

SHOULDER AND EDGE LINE RUMBLE STRIPS

T 5040.39

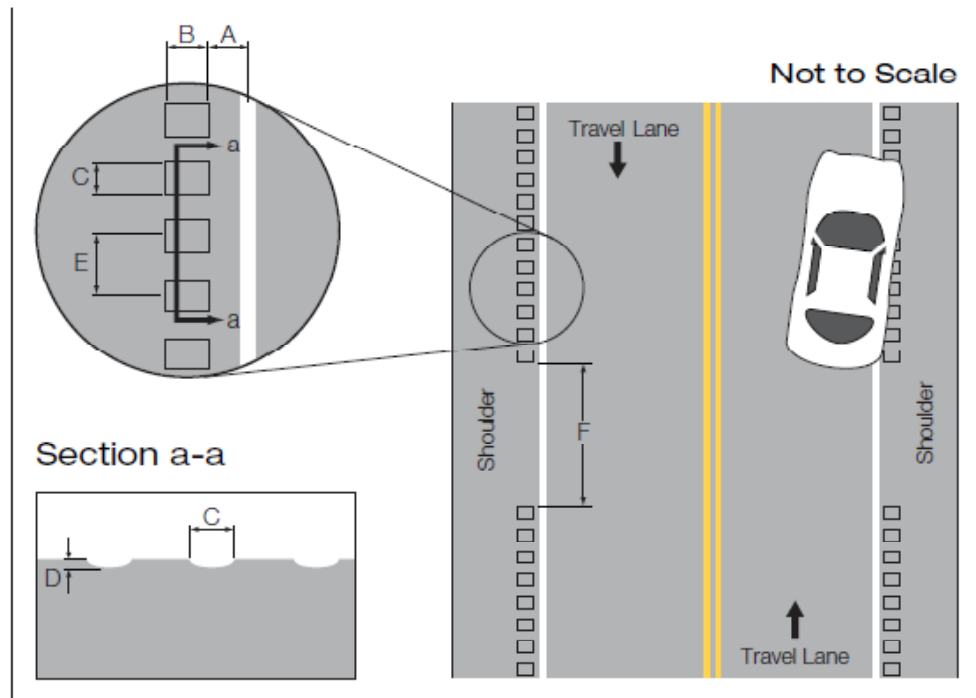
April 22, 2011

1. **PURPOSE:** To transmit information and guidelines for the design and installation of shoulder rumble strips and edge rumble strips on appropriate segments of paved roads in the United States.
2. **CANCELLATION:** This Technical Advisory supersedes the information contained in T 5040.35, Roadway Shoulder Rumble Strips, dated December 20, 2001.
3. **DEFINITIONS:** A ***shoulder rumble strip*** is a longitudinal design feature installed on a paved roadway shoulder near the outside edge of the travel lane. It is made of a series of indented or raised elements intended to alert inattentive drivers through vibration and sound that their vehicles have left the travel lane. An ***edge line rumble strip*** is a shoulder rumble strip placed at the edge of the travel lane, in line with the edge line pavement marking; this is sometimes referred to as an ***edge line rumble stripe***.
4. **BACKGROUND:** One of Federal Highway Administration's primary goals is to reduce the number and severity of roadway departure crashes, which include both run-off-road and cross center line or cross median crashes. Safety improvements intended to address this goal include those that are intended to keep the vehicles on the roadway, those that improve the likelihood of a safe recovery after a roadway departure, and those that reduce the severity of those crashes that do occur. Shoulder or edge line rumble strips are one of the proven countermeasures that reduce the risks of run-off-road crashes.
 - a. ***The target driver:*** Rumble strips are designed primarily to assist distracted, drowsy, or otherwise inattentive drivers who may unintentionally drift over the edge line. For this set of drivers, the audible and vibratory warning provided by rumble strips greatly improves the opportunity for a safe recovery. Where drivers don't safely recover, the warning provided by rumble strips may at least result in a less severe crash. In a study of 1,800 run-off-road freeway crashes, one state found that drift-off-road crashes (due to inattentive driving) resulted in death or serious injury at a rate 3 to 5 times that of other categories of run-off-road crashes.
 - b. ***Early rumble strip development:*** Audible and vibration treatments produced through surface texture in pavements have been in use for over fifty years as a means to alert errant drivers leaving the travel lane. Rolled-in strips on asphalt shoulders and formed-in strips on concrete shoulders were two of the earlier designs used in installing shoulder rumble strips by a number of states. A major limitation was that they had to be installed with new pavement. There are also difficulties in obtaining the desired shape. In the 1980s the Pennsylvania Turnpike Commission developed a milled-in rumble strip design that could be installed on existing pavement. A series of trials of the new design led to a preferred design of ½ inch deep and 7 inches by 16 inches, producing tire vibration and noise with much greater alerting capacity than the rolled-in installation. Specified dimensions could also be produced more consistently. Subsequently, many other states began to use this milled-in design because of its effectiveness and ease of installation.
 - c. ***Recent history:*** In the 1990's, several State transportation agencies and toll road authorities installed the milled-in shoulder rumble design pioneered in Pennsylvania, mostly on rural freeways and expressways. In recent years, many agencies have extended the use of rumble strips to two-lane roads. Some agencies have also designed and installed narrower rumble strips where roadway widths limited the use of standard designs.

