 1/2-inch
Microsurfacing	Varies	No, if material will not fill rumble strip groove	Maintain ≥ 3/8-inch existing groove depth**		
		No, if material will fill existing rumble strip groove	Fill existing grooves with scratch layer and then tack coat surface		3/8- or ½-inch
		Yes*	Full roadway (travel lanes and shoulders)	Tack coat on milled surface	3/8- or ½-inch

* Groove depth of existing rumble strip pattern should be checked along 100-foot test section within the limit of the seal coat or microsurfacing overlay project. If a rumble strip groove depth ≥ 3/8-inch is maintained, no milling is recommended. If the average groove depth, measured in at least 5 locations within the test section, is less than 3/8-inch, the existing rumble strip pattern should be milled in accordance with the seal coat or microsurfacing rumble strip treatment process.

Table 4. New Rumble Strips on Thin Pavement Overlays

Thin Overlay Type	Overlay Depth	Pre-Rumble Strip Milling Surface Preparation	Milled Rumble Strip Depth
Hot-mix Asphalt	1 to 1.25-inches	Crack seal	3/8-inch
	≥ 1.25-inches	Crack seal	3/8- or ½-inch
Seal Coat	1 Seal Coat	Do not apply milled rumble strip on single seal coat	N/A
	2 Seal Coats	None	3/8- or ½-inch
Microsurfacing	7/8- to 1-inch	None	3/8-inch
	> 1-inch	None	3/8- to ½-inch

Monitoring Performance

The guidance developed above is based on published literature, results of a state transportation agency survey, and professional engineering judgment. It is recommended that PennDOT construction and maintenance crews monitor the performance of rumble strips that have been installed or re-installed on thin pavement overlays. Engineering districts should use discretion to modify the guidance presented in this report, if deemed necessary. All modifications to the guidance should be done in consultation with the Highway Safety and Traffic Operations Division, Safety Management Division, and the Bureau of Maintenance and Operations Pavement Testing and Asset Management Section.

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APPENDIX A: LITERATURE REVIEW

The purpose of the literature review was to identify and synthesize the range of practices associated with installing and re-installing rumble strips on thin pavement overlays with or without existing rumble strips. Published pavement performance (e.g., life-cycle cost analysis) evaluations with rumble strips milled at the centerline or outside the limits of the traveled way were also sought in the published research literature. The primary source that was used to identify published literature was the Transportation Research Board's (TRB) TRID database.

Federal Highway Administration Guidance

The Federal Highway Administration's (FHWA) Office of Safety maintains a Roadway Departure Safety webpage (FHWA, 2014) which includes an answer to the question: "How do you re-install rumbles after paving operations, especially thin overlays (FHWA, 2011)?" The response to this question describes a variety of methods, including the following:

- Some agencies re-install the rumble strips immediately after resurfacing the roadway, while others may re-install the rumble strips during area-wide repaving and rumble strip milling activities.
- Some agencies mill out the existing rumble strips and then either inlay and overlay, or overlay a thin pavement layer before re-installing the rumble strips.
- Some agencies overlay the existing the rumble strips without milling the existing rumble strips.

Although a reference is not cited by FHWA, the webpage indicates that Michigan has determined that chip sealing over existing rumble strips increases the noise and vibrations when the rumble strips are crossed, while also slightly changing the cross-section of the rumble strip. Furthermore, it was noted that microsurfacing and ultra thin hot-mix asphalt overlays fill in existing rumble strip patterns and then a newly-milled pattern can be installed at the overlay location without delamination resulting from the underlying filled-in pattern.

New Hampshire Department of Transportation Research

Published research related to rumble strip installation on thin pavement overlays is limited. The New Hampshire Department of Transportation (NH DOT) completed the only research that was identified – the purpose of the research was focused on determining how to adequately prepare the surface of a roadway that has rumble strips (Boisvert, 2010) prior to a pavement resurfacing project. The research project was initiated as a result of a pavement resurfacing project along the Central Turnpike (Interstates 93 and 293) in 2003, when the NH DOT completed its first overlay of rumble strips on this freeway. The overlay was one-inch deep and the rumble strips protruded through the overlay, which raised questions about how rumble strips should be prepared prior to a pavement overlay.

The first objective of the NH DOT study was to determine the practices of other state and provincial agencies with regard to preparing existing rumble strip pavements prior to an overlay.

Responses to this inquiry, which are documented in a Wisconsin DOT Transportation Synthesis Report (CTC & Associates, 2006), describe the following practices:

- Georgia DOT mills the existing rumble strip pattern if it is deteriorated. If the existing pattern is not deteriorated, the Georgia DOT cleans the shoulders with power brooms, applies a dense-graded fine leveling mix (depth of 4.75 or 9.5 mm), and then sprays the surface with a tack coat to limit delamination.
- Maine DOT applies a leveling course by extending the traveled way leveling over the rumble strips, or by leveling the full width of the shoulder.
- Maryland State Highway Administration did not report problems with overlays of unprepared rumble strips, most likely resulting from overlays that were two or more inches deep, which may be applied in multiple layers.
- Nebraska Department of Roads does not prepare existing rumble strips prior to a pavement overlay and uses overlay depths of 2 inches or more when resurfacing existing rumble strips.
- New Jersey DOT mills the rumble strip pattern before resurfacing the roadway.
- New York DOT recommends a shim (thin asphalt layer) or sand mix be applied, followed by a tack coat, before resurfacing existing rumble strips.
- North Carolina DOT reports no pavement performance or rumble strip pattern issues after applying an overlay of milled rumble strips.
- Utah DOT fills and levels rumble strips that are 1 or more inches deep using hot-mix asphalt or a combination of aggregate and sprayed asphalt.

In response to the range of state transportation agency practices, the NH DOT completed a field evaluation to determine the best techniques for preparing and overlaying pavements with rumble strips. Four rumble strip preparation scenarios were developed and implemented in continuous 500-foot test sections of Interstate 89, and a 1.5-inch overlay was placed once the different preparations were completed. The different surface preparation scenarios included the following:

1. Tack-Shim-Overlay (Test Section A)
    a. The entire 10-foot wide shoulder was tacked.
    b. A 0.5–inch leveling shim was placed and compacted with a 10-ton roller.
    c. A 1.5-inch overlay was placed and compacted with 10- and 30-ton rollers.
2. Tack-Overlay (Test Section B)
    a. No special treatment for the rumble strip pattern.
    b. The entire 10-foot wide shoulder was tacked.
    c. A 1.5-inch overlay was placed and compacted with 10- and 30-ton rollers.
3. Mill-Inlay-Overlay (Test Section C)
    a. The rumble strip pattern was milled out 20-inches wide with a cold-plane trimmer to 0.5-inches deep.
    b. The milled-out rumble strip was tacked.
    c. A jig mounted to a Bobcat was used to inlay the milled-out rumble strip.
    d. The inlay was compacted with a 10-ton roller.
    e. The inlay and entire shoulder was tacked.
    f. A 1.5-inch overlay was placed and compacted with 10- and 30-ton rollers.

4. Mill-Overlay (Test Section D)
    a. The rumble strip pattern was milled out 20-inches wide with a cold-plane trimmer to 0.5-inches deep.
    b. The entire shoulder was tacked.
    c. A 1.5-inch overlay was placed and compacted with 10- and 30-ton rollers.

After the overlays were completed, they were observed within a week to determine the short-term conditions of the overlay. Test Section A did not show any reflection of the rumble strip, while Test Section B showed occasional longitudinal cracking along the edge of the rumble strip and there was a reflected rumble strip parallel to the existing rumble strip. Test Sections C and D did not show any reflection of the rumble strips.

Another site inspection of the test sections was performed approximately 10 months after the installation of the test sections. During this inspection, Test Section A showed mild reflection of the rumble strip, and vibrations could be felt when traversed in a vehicle. There was no structural distress of the pavement. Test Section B continued to show a pronounced rumble strip reflection and the rumble strip was more visible from the snowplow blades repeatedly "grinding" against the pavement. Test Sections C and D did not show any reflection of the rumble strips; however, there was discoloration of the rumble strip in Test Section D.

A final inspection was performed approximately 23 months after the installation of the test sections. There were no significant changes from the previous inspection. After the final inspection, new rumble strips were milled into the pavement as part of a statewide rumble strip installation project.

In addition to the visual inspections that were performed, five cores were taken from the rumble strip locations in Test Sections C and D to compare with the densities of five cores taken from typical shoulder areas. The cores taken from Test Section C had a density 0.76% lower than the control (typical shoulder area), on average. The cores taken from Test Section D had a density 0.48% lower than the control (typical shoulder area), on average. These differences were practically insignificant and showed that the density of the pavement in the rumble strip area is not negatively impacted from milling out the existing rumble strips before a pavement overlay. All four test scenarios performed equally well after the new rumble strips were milled into the pavement, and there was no evidence of raveling or deterioration.

Based on the results of the four test scenarios, it was recommended to only tack and overlay the existing rumble strips since it was the most efficient and economical of the scenarios evaluated. However, this recommendation was implemented and there were additional issues that were later identified, resulting in subsequent changes to NH DOT practice. In 2007, a 1.5-inch overlay was installed on Interstate 89 and there were problems achieving compaction. If the pavement was compacted to meet density requirements, cracks appeared along the rumble strip. As a result, the New Hampshire DOT decided to mill all rumble strips and overlay without inlaying, starting in the 2008 construction season. On Interstate 93 and NH Route 101, a 1.5-inch overlay of 75-gyration mix was placed. During compaction, 0.25-inch wide, longitudinal cracks started to appear on the outside edge of the rumble strips. The solution that was implemented was to

increase the asphalt content of the mix, so it was essentially a 50-gyration mix, and this eliminated the cracking issue.

Starting in 2010, the New Hampshire DOT required all rumble strips to be milled and inlayed prior to the installation of the overlay. This is the current technique that is being used in New Hampshire, and the contractors have developed techniques so that it is not a laborious installation and is not as costly as in 2005.

Summary of Literature Review

Rumble strips are an effective countermeasure to reduce the number of roadway departure crashes and, as such, have been installed on many roadways in the United States. However, many of the roadways that were treated with the first shoulder or centerline rumble strips in the 1990s and early part of the 2000s have been resurfaced or are now planned for resurfacing. While many overlay projects are taking place on roadways with rumble strips, there is only limited research focusing on methods to overlay the rumble strips. There is not a common method documented in the research literature that describes an effective preparation and overlay method and, as a result, variability in practices is evident among transportation agencies. Most of the agencies that have developed guidelines have done so based on field experience and have not conducted research to support the methods used to prepare the rumble strips prior to overlay, or to re-install the rumble strips after completing the pavement overlay.

APPENDIX B: SURVEY INSTRUMENT

PENN STATE UNIVERSITY-PENNDOT RESEARCH PROJECT

Title: Rumble Strip Installation on Thin Pavement Overlays

Step 1: The survey will begin with a short statement of the project objective, which is shown below.

Project Objective:

The purpose of this project is to establish a synthesis of best practices from various states and other transportation agency stakeholders regarding the installation and reinstallation of rumble strips on pavements being treated with a thin pavement overlay. The best practices will provide a standardized, cost-effective process for the Pennsylvania Department of Transportation (PennDOT) to effectively utilize rumble strips in conjunction with thin pavement overlays.

Step 2: The survey will continue with a set of instructions for survey participants to read prior to responding to the questions. The instructions are shown below.

Survey Instructions:

The Thomas D. Larson Pennsylvania Transportation Institute at Penn State University is gathering information related to the project objectives. Your participation in this survey is voluntary and the results of the survey will not reveal any personal information about the respondent; rather, all responses will be linked only to the transportation agency represented by the respondent. The study is being conducted only for research purposes and you may end your participation in the survey at any time. It is anticipated that the survey will take less than 5 minutes to complete. You may choose not to answer specific questions.

Prior to beginning the survey, please review the following terms, which we ask you to consider when responding to each survey question:

1. Rumble strips: milled or rolled-in grooves in the pavement surface intended to provide haptic or tactile vibrations to drivers that are departing the traveled way. In this survey, please consider centerline, edge line, and shoulder rumble strips in your response.
2. Rumble strip depth: the Pennsylvania Department of Transportation currently applies rumble strips with either 3/8- or ½-inch groove depths. Please consider only these two depths in your response.
3. Thin pavement overlays: the Pennsylvania Department of Transportation currently employs three thin pavement overlay types. These include: hot-mix asphalt 1.5-

inches or less, microsurfacing, and seal coat. Please consider only these three types of overlays in your response.

Step 3: *Administer Survey*

Participants will be asked to complete the following questions:

1. Does your agency have a written policy or set of guidelines concerning the installation or re-installation of rumble strips on thin pavement overlays?

☐ Yes ☐ No (if "no," skip to question 4)

2. If your policy or guidelines are available on your website, please provide a link to the documentation in the space provided below. If your policy or guideline is not available on your website, but is in electronic from, please e-mail a copy of the documentation to Dr. Eric Donnell at edonnell@engr.psu.edu. Alternatively, if your policy or guideline is available only in paper copy form, please mail a copy of the documentation to Dr. Eric Donnell at the address provided below.

Link to policy or guideline: _____

Address of Dr. Eric Donnell
The Pennsylvania State University
Department of Civil and Environmental Engineering
212 Sackett Building
University Park, PA 16802

3. Based on your experience related to installing or re-installing rumble strips at locations with thin pavement overlays, are there any improvements that you would recommend to your current policy or guidelines?

☐ Yes (please explain): _____
☐ No

4. Has your agency completed research related to the installation or re-installation of rumble strips on thin pavement overlays?

☐ Yes ☐ No (if "no," skip to question 6)

5. If this research is available on your website, please provide a link to the documentation in the space provided below. If your policy or guideline is not available on your website, but is in electronic form, please e-mail a copy of the documentation to Dr. Eric Donnell at edonnell@engr.psu.edu. Alternatively, if your policy or guideline is available only paper copy, would you please mail a copy of the documentation to Dr. Eric Donnell at the address provided below.

Link to policy or guideline: _____

Address of Dr. Eric Donnell:
The Pennsylvania State University
Department of Civil and Environmental Engineering
212 Sackett Building
University Park, PA 16802

If respondents answered "yes" to question #1, the survey will conclude after question #5. The conclusion to the survey is as follows:

Please indicate your agency in the space provided: _____

Please indicate your name and telephone number in the space provided in case the research team has questions concerning your policy or guidance document(s):
_____

Thank you for your participation!

If respondents answered "no" in question #1, respondents will then be asked to answer question #4. If the respondent answers "no" to question #4, the survey will continue as follows:

6. Does your agency install or re-install rumble strips on thin pavement overlays?

☐ Yes ☐ No (if "no," survey concludes)

7. If rumble strips exist on a roadway that is planned for a thin pavement overlay, how does your agency prepare the roadway surface prior to application of the thin pavement overlay?

☐ Mill out the rumble strips and inlay (i.e., fill-in milled area) before applying the thin pavement overlay
☐ Overlay the rumbles without milling (i.e., do nothing before applying the overlay)
☐ Dependent on rumble strip depth or thin pavement overlay type
☐ Other (please describe): _____

8. After completing the thin pavement overlay, which of the following rumble strip re-installation practices does your agency employ?

☐ Install the rumble strips immediately after the thin pavement overlay is complete
☐ Install the rumble strips at a later time, as part of a large-scale area-wide project
☐ Dependent on the thin pavement overlay type
☐ Leave re-paved surface "as is" (resulting in partially-filled rumble strips)
☐ Other (i.e., criteria that your agency uses to determine if rumble strips pattern is acceptable after thin pavement overlay):
_____

9. When applying a thin pavement overlay over an existing rumble strip that has not been inlayed, which overlay type is most effective in retaining the existing shape of the rumble strip?

☐ Hot-mix asphalt
☐ Microsurfacing
☐ Seal coat

10. When applying a thin pavement overlay over an existing rumble strip that has not been inlayed, which overlay type is most effective in producing the level of in-vehicle noise and vibration desired of rumble strips?

☐ Hot-mix asphalt
☐ Microsurfacing
☐ Seal coat

11. If a rumble strip pattern is milled and inlayed prior to applying a thin pavement overlay, what material is most often used to inlay the rumble strip pattern?