- d. **Striping the rumble:** The practice of placing pavement markings over the rumble strip improves wet nighttime marking visibility; the back wall of each rumble enhances bead reflection of headlight beams back to the driver with or without the presence of water in the rumble. This practice also increases the longevity of the markings (within the rumble) due to tire wear or plowing activity.
 - e. **Benefits to other road users:** The noise that is generated when a vehicle begins to cross a rumble strip has the additional benefit of providing warning to bicyclists, pedestrians, or highway workers who may be in the path of the straying vehicle.
5. **EFFECTIVENESS:** Run-off-road crashes account for approximately one-third of the deaths and serious injuries each year on the Nation's highways. Drift-off crashes, caused by drowsy, distracted, or otherwise inattentive driving, are a subset of run-off-road crashes, those that are most likely to be reduced by this countermeasure. Many researchers have studied the effect of rumble strips on the larger set of data because these crashes can be identified in crash databases. Some studies have addressed the more specific drift-off subset by analyzing narratives in the crash reports. In both cases, milled rumble strips have been found to be among the most cost-effective safety features available due to the high benefit to cost ratio.
- a. **Run-off-road injury crashes:** NCHRP Report 641 documents milled shoulder and edge rumble strips to provide statistically significant reductions in single-vehicle run-off-road injury crashes: 10 to 24 percent on rural freeways, and 26 to 46 percent on two-lane rural roads. Reductions were also shown on other types of roadways, but the estimates are not as reliable.
 - b. **Drift-off-road crashes:** Studies of milled freeway shoulder rumble strips in Michigan and New York documented drift-off-road crash reductions of 38 and 79 percent.
 - c. **Navigation aid in bad weather:** Shoulder and edge line rumble strips may also serve as an effective means of locating the travel lane during inclement weather. Fog, snow, or blinding rain often covers pavement markings. The vibration provided by rumble strips can assist drivers from unintentionally leaving the roadway in these conditions. In addition to vibration, there are potential striping benefits. Even a light rain can seriously reduce the retroreflective capacity of pavement markings. When the edge line marking is placed within the rumble strip, the vertical component will often still be visible under these adverse conditions.
 - d. **Noise and vibration:** The common milled rumble designs have been shown to be more effective at producing both noise and vibration, as compared to earlier designs, and are credited with higher crash reduction factors. Design, application, and construction factors also contribute to the effectiveness of a rumble strip installation. Further information on these factors is discussed below.
6. **APPLICATION CONSIDERATIONS:** Edge line and shoulder rumble strips have the potential to reduce run-off-road crashes on any paved road. A summary of rumble strip practices and policies as of 2005 is included in NCHRP Report 641.
- a. **Corridor vs. spot treatment:** It is recommended that rumble strips be installed in corridors or long sections, prioritized by the frequency of target crash types. In the type of run-off-road event for which rumble strips are most likely to prevent a crash, the location of the event is typically random, related more to when the driver became distracted or drowsy than to where the vehicle was on the road system. Spot installations of rumble strips are not expected to be as effective. However, within a corridor application, there may be spots where discontinuing the rumble strip installation may be prudent. Some of these issues are covered under Section 9 below.