☐ Hot-mix asphalt
☐ Microsurfacing
☐ Seal coat
☐ Other (please describe): _____

12. When applying a thin pavement overlay over an existing rumble strip that has been inlayed, which overlay type most effectively enables a re-installed rumble strip pattern to be milled into the overlay without delaminating the inlayed rumble strips?

☐ Hot-mix asphalt
☐ Microsurfacing
☐ Seal coat

13. Does your agency practice concerning installation or re-installation of rumble strips on thin pavement overlays depend on rumble strip type (i.e., centerline, shoulder, or edge line)?

☐ Yes ☐ No

14. Does your agency practice concerning installation or re-installation of rumble strips on thin pavement overlays depend on rumble strip depth (e.g., 3/8- or ½-inch)?

☐ Yes ☐ No

If respondents answered "no" to question #1 and question #6, the survey concludes after question #6. If respondents answered "no" to question #1 and "yes" to question #6, the survey concludes after question #14. The conclusion to the survey is as follows:

Please indicate your agency in the space provided: _____

Please indicate your name and telephone number in the space provided in case the research team has questions concerning your responses to the questions in this survey:
_____

Thank you for your participation!

APPENDIX C: SURVEY RESPONSES

STATE	Q1 Does your agency have a written policy or set of guidelines / concerning the installation or re-installation of rumble strips on / thin pavement overlays?	Q2 If your policy or guidelines are available on your website, please / provide a link to the documentation in the space provided below. / If your policy or guideline is not available on your website, / bu...
South Dakota Department of Transportation	Yes	http://sddot.com/resources/manuals/PavementPreservationGuidelines1112011.pdf
Wisconsin DOT	No	
MassDOT - Highway Division	Yes	http://www.massdot.state.ma.us/Portals/8/docs/engineeringDirectives/2004/e-04-006.pdf
Nevada DOT	Yes	http://www.nevadadot.com/uploadedFiles/NDOT/About_NDOT/NDOT_Divisions/Engineering/Specifications/2001StandardSpecifications.pdf http://www.nevadadot.com/About_NDOT/NDOT_Divisions/Engineering/Design/Design_Division_-_Road_Design_Guide.aspx
Indiana Department of Transportation	Yes	http://www.in.gov/dot/div/contracts/standards/memos/memos.html
Washington State Department of Transportation	Yes	http://www.wsdot.wa.gov/publications/manuals/fulltext/M22-01/1600.pdf http://www.wsdot.wa.gov/NR/rdonlyres/D7971B81-5443-45B9-8B9B-BFC0D721F5A1/0/WSDOTPavementPolicyFinal71211.pdf
Delaware DOT	No	
Kentucky Transportation Cabinet	No	
Maine Department of Transportation	Yes	http://www.maine.gov/mdot/technicalpubs/documents/ecdocs/Revised_Rumble Strip Policy_06132013.doc
New Hampshire Department of Transportation	Yes	http://www.nh.gov/dot/org/projectdevelopment/highwaydesign/documents/2013_11_01_milled_rumble_strips.pdf
New York State DOT	Yes	https://www.dot.ny.gov/portal/pls/portal/mexis_app.pa_ei_eb_admin_app.show_pdf?id=11376
South Carolina DOT	Yes	
Wyoming Department of Transportation	No	
Oklahoma DOT	Yes	internal only at this point, three different policies, we are wanting to compile later
Connecticut Department of Transportation	No	
Texas DOT	Yes	http://www.dot.state.tx.us/insdtdot/orgchart/cmd/cserve/standard/toc.htm
Arkansas State Highway and Transportation Dept.	Yes	
Ohio DOT	Yes	http://www.dot.state.oh.us/Divisions/Engineering/Roadway/DesignStandards/roadway/Location%20and%20Design%20Manual/Section_600_July_2013.pdf
Montana Department of Transportation	Yes	
Oregon DOT	No	
Alaska DOT&PF	No	
Kansas DOT	Yes	
Minnesota Dept of Trans	No	
Florida Dept. of Transportation	No	
Missouri DOT	No	
Alabama DOT	No	
Iowa Department of Transportation	No	
Michigan Department of Transportation	No	
Louisiana DOTD	Yes	http://wwwsp.dotd.la.gov/Inside_LaDOTD/Divisions/Engineering/Road_Design/Systems_Preservation/Documents/Implementation%20Letter%20for%20Rumble%20Strips%2007%2009%202012.pdf
The VA Dept. of Transportation	No	
North Carolina Department of Transportation	Yes	http://www.ncdot.org/doh/preconstruct/ps/specifications/specifications_provisions.html

STATE	Q3	Q3_TEXT
South Dakota Department of Transportation	No	
Wisconsin DOT		
MassDOT - Highway Division	Yes (please explain):	the guidelines currently apply to all pavements regardless of thickness. There's no mention of how to treat the existing rumble strips.
Nevada DOT	No	
Indiana Department of Transportation	No	
Washington State Department of Transportation	Yes (please explain):	The improvements are included in the upcoming update to Chaper 1600 of WSDOT's Design Manual. The proposed update is as follows: Consult with the Region Materials Engineer to consider installation procedure and verify that the pavement structure is adequate.provide adequate pavement structure and thickness for all proposed rumble strip locations. When installing both rumble strips and recessed lane markers, follow the standard plan to avoid overlapping the grindings. Installing rumble strips in bituminous surface treatment (or BST) or other thin surface treatments can expose pavement structure and lead to delamination. The best practice is to install the rumble strips immediately prior to placing the surface treatment in order to seal the installation. In all cases, avoid placing HMA pavement joints and centerline rumble strips along the same (coincident) line wherever practical (see Standard Plan 65.10-02). Where rumble strips currently exist and an additional BST application is contemplated, evaluate whether the depth of the grooves following paving will support their continuing function to alert drivers. If not, or in the case of an HMA overlay, it may be necessary to remove existing rumble strips and install new ones. Note that WSDOT experience has shown that BST can be placed over existing rumble strips at least once and still be effective. Additionally, there are some specific surface preparation requirements for areas to be resurfaced where rumble strips currently exist. In many instances, it is necessary to remove and inlay the existing rumble strips prior to resurfacing.
Delaware DOT		
Kentucky Transportation Cabinet		
Maine Department of Transportation	Yes (please explain):	Although not not specifically stated, our guidlines are 3/4" overlay can get RS, but RS depth has to be 3/8" (not 1/2 ")
New Hampshire Department of Transportation	No	
New York State DOT	Yes (please explain):	Centerline joint condition should be carefully reviewed
South Carolina DOT	No	
Wyoming Department of Transportation		
Oklahoma DOT	Yes (please explain):	we are in the process with no recommendations at this time
Connecticut Department of Transportation		
Texas DOT	No	
Arkansas State Highway and Transportation Dept.	No	
Ohio DOT	No	
Montana Department of Transportation	No	
Oregon DOT	No	
Alaska DOT&PF		
Kansas DOT	Yes (please explain):	More detail or specificity.
Minnesota Dept of Trans		
Florida Dept. of Transportation		
Missouri DOT		
Alabama DOT		
Iowa Department of Transportation		
Michigan Department of Transportation	Yes (please explain):	Require rumble strips to be re-milled following a double chip seal (still effective after a single chip seal, but not a double)
Louisiana DOTD	No	
The VA Dept. of Transportation		
North Carolina Department of Transportation	No	

STATE	Q4	Q5	Q6	Q7	Q7_TEXT
South Dakota Department of Transportation	No				
Wisconsin DOT	No		No		
MassDOT - Highway Division	No				
Nevada DOT	No				
Indiana Department of Transportation	Yes				
Washington State Department of Transportation	No				
Delaware DOT	No		No		
Kentucky Transportation Cabinet	No		Yes	Overlay the rumbles without milling (i.e., do nothing before applying the overlay)	
Maine Department of Transportation	No				
New Hampshire Department of Transportation	No				
New York State DOT	No				
South Carolina DOT	No				
Wyoming Department of Transportation	No		Yes	Overlay the rumbles without milling (i.e., do nothing before applying the overlay)	
Oklahoma DOT	Yes	internal research only and ongoing, small committee			
Connecticut Department of Transportation	No		No		
Texas DOT	No				
Arkansas State Highway and Transportation Dept.	No				
Ohio DOT	No				
Montana Department of Transportation	No				
Oregon DOT	No		Yes	Mill out the rumble strips and inlay (i.e., fill-in milled area) before applying the thin pavement overlay	
Alaska DOT&PF	No		No		
Kansas DOT	No				
Minnesota Dept of Trans	No		Yes	Mill out the rumble strips and inlay (i.e., fill-in milled area) before applying the thin pavement overlay	
Florida Dept. of Transportation	No		No		
Missouri DOT	No		Yes	Other (please describe):	We may overlay w/o milling if the existing rumble strip is in good condition, but if it's raveled we'll probably mill the old rumble.
Alabama DOT	No		Yes	Other (please describe):	If the roadway and/or shoulder is milled, then the rumble strips are milled, roadway and shoulders overlayed, and then the pavement is rescored to provide the rumble strips. If milling of the pavement and shoulders is not required, the roadway and shoulder is resurfaced and the shoulders are scored.
Iowa Department of Transportation	No		Yes	Dependent on rumble strips depth or thin pavement overlay type	
Michigan Department of Transportation	No		Yes	Dependent on rumble strips depth or thin pavement overlay type	
Louisiana DOTD	No				
The VA Dept. of Transportation	No		No		
North Carolina Department of Transportation					

STATE	Q8	Q9	Q10	Q11	Q12	Q13	Q14
South Dakota Department of Transportation							
Wisconsin DOT							
MassDOT - Highway Division							
Nevada DOT							
Indiana Department of Transportation							
Washington State Department of Transportation							
Delaware DOT							
Kentucky Transportation Cabinet	Leave re-paved surface "as is" (resulting in partially-filled rumble strips)	Microsurfacing	Microsurfacing	Hot mix asphalt	Hot mix asphalt	Yes	Yes
Maine Department of Transportation							
New Hampshire Department of Transportation							
New York State DOT							
South Carolina DOT							
Wyoming Department of Transportation	Install the rumble strips at a later time, as part of a large-scale area-wide project	Seal coat	Seal coat	Hot mix asphalt	Hot mix asphalt	Yes	No
Oklahoma DOT							
Connecticut Department of Transportation							
Texas DOT							
Arkansas State Highway and Transportation Dept.							
Ohio DOT							
Montana Department of Transportation							
Oregon DOT	Install the rumble strips immediately after the thin pavement overlay is complete	Seal coat	Seal coat	Hot mix asphalt	Hot mix asphalt	No	No
Alaska DOT&PF							
Kansas DOT							
Minnesota Dept of Trans	Install the rumble strips at a later time, as part of a large-scale area-wide project	Microsurfacing	Microsurfacing	Hot mix asphalt	Hot mix asphalt	No	No
Florida Dept. of Transportation							
Missouri DOT	Install the rumble strips immediately after the thin pavement overlay is complete	Seal coat	Seal coat	Hot mix asphalt	Hot mix asphalt	No	No
Alabama DOT	Install the rumble strips immediately after the thin pavement overlay is complete				Hot mix asphalt	No	No
Iowa Department of Transportation	Install the rumble strips immediately after the thin pavement overlay is complete			Hot mix asphalt	Hot mix asphalt	No	No
Michigan Department of Transportation	Dependent on the thin pavement overlay type	Seal coat	Seal coat	Hot mix asphalt	Hot mix asphalt	No	No
Louisiana DOTD							
The VA Dept. of Transportation							
North Carolina Department of Transportation							

APPENDIX D: TRANSPORTATION AGENCY SURVEY RESULTS

The literature review was used to inform a transportation agency survey intended to collect data related to the project objectives. The survey instrument is provided in Appendix A of this report. Recipients of the survey were identified from the following committees or groups:

- Transportation Research Board (TRB) Committees on Full-scale Accelerated Pavement Testing (AFB40), Strength and Deformation Characteristics of Pavement Sections (AFD80), and Flexible Pavement Construction and Rehabilitation (AFH60).
- American Association of State Highway and Transportation Officials (AASHTO) Joint Technical Committee – Pavements
- State Highway Safety Engineers Listserv.

At least one representative from each state transportation agency (STA) in the United States received the survey. A total of 31 state transportation agencies provided a complete response to the survey. The agencies responding are shown in Figure 1.

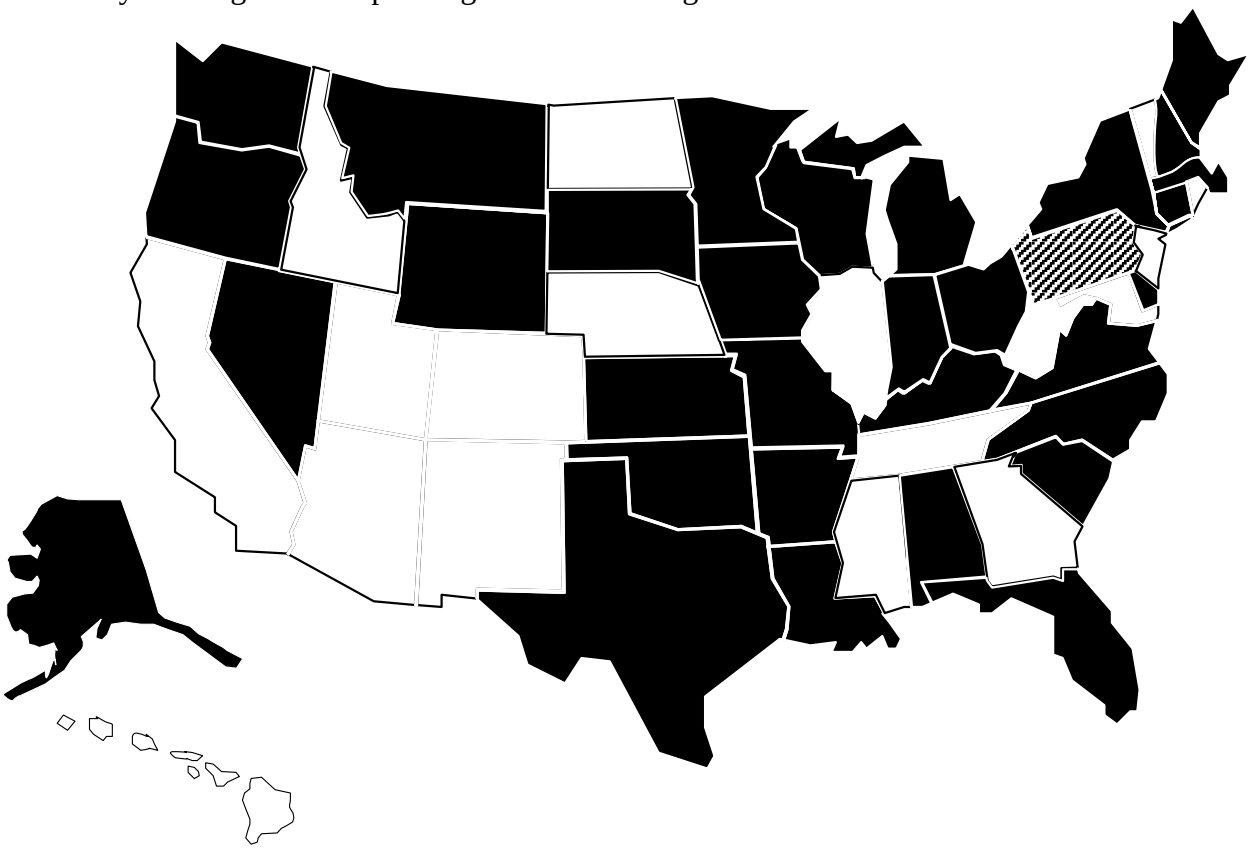

Figure 3. Illustration of State Transportation Agencies Responding to Survey.