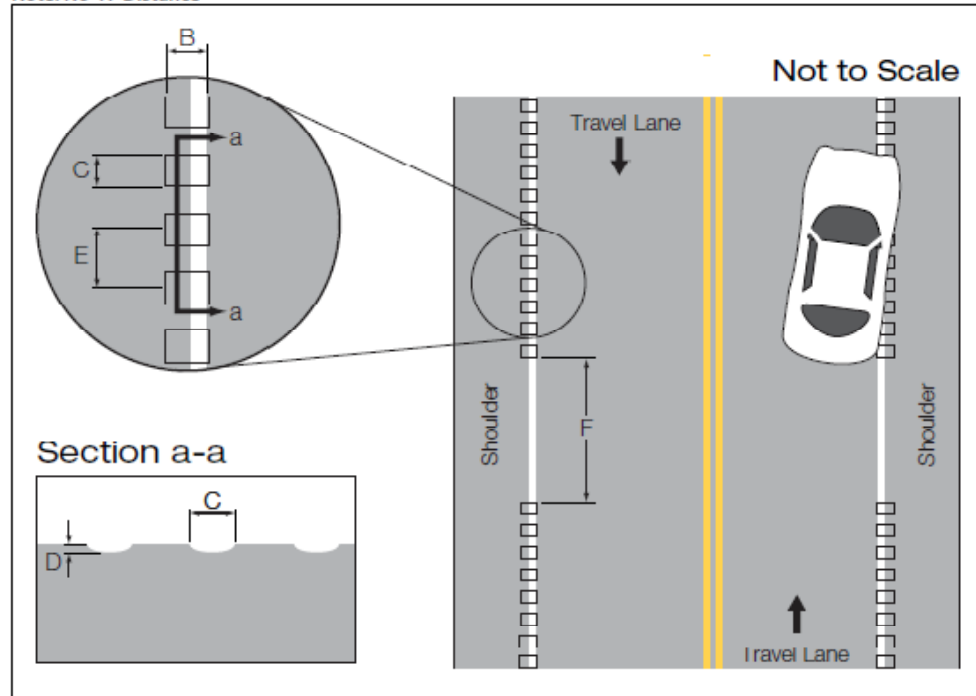
- b. **Urban vs. rural:** While rumble strips have been extensively used in rural areas, use in urban areas is also effective in producing safety benefits. It is more common for other issues such as low speeds or noise issues to limit the need for or use of rumble strips in urban areas.
 - c. **Left vs. right:** On divided highways, shoulder rumble strips should be placed on the left shoulder as well as on the right. A comprehensive Michigan study of 1,887 drift-off freeway crashes showed that approximately equal percentage of vehicles involved in crashes initially drifted to the left as to the right.
 - d. **Combination of shoulder and center line rumble strips:** The practice of installing both center line and shoulder rumble strips along the same segments of road is becoming more common with no noted detrimental effects. A Missouri study of the installation of rumble strips with wider markings during resurfacing showed the greatest reduction in serious injury crashes were found when both center line and edge line rumble strips were installed with the wider markings.
7. **DESIGN:** The design of rumble strips factor into their effectiveness. The terminology used in this technical advisory is shown Figure 1.
- a. **Types:** There are four basic rumble strip designs or types: milled-in, raised, rolled-in, and formed. Research indicates milled rumble strips produce significantly more vibration and noise inside the vehicle than rolled rumbles. The key design parameter related to effectiveness of the rumble strips is the dimensions, which tend to be easier to control with milled-in rather than rolled-in or formed rumbles. Raised rumble strips are typically only used where there is no need to plow snow. The effectiveness of raised rumble strips has not been studied. They are typically very narrow and prone to wear.
 - b. **Dimensions:** Optimum dimensions for milled rumble strips depend on operating conditions, cross-sectional characteristics, and potential road users. Two key dimensions to increase the alerting sound and vibration, and thereby effectiveness, are depth (D) and width longitudinal to the road (C). Most crash studies referenced here evaluated shoulder or edge line rumble strips of 7 inches long by 16 inches wide with a depth of one-half to five-eighths of an inch.
- One study showed the variation in length transverse to the road (B) had the least effect on noise produced in the vehicle compared to the other dimensions. The same study indicated that a rumble acting on the driver side tires, such as a shoulder rumble strip located on the inside (left) of a divided highway, produced more noise in the vehicle than rumbles to the right.
- c. **Location:** Edge line rumble stripes or shoulder rumble strips with a narrow offset (A) from the edge line have been shown to be most effective, because the driver is alerted sooner and it provides a slightly larger recovery area after being alerted. This is supported by research showing a statistically significant higher reduction in crashes for rumble strips with narrow or no offset than those with 9 inches or more offset. Most agencies also take the location of the pavement joint into account to avoid cutting the strip across or immediately adjacent to the joint. In superelevated sections where the shoulder slopes in the opposite direction from the roadway, consideration should be given to placing the rumbles strip on the superelevated side so that the driver is warned prior to crossing the slope break.