As shown in the survey instrument (see Appendix A), survey respondents were first asked if their agency had a written policy or set of guidelines concerning the installation or re-installation of rumble strips on thin pavement overlays. Of the responding STAs, 45 percent (14 of 31) do not

have an explicit policy regarding the installation or re-installation of rumble strips on thin pavement overlays. None of these STAs has completed any research related to the topic and, therefore, the respondents were asked a series of questions related to their STA practices related to the installation or re-installation or rumble strips on thin pavement overlays (see questions #6 through #14 in Appendix A). These results are described in the next section of this report – STA responses to the survey are shown in Appendix B.

In addition to the STAs that were sent the survey instrument, all 11 engineering districts in Pennsylvania were sent a survey. Because PennDOT does not currently have a policy on the installation or re-installation of rumble strips on thin pavement overlays, the survey included only questions #6 through #14 in Appendix A. Five engineering districts completed the survey and the results are provided after the STA survey results.

State Transportation Agencies without Rumble Strip Policies

As noted previously, 45 percent of responding STAs (14 of 31) do not have a written policy regarding the installation of rumble strips on thin pavement overlays. Six of these 14 STAs indicated that they do not install or re-install rumble strips on thin pavement overlays (Alaska, Connecticut, Delaware, Florida, Virginia, and Wisconsin). The Alaska Department of Transportation and Public Facilities (Alaska DOT/PF) *Policy on Rumble Strip Installation* indicates that shoulder and centerline rumble strips should not be installed on pavements or surface treatments less than two-inches thick. However, personal correspondence with the Alaska DOT/PF indicated that, for pavement resurfacing projects, the agency mills 1.5-inches of the paved roadway surface and then fills the milled section with 1.75-inches of hot-mix asphalt, or the agency mills 1.75-inches of the roadway surface and then fills the roadway with 2-inches of hot-mix asphalt. If the mill-and-fill is between the fog lines (white edge lines), the shoulder rumble strips are left intact. If the mill-and-fill includes the shoulders, the rumble strips are re-installed. Milled shoulder rumble strip dimensions in Alaska are 16-inches long, 7-inches wide, ½-inch deep, with 12-inch center-to-center groove spacing. Centerline rumble strips in Alaska are milled with a 12-inch length, 7-inch width, and 3/8-inch depth, with 12-inch center-to-center spacing.

Eight of 14 STAs that do not have a written policy concerning the installation or re-installation of rumble strips on thin pavement overlays indicate that they do perform this activity during pavement resurfacing projects. If rumble strips exist on a roadway that is planned for a thin pavement overlay, one STA overlays the rumble strip without milling (Kentucky), two STAs (Minnesota and Oregon) mill out the rumble strips and inlay (fill-in the milled area) before applying the thin pavement overlay, two STAs (Iowa and Michigan) indicate that roadway surface preparation is dependent on the depth or thin pavement overlay type, and two STAs indicate that they have alternative practices to prepare the roadway surface prior to application of the thin pavement overlay. Alabama and Missouri overlay the existing rumble strip without milling, if the pattern is in good condition, but will mill the existing rumble strip pattern if it is in poor condition.

After completing the overlay, 3 of 8 STAs that do install or re-install rumble strips on thin pavement overlays indicate that they install the rumble strips immediately after the thin pavement overlay is complete, while 2 of 8 STAs indicate that they install the rumble strips as part of an area-wide project. One of 8 STAs (Kentucky) indicates that they leave the re-paved surface "as is," resulting in a partially-filled rumble strip groove. One STA indicates that rumble strip re-installation is dependent on the thin pavement overlay type after the overlay project is complete.

When applying a thin pavement overlay over an existing rumble strip that has not been inlayed, 3 STAs indicated that a seal coat is most effective in retaining the existing shape of the rumble strip, while 2 STAs indicated that microsurfacing is most effective. When applying a thin pavement overlay over an existing rumble strip pattern that has not been inlayed, 3 STAs indicated that a seal coat is most effective in producing the level of in-vehicle noise and vibration desired of rumble strips, while 2 STAs indicated that microsurfacing is most effective. Three of 8 STAs that install or re-install rumble strips on thin pavement overlays, but do not have a formal policy for this process, did not respond to survey questions #9 and #10.

Seven of 8 STAs indicated that a hot-mix asphalt is most often used to inlay rumble strips prior to applying a thin pavement overlay. Similarly, 7 of 8 STAs that do not have a policy concerning the installation or re-installation of rumble strips on thin pavement overlays indicate that a hot-mix asphalt most effectively enables a re-installed rumble strip pattern to be milled into the overlay without delaminating the inlayed rumble strips.

Finally, 7 of 8 STAs that do not have a written policy concerning the installation or re-installation of rumble strips on thin pavement overlays indicated that they do not consider the rumble strip type (i.e., centerline, shoulder, or edge line) or rumble strip depth (i.e., 3/8- or ½-inch) when making decisions concerning this practice.

In summary, 8 of 14 STAs that do not have a written policy regarding the installation or re-installation of rumble strips on thin pavement overlays do apply rumble strips on roadway resurfacing projects that include pavement overlays with a depth of 1.5-inches or less. The most common practices among these 8 STAs is as follows:

- Half of the STAs mill the existing rumble strips before applying a thin overlay, while the other half do not mill the existing pattern. Similarly, half of the agencies re-install the rumble strip pattern immediately after the pavement overlay, while half re-install rumble strips as part of an area-wide project.
- STAs are nearly split concerning the application of seal coat versus microsurfacing with regards to retaining the shape of the rumble strip pattern and producing desirable levels of noise and vibration. This suggests that use of either of these thin pavement overlay types may not require milling or rumble strip re-installation if a rumble strip pattern is to be retained as part of an overlay project. No STAs indicated that hot-mix asphalt will

effectively retain the shape or produce desirable noise and vibration properties when overlaying existing rumble strips.

- There is near consensus among the 8 STAs that a hot-mix asphalt overlay is the best material to use if installing or re-installing milled rumble strips. The depth of the pattern is not considered by these agencies.

State Transportation Agencies with Rumble Strip Policies

Approximately 55 percent (17 of 31) responding STAs indicated that they have a written policy concerning the installation or re-installation of rumble strips on thin pavement overlays. In many cases, these STAs provided documentation to support the policy while, in some cases, personal communication with the responding STA was used to collect this information. Each STA who has a policy concerning the installation or re-installation of rumble strips on thin pavement overlays is described below. In a few cases, agencies did not provide a policy or respond to requests for additional information concerning their policies, thus this information is not summarized in this section of the report.

Arkansas

The Arkansas State Highway and Transportation Department (ASHTD, 2012) developed a policy in November 2011 to install shoulder and centerline rumble strips on the state highway network. On rural, divided highways with full access control, shoulder rumble strips are milled 16-inches long, 7-inches wide, and ½-inch deep, with 12-inch center-to-center groove spacing. The rumble strip pattern is offset 4-inches from the edge line of the traveled way. On rural divided highways with partial access control, shoulder rumble strips are 12-inches long, 5-inches wide, and 3/8-inch deep, with a 12-inch center-to-center groove spacing. This pattern is also offset 4-inches from the edge line of the traveled way. On rural, undivided highways the shoulder rumble strip pattern is the same as that which is used on rural, divided highways with partial access control. Centerline rumble strips are 16-inches long, 5-inches wide, and 3/8-inch deep, with a 12-inch center-to-center spacing.

The ASHTD rumble strip policy notes concerns related to how shoulder rumble strips may contribute to the deterioration of paved shoulders. As such, an ASHTD District Engineer is responsible for determining, on a case-by-case basis, if the shoulder is structurally-adequate for the milled shoulder rumble strip pattern.

Indiana

The Indiana Department of Transportation recommends that shoulder rumble strips be considered on rural, multi-lane highways. Use of edge line rumble strips in lieu of shoulder rumble strips may be considered if approved by district technical services division staff. Indiana also uses centerline rumble strips on rural, undivided highways. Design elements that preclude the application of milled rumble strips include a chip seal surface within one year of application

and any pavement surface treatment (e.g., microsurfacing) with an active warranty within three years of construction. Further, Indiana DOT does not recommend retrofitting (i.e., re-installing) rumble strips when the District Pavement Engineer deems the shoulder to be in poor condition, the segment is programmed for re-surfacing within the next three years, or when the road section is under pavement warranty that has not expired.