Shoulder Rumble Strips



Edgeline Rumble Strips

Note: No "A" Distance



Legend

→ = Direction of Travel	<i>B</i> = Length	<i>E</i> = Spacing
ooo = Rumble Strip	<i>C</i> = Width	<i>F</i> = Bicycle Gap
<i>A</i> = Offset	<i>D</i> = Depth	

Figure 1

- d. **Continuous vs. intermittent application:** Most shoulder rumble strips are installed without any breaks or gaps except at ramps on freeways and at approaches to intersections and major driveways on non-freeways. Where bicycle use is expected, recurring gaps in the rumble strip pattern can be included in continuous rumble strips to accommodate movement of bicyclists from one side of the rumbles to the other (see Section 9b).
8. **INSTALLATION:** It is important to ensure strips are placed at a uniform offset from the edge of the travel lane, which may not correspond to a constant offset from the edge of the shoulder. Monitoring to insure the proper depth and center to center spacing is maintained throughout the length of the installation is also recommended.
- a. **Milled rumble strips:** Most North American transportation agencies mill rumble strips into their asphalt or concrete pavement. The milling operation can be performed at any time, either in small quantity as part of a construction project, or in large quantity, taking advantage of the economy of scale by installing rumble strips for long sections or a number of corridors.
 - b. **Raised rumble strips:** Raised rumble strips using raised pavement markers or other available products are sometimes used in climates where snow-plowing is not a practice. These can be placed where milling would create a concern with the pavement integrity.
 - c. **Rolled-in rumble strips:** Rolled-in rumble strips are installed on still-hot asphalt pavement using a steel drum roller fitted with protruding tubes to provide indentations in the asphalt. This method cannot attain common dimensions for milled rumbles and therefore produces less vibration to alert drowsy drivers. Construction difficulties have been reported with the installation of rolled-in rumble strips. The indentations may not reach the proper depth if the operation is performed when the temperature is too low and the asphalt may not stabilize if the asphalt temperature is too high, resulting in problems with both the depth and shape of the indentations. Insufficient asphalt compaction between the indentations may also result from the roller riding on steel pipes, which may lead to premature deterioration of the shoulder surface.
 - d. **Formed rumble strips:** Rumble strips of similar shape and depth of milled designs have been successfully formed into fresh PCC pavement. However, while the formed rumbles can achieve the desired rumble shape, consistency concerns and the limitation on installation during the paving operation remain.
 - e. **Edge line rumble stripes:** Milling over existing pavement markings initially reduces the area of the marking visible to the motorist. Proper installation of an edge line rumble stripe includes the step of applying the pavement marking over the top of the rumble strips.
9. **MITIGATING ADVERSE EFFECTS:** A balance between the safety of motorists and the potential adverse effects on the life of the pavement, other road users and nearby residents should be considered when installing rumble strips.
- a. **Maintenance:** Early concerns of accelerated pavement deterioration due to installation of rumble strips appear to be unfounded. However, common practice is to locate the rumble strips at least a few inches from joints to reduce any potential acceleration of pavement deterioration. While rumble strips placed on pavement in good condition will be more cost-effective by virtue of being in place longer, shoulder deterioration is a safety issue with or without the presence of rumble strips. Experience has shown that traffic flow near the rumble keeps water from accumulating in the strip. Where there are deterioration concerns, an asphalt fog seal can be placed over milled-in strips to preserve them from oxidation and moisture.