Subsequent personal communication with Indiana DOT indicated that only roadways with shoulder rumble strip locations have had thin pavement overlays applied in recent years, as shoulder rumble strips have been applied in Indiana for nearly 20 years. Centerline rumble strip locations have not yet been programmed for any pavement overlay cycle. With regards to installing or re-installing shoulder rumble strips at locations planned for thin pavement overlays, Indiana most often leaves the existing rumble strip pattern in place, fills grooves with hot-mix asphalt (as part of thin pavement overlay process), and then re-mills the rumble strip pattern.

Kansas

Shoulder rumble strips are used on all reconstruction and new construction projects at locations with full-width shoulders (KDOT, 2007). When full-width shoulders are overlaid with a minimum of 1-inch of asphalt, milled shoulder rumble strips may be used. Milled centerline rumble strips may be used on two-lane, rural highways with asphalt pavement surfaces that have a depth of at least 1.5-inches and a shoulder width of at least 3-feet. The centerline rumble strip pattern may be used on all reconstruction, new construction, and surface overlays, with the exception of seal overlays. Because the milled rumble strip policy has been in place since July 2007, few instances have occurred when existing rumble strip patterns have been planned for a thin overlay.

Louisiana

The Louisiana Department of Transportation and Development (LaDOTD, 2012) recently recommended that milled shoulder and centerline rumble strips be included in all new construction, reconstruction, and pavement preservation/rehabilitation/replacement projects. Use, however, is limited to roadways with a 50 mph or greater posted speed limit, and must be supported by crash analysis. LaDOTD is currently developing specifications for design and construction or rumbles on thin pavement overlays. Subsequent personal communication indicated that, when microsurfacing is the thin overlay used, the LaDOTD fills the existing grooves with the microsurfacing product, then overlays the entire roadway surface with the same microsurfacing material. Once the microsurfacing is complete, the rumble strip grooves are re-milled into the thin overlay. The same process is used for hot-mix asphalt thin pavement overlays.

Maine

The Maine Department of Transportation (MaineDOT, 2013) installs milled centerline and edge line rumble strips on non-Interstate highways with posted speed limits of 45 mph and greater. Guidance in the policy that is related to the present study includes the following:

- The surface pavement must be at least 1.25-inches in depth to install a ½-inch milled centerline rumble strip pattern and the pavement surface must be less than three years old and show no signs of distress. If the paved traveled way surface is ¾-inch deep, a 3/8-inch milled centerline rumble strip pattern is milled. No pre-treatment is applied if applying a surface overlay on existing rumble strips.
- For edge line rumble strips, the shoulder pavement depth must be at least 3-inches to apply a milled rumble strip. Additionally, the shoulder pavement must be less than five years old and show no signs of distress.
- Sealant is applied over rumble strips to protect pavements and joints.

Massachusetts

The Massachusetts Department of Highways issued an engineering directive in December 2004 (Mass Highways, 2004) containing standard specifications for shoulder rumble strips on highways with full-control of access, and for all highways with a posted speed limit of 40 mph or greater. The pattern is 16-inches long, 7-inches wide, and ½-deep, with 12-inch center-to-center spacing. The milled pattern is to be installed only on hot-mix asphalt pavement surfaces. No written documentation exists concerning how rumble strips are installed or re-installed on thin pavement overlays.

Michigan

Although the Michigan Department of Transportation (MDOT) indicated that they do not have a written policy concerning the installation or re-installation of rumble strips on thin pavement overlays, the Capital Preventive Maintenance Manual (MDOT, 2010) does contain guidelines concerning the use of rumble strips on non-structural hot-mix asphalt overlays. A non-structural overlay is limited to a 1.5-inch dense-graded hot-mix asphalt. If rumble strips exist on a roadway that is planned for capital preventive maintenance, they are filled-in with the hot-mix asphalt overlay and re-installed after the overlay is completed.

Montana

The Montana Department of Transportation (Montana DOT, 2012) requires rumble strips on Interstate and primary roadways. Shoulder rumble strips are placed on all new construction, reconstruction, and overlay projects. The pattern may be milled (on asphalt surfaces) or rolled (on concrete surfaces). The dimensions for the milled pattern are 12-inches long, 7.625-inches

wide, and ½- to ¾-inches deep, with 12-inch center-to-center spacing. Montana DOT re-installs the milled pattern on asphalt pavement surfaces after thin pavement overlays and chip seals, but does not prepare the existing patterns before an overlay.

Nevada

The Nevada Department of Transportation (Nevada DOT, 2001) uses a milled rumble strip pattern on shoulders. Two applications of a seal coat may be applied to the rumble strips grooves after milling. No other explicit documentation concerning the installation or re-installation of rumble strips on thin pavement overlays was provided.

New Hampshire

The New Hampshire Department of Transportation rumble strip installation guidelines (NH DOT, 2013) indicate that milled shoulder rumble strips are installed on all Interstate and limited access, divided highways with a posted speed limit of 40 mph or greater, and shoulder width at least 6-feet wide. Milled centerline rumble strips are installed on undivided highways with a posted speed limit of 40 mph or greater, pavement width of 28-feet or greater, and with pavements that are in good condition with a wearing course depth of at least 1.25-inches so that the rumble strip will not accelerate pavement delamination or deteriorate the pavement joint. The milled groove depth for all rumble strips are ½-inch. The research by Boisvert (2010), which is detailed in the Literature Review section of this report, indicates that NH DOT requires that existing rumble strips be milled and inlayed prior to applying an overlay. The inlay technique has also proven effective without an overlay for temporary traffic control or detours, when vehicles cross the shoulder rumble strip pattern location.

New York

The New York State Department of Transportation (NYSDOT) installs milled centerline and shoulder rumble strips on various road classes (2013). To be eligible for centerline rumble strips on undivided highways, the pavement surface must have a score of 7 or better. NYSDOT's *Pavement Condition Assessment* (NYSDOT, 2010) provides a procedure to assess the pavement surface quality – a score of 7 is a paved surface with the following characteristics:

- Infrequent to occasional distress with minor crack severity;
- Cracks are mostly 1/8-inch wide or less with little connected cracking;
- Appearance of pavement is good with noticeable cracking.

An example of a pavement with a score of 7 is provided in Figure 2. If a pavement surface has a score of 7 or less and is five years or older, a field evaluation is required for centerline rumble strips to be installed on undivided highways. If the centerline joint is deemed inadequate for milling centerline rumble strips, and a repaving project is not scheduled within the next three years, NYSDOT mills out a 2-inch deep and 2-foot wide area, centered over the centerline joint.

The milled area is cleaned, a tack coat is applied, and a hot-mix asphalt inlay is applied. The centerline rumble strips are then applied. The policy (NYSDOT, 2013) notes that a 1-inch overlay is preferred, although centerline rumble strips have been successfully applied into 0.75-inch hot-mix asphalt, chip seals, and microsurfacing overlays.

North Carolina

Personal communication with North Carolina DOT indicated that, when re-installing rumble strips on thin pavement overlays, the existing rumble strip pattern is milled and inlayed, and the milled pattern is then re-installed after the thin overlay is completed.

Figure 4. Example of Pavement Score = 7 in New York State (NYSDOT, 2010).

Ohio

The Ohio Department of Transportation (Ohio DOT) installs shoulder rumble strips on new, reconstructed, and resurfaced shoulders of rural full-access- and partial-access controlled highways, as well as urban fully access-controlled highways. A rolled (in asphalt), milled, or formed pattern may be used; however, the milled pattern is preferred on most rural roadways. The formed pattern is often used in urban areas because it produces lower noise levels to nearby residents.

When installing rumble strips on existing pavements, the shoulder must be in good condition. On pavement overlays, the shoulder pattern is restored in accordance with the guidance above

(Ohio DOT, 2013a). The typical pattern is 16-inches long, 7-inches wide, and ½-inch depth, with 12-inch center-to-center spacing (Ohio DOT, 2013b).

Oklahoma

The Oklahoma Department of Transportation is currently in the process of developing a policy for the installation or re-installation of rumble strips on thin pavement overlays. Personal communication indicated that thin overlays are only applied on the traveled way, thus shoulder rumble strips are not impacted by overlays. Oklahoma is currently experimenting with thin overlays on undivided roadways with rumble strips. A chip seal is the most commonly-applied overlay, and the rumble strips are re-milled into the pavement surface after applying the chip seal (no pre-treatment is done prior to applying the chip seal). Visual inspection of this process has indicated no issues with the rumble strip pattern or pavement surface.

South Carolina

The South Carolina Department of Transportation (SC DOT) installs milled rumble strips on shoulders of full access-controlled highways and on partial access-controlled highways that are classified as rural with a roadway width of 20-feet or greater, having an average daily traffic volume of at least 500 vehicles per day, and a posted or design speed of 45 mph or greater. The SC DOT rumble strip policy does not contain explicit information related to the installation or re-installation of rumble strips at thin pavement overlay locations.

South Dakota

The South Dakota Department of Transportation (SD DOT) *Pavement Preservation Guidelines* (2010) contain policies related to rumble strips on pavement surface treatments. Chip seals (asphalt surface treatments) are effective methods to improve friction, inhibit raveling, correct minor roughness or bleeding, or seal the pavement surface. At locations with existing rumble strips, only one asphalt surface treatment should be applied. SD DOT policy indicates that a second surface treatment can fill an existing rumble strip pattern and reduce rumble strip effectiveness. If a second or third asphalt surface is applied, the rumble strip is fog sealed and the rumble strip is re-milled.

Washington

The Washington State Department of Transportation (WSDOT) *Design Manual* (2013) indicates that most milled rumble strip installations do not adversely impact pavement performance. However, there have been instances where bituminous surface treatments and hot-mix asphalt pavements with low density, along longitudinal joints, have produced advanced levels of pavement deterioration, rutting, or delamination.

For hot-mix asphalts, existing rumble strips may be overlayed at locations where the treatment has a minimum depth of 1.75-inches (0.15 feet), provided that the lane configuration does not require traffic to crossover the rumble strip pattern (WSDOT, 2011). If the lane configuration shifts traffic so that it crosses the overlayed rumble strip pattern, reflection of the underlying rumble strip will likely occur. Shoulder rumble strips that are adjacent to road sections that are included in a mill and inlay project should be milled and inlayed as well. Similarly, shoulder rumble strips that are located on detour routes should be milled and inlayed with a minimum of 1.75-inches of hot-mix asphalt. A tack coat is required between all hot-mix asphalt layers.

Texas

The Texas Department of Transportation (Tx DOT, 2006) installs edge line, centerline, and shoulder rumble strips on a variety of roadway types. The dimensions of the milled pattern vary depending on the roadway cross-section and rumble strip type. The policy does not contain information concerning the installation or re-installation of rumble strips on thin pavement overlays; however, personal communication indicated that the most common practice is to mill existing patterns, apply a tack coat, and then apply an overlay. Rumble strips are then re-installed into the pavement overlay.

Summary

State transportation agency practices with regards to the installation or re-installation of rumble strips on thin pavement overlays vary widely among the 17 STAs indicating that they have a policy concerning this practice. Among the responding agencies that indicate having a policy, Kansas, Maine, New Hampshire, New York, South Dakota, and Washington State have the most specific guidance regarding the application of rumble strips on thin pavement overlays. A summary of these practices is provided below:

- Kansas has had few occurrences where existing rumble strips have been planned for thin pavement overlays. However, on pavement overlay projects at locations without rumble strips, the depth of the asphalt overlay must be at least 1-inch to apply a milled shoulder rumble strip, while the asphalt overlay must be at least 1.5-inches deep to apply a milled centerline rumble strip.
- The Maine policy is similar to Kansas, with the exception being that the asphalt overlay must be 1.25-inches deep to install a ½-inch deep centerline rumble strips. If the traveled way surface has an asphalt pavement depth between 0.75- and 1.25-inches, a 3/8-inch milled groove may be installed on the overlay. For edge line rumble strips, the asphalt pavement depth must be at least 3-inches to install the milled pattern.
- Milled centerline rumble strips in New Hampshire are installed on asphalt pavements that are at least 1.25-inches deep (0.5-inch groove depth). If applying a thin pavement overlay on top of existing rumble strips, the existing pattern is milled and inlayed prior to applying the thin pavement overlay.

- New York State mills out a 2-inch deep and 2-foot wide area when roadways with existing centerline rumble strips are scheduled for a thin pavement overlay. A hot-mix asphalt inlay is then applied prior to applying a thin pavement overlay. Re-installation of the rumble strips is then completed – the policy notes that a 1-inch hot-mix asphalt overlay is preferred, although 0.75-inch deep chip seals, microsurfacing, and hot-mix asphalt overlay projects have included re-installed rumble strips.
- South Dakota will leave the rumble strip pattern "as is" when applying a chip seal to a roadway with existing rumble strips. When a second or third chip seal is applied, the rumble strip is fog sealed and the milled strip pattern is re-installed.
- Washington State mills existing rumble strips when applying bituminous surface treatment (chip seal) overlays. A surface overlay thickness of at least 3-inches is required to re-install the milled groove pattern on chip seal overlays. Existing rumble strips may be overlayed at locations when a hot-mix asphalt overlay is applied at a depth of 1.75-inches or more, if traffic is not intended to cross the pattern. If traffic will cross the pattern, the existing rumble strips are milled and inlayed prior to applying the hot-mix asphalt overlay.

Appendix C includes a brief tabular summary of the rumble strip dimensions and documentation provided by each state transportation agency that responded to the survey. Many of the dimensions were obtained from Torbic et al. (2009).

Pennsylvania Department of Transportation Engineering District Practices

Each district traffic engineer in PennDOT was sent the survey instrument shown in Appendix A; only questions #6 through #14 were included in the survey as PennDOT does not have a formal, statewide policy on the installation or re-installation of rumble strips on thin pavement overlays. Five engineering districts completed the survey, while a sixth district indicated that no field data were available to provide a complete response to the survey. The following is a summary of the results:

- Four districts overlay existing rumble strips without milling. One district indicated that, for overlays greater than 1.5-inches, a ¾-inch scratch/leveling course is applied to fill-in the rumble strips. One district indicated that they call for a leveling course to fill-in the rumble strip grooves before applying the overlay. One district indicated that surface preparation is dependent on the rumble strip depth or thin pavement overlay type, when a thin pavement overlay is planned over an existing rumble strip pattern.
- After completing the thin pavement overlay, one district installs or re-installs the rumble strips as part of an area-wide project while one district re-installs or installs rumble strips immediately after a hot-mix asphalt thin overlay project is completed. One district indicated that, on seal coat projects, the rumble strip groove is left "as is" once the overlay is completed. Two districts indicated that they leave the rumble strip groove "as is" after all thin pavement overlays.

- When applying a thin pavement overlay over an existing rumble strip that has not been inlayed, all five districts indicated that a seal coat is most effective in retaining the existing shape of the rumble strip and maintaining effective noise and vibration levels to alert drowsy or fatigued driving that have departed the travel lane.
- If a rumble strip pattern is milled and inlayed prior to applying a thin pavement overlay, one district uses a ¾-inch scratch/leveling course to inlay the rumble strip pattern, while three districts use a hot-mix asphalt as the inlay material. One district did not reply to this question.
- When applying a thin pavement overlay over an existing rumble strip that has been inlayed, four districts indicated that hot-mix asphalt most effectively enables the rumble strip pattern to be re-installed. One district did not reply to this question.

Four districts indicated that the rumble strip type (shoulder, centerline, or edge line) does not impact their practice concerning the installation or re-installation of rumble strips on thin pavement overlays. One district indicated that the rumble strip type and depth of rumble strip do affect installation or re-installation practices on thin pavement overlays.

APPENDIX E: SUMMARY OF STATE TRANSPORTATION AGENCY RUMBLE STRIP DIMENSIONS AND THIN OVERLAY GUIDANCE

State	Rumble Strip Dimensions (inches)*										Thin Overlay Guidance	
	Centerline			Shoulder				Edge Line			No Policy	Policy
	L	W	D	L	W	D	Off.	L	W	D		
Alabama				16	7	0.5-0.625	18				• Mill and inlay rumble strips, then immediately re-install grooves. • Hot-mix asphalt is most effective overlay product to re-install rumble strip grooves. • Rumble strip type and depth do not affect practices.	
Alaska	12	5-7	0.5	16	7	0.5	2-6				Does not install or re-install rumble strips on thin pavement overlays.	
Arkansas	16	5	0.375	12-16	7	0.375-0.625	4					District Engineer responsible for determining how to prepare shoulder prior to installing rumble strips.
Connecticut				16	7	0.5-0.625	6-12				Does not install or re-install rumble strips on thin pavement overlays.	
Delaware	16	7	0.5	16	7	0.5	12				Does not install or re-install rumble strips on thin pavement overlays.	
Florida				16	7	0.5-0.625	16				Does not install or re-install rumble strips on thin pavement overlays.	
Indiana				16	7	0.5	0-6					• Do not apply rumble strips when roadway will be chip sealed within one year. • Do not apply rumble strips on microsurfacing that has active warranty. • Most often fill existing grooves with hot-mix asphalt and then re-mill rumble strips on shoulders.

State	Rumble Strip Dimensions (inches)*										Thin Overlay Guidance	
	Centerline			Shoulder				Edge Line			No Policy	Policy
	L	W	D	L	W	D	Off.	L	W	D		
Iowa				16	7	0.5-0.625	0				• Surface preparation is dependent on thin pavement overlay type. • Rumble strips re-installed immediately after thin pavement overlay. • Hot-mix asphalt is most effective inlay and overlay product to re-install rumble strip grooves. • Rumble strip type and depth do not affect practices.	
Kansas	12	6.5	0.5	16	7-8	0.5	16					• Will mill rumble strips on 1-inch hot-mix asphalt shoulder pavement overlays. • Milled centerline rumble strips are applied on asphalt surfaces that are at least 1.5-inches thick. • No milled centerline rumble strips are applied on seal coats.
Kentucky	24	7	0.5-0.625	16	7	0.5	12				• Overlay rumble strips without milling and leave re-paved surface “as is.” • Microsurfacing most effective in retaining rumble strip pattern and producing noise/vibration. • Hot-mix asphalt is most effective inlay and overlay product to re-install rumble strip grooves. • Rumble strip type and depth affect practices.	

State	Rumble Strip Dimensions (inches)*										Thin Overlay Guidance	
	Centerline			Shoulder				Edge Line			No Policy	Policy
	L	W	D	L	W	D	Off.	L	W	D		
Louisiana												• For hot-mix asphalt overlays, fill grooves with hot-mix asphalt, than re-mill grooves. • On microsurfacing projects, fill existing grooves then overlay, then re-mill grooves.
Maine				16	7	0.5-0.75	0					• Pavement must be less than three years old and 1.25-inches deep to install ½-inch centerline rumble strips. • On pavements less than three years old and ¾-inches deep, 3/8-inch milled centerline rumble strips is used. • No pre-treatment is applied when rumble strips exist at locations that receive thin pavement overlay. • Pavement must be less than five years old with no distress, with at least 3-inches of pavement, to install edge line rumble strips. • Sealant is applied on all milled rumble strips to protect pavements and joints.
Massachusetts	16	6	0.5	16	7	0.5	4					

State	Rumble Strip Dimensions (inches)*										Thin Overlay Guidance	
	Centerline			Shoulder				Edge Line			No Policy	Policy
	L	W	D	L	W	D	Off.	L	W	D		
Michigan	16	7	0.375	16	7	0.5-0.625	12				• Surface preparation is dependent on thin pavement overlay type. • Rumble strips re-installed immediately after thin pavement overlay. • Seal coat most effective in retaining rumble strip pattern and producing noise/vibration. • Hot-mix asphalt is most effective inlay and overlay product to re-install rumble strip grooves. • Rumble strip type and depth do not affect practices.	On preventive maintenance projects, mill and inlay existing rumble strips, then apply 1.5-inch dense-graded, hot-mix asphalt overlay, then re-mill rumble strip pattern.
Minnesota	12-16	7	0.5	15	7	0.5-0.625	0				• Mill and inlay rumble strips, then re-install grooves later as part of area-wide project. • Microsurfacing most effective in retaining rumble strip pattern and producing noise/vibration. • Hot-mix asphalt is most effective inlay and overlay product to re-install rumble strip grooves. • Rumble strip type and depth do not affect practices.	
Missouri	12	6.5	0.5								• Mill and inlay rumble strips, then immediately re-install grooves. • Seal coat most effective in retaining rumble strip pattern and producing noise/vibration. • Hot-mix asphalt is most effective inlay and overlay product to re-install rumble strip grooves. • Rumble strip type and depth do not affect practices.	

State	Rumble Strip Dimensions (inches)*										Thin Overlay Guidance	
	Centerline			Shoulder				Edge Line			No Policy	Policy
	L	W	D	L	W	D	Off.	L	W	D		
Montana				12-16	7	0.5-0.75	6					• No surface preparation before applying thin pavement overlay. • Re-mill rumble strips after chip seal and hot-mix asphalt overlays.
Nevada				16	7	0.5-0.625	4					• Will apply up to two seal coats on existing rumble strips before re-milling grooves.
New Hampshire				16	7	0.5	6-30					• Will apply milled centerline rumble strips on wearing course that is at least 1.25-inches deep. Milled pattern is ½-inch deep. • Existing rumble strips are milled and inlayed prior to applying thin pavement overlays.
New York				16	7	0.5-0.625	Varies					• Mill 24-inch wide by 2-inch deep area around existing centerline rumble strips, then inlay with hot-mix asphalt before applying overlay. • A one-inch overlay is preferred before milling rumble strips, however, 0.75-inch chip seals, microsurfacing, and hot-mix asphalt have been re-milled successfully.
North Carolina				16	7	0.5	0					Mill and inlay existing rumble strips before overlay, and then re-mill groove pattern after overlay.
Ohio				16	7	0.5	4-6					Will only install milled, ½-inch deep rumble strips on shoulders in good condition.

State	Rumble Strip Dimensions (inches)*										Thin Overlay Guidance	
	Centerline			Shoulder				Edge Line			No Policy	Policy
	L	W	D	L	W	D	Off.	L	W	D		
Oklahoma				16	7	0.5-0.625	24					No surface preparation is performed prior to chip seal overlays, and rumble strips are re-milled after overlay.
Oregon	16	7	0.5		5.5	0.5	0				• Mill and inlay rumble strips, then immediately re-install grooves. • Seal coat most effective in retaining rumble strip pattern and producing noise/vibration. • Hot-mix asphalt is most effective inlay and overlay product to re-install rumble strip grooves. • Rumble strip type and depth do not affect practices.	
Pennsylvania	14-18	7	0.5	16	5-7	0.375-0.625	6-18	6	5	0.375		
South Carolina												
South Dakota												• Will apply up to one chip seal on existing rumble strips and leave rumble strips as is. • After second chip seal, rumble strips are re-milled after applying a fog seal to the existing roadway surface.
Texas	16	7	0.5	16	6-7	0.375-0.625	0-6					Mill existing rumble strips, apply task coat, overlay, and then re-mill rumble strips.
Virginia	16	7	0.5	16	7	0.5	0				Does not install or re-install rumble strips on thin pavement overlays.	
Washington	16	5	0.375	16	7	0.5-0.625	6					Mill and inlay existing grooves, then apply hot-mix asphalt overlay of 1.75-inches, and re-mill rumble strips.

State	Rumble Strip Dimensions (inches)*										Thin Overlay Guidance	
	Centerline			Shoulder				Edge Line			No Policy	Policy
	L	W	D	L	W	D	Off.	L	W	D		
Wisconsin				16	7	0.5-0.625	30				Does not install or re-install rumble strips on thin pavement overlays.	
Wyoming	12	7.5	0.5	16	7	0.5-0.625	6				• Overlay rumble strips without milling and re-install as area-wide project. • Seal coat most effective in retaining rumble strip pattern and producing noise/vibration. • Hot-mix asphalt is most effective inlay and overlay product to re-install rumble strip grooves. • Rumble strip type affects practices, but rumble strip depth does not.	
*L = Length (measured perpendicular to travel direction); W = Width (measured parallel to travel direction); D = Depth; Off. = Offset from edge line												