Recent experience in Michigan has shown that shoulder preventative maintenance treatments such as chip seal, ultra-thin hot mix asphalt, and micro-surface, can be compatible with rumble strips. Chip seal on top of an existing rumble strip has been shown to retain the basic shape of the rumble, although losing some cross-section. However, stones from the chip seal enhance the noise and vibratory properties of the rumble. Micro-surface and ultra-thin hot-mix asphalt overlays fill in existing lines of rumble strips, but a fresh line of rumble strips can be cut into the overlay at the same location without significant delaminating caused by the underlying filled-in rumbles.

- b. ***Bicycle compatibility:*** Shoulder or edge line rumble strips can make bicycling unpleasant and inconvenient if the rumbles crowd the space that the bicyclist would normally use for travel. There are a number of mitigation measures available. Agencies should consider which may be appropriate. Mitigation is particularly encouraged on designated bike routes or those with heavy bicycle traffic where less than 4 feet of pavement exists beyond the rumble strip. Mitigation measures include:
 - i. Use of edge line rumble stripes rather than shoulder rumble strips, where it will allow additional shoulder area beyond the rumble strip that is usable to a bicyclist.
 - ii. Periodic gaps of 10 to 12 feet between groups of the milled-in elements, spaced at 40 to 60 feet, throughout the length of the shoulder rumble strip. This aids a bicyclist's movement to the left of a shoulder rumble strip when needed to avoid debris, make turns or avoid other shoulder users.
 - iii. Minor adjustments in design dimensions that have been shown to produce rumble strip designs more acceptable to bicyclists. The principal adjustments to the milled-in strip elements studied are decreased length transverse to the roadway (B), increased center-to-center spacing (E), reduced depth (D), and reduced width longitudinal to the roadway (C). This produces a rumble strip with a somewhat reduced effectiveness in alerting drivers, but is considered a reasonable trade-off for an agency that is attempting to balance the needs of all road users.
 - iv. A number agencies have policies rather than dealing with mitigation on a case-by-case basis. Some policies designate routes where rumble strips will not be placed unless a certain paved width beyond the rumble strip can be maintained or provided for use by bicyclists. Other policies are based on agreements regarding how mitigation decisions will be made when projects with rumble strips are proposed.
- c. ***Noise to nearby residents:*** Citizen acceptance of a state or local agency safety countermeasure should be taken into consideration as it can affect the long-term viability of that strategy. Although rumble strips are not intended to be traversed except when a driver leaves the roadway, rumble strip installations may produce noise complaints where there are nearby residences, depending on the type of vehicles, the lane width and curvature, and the type of maneuvers occurring on the road. Mitigation may include:
 - i. Increasing the offset (A), particularly through curves where off-tracking is prevalent or in corridors with high volumes of truck traffic.
 - ii. Removal of the rumbles in the vicinity of turn lanes or in spot locations such as a single house along a segment of roadway. The need to discontinue the use of rumbles in spot locations should not necessarily prevent their use along a segment or corridor.

- iii. Modifying other dimensions of the rumble strip. Note that noise measurements outside the vehicle should be used when mitigating this issue, not passenger compartment noise measurements that are used in studies of the effectiveness in alerting the driver.

Some surveys have shown that informed citizens often consider the improved safety worth the nuisance noise and that residents become accustomed to the noise fairly quickly.

10. PUBLIC OUTREACH: Public outreach should be considered by any agency that is introducing edge line or shoulder rumble strips into an area for the first time or on a large scale. The outreach goals should make a case to the general public for the expenditure of public funds for this safety treatment, explain how the treatment works, document historical success, and attempt to allay any fears that individuals may have about adverse side effects. Proactive newspaper articles, explanatory brochures, web-based videos, agency websites, and a variety of other outreach efforts have been used by many state DOTs and local agencies for this purpose.

11. RECOMMENDATIONS:

- a. **Installation:** Continuous, milled edge line or shoulder rumble strips should be installed:
 - i. Along rural or urban corridors where significant numbers of run-off-road crashes that involve any form of motorist inattention have been identified.
 - ii. System-wide on all rural freeways and other rural highways with travel speeds of 50 mph or greater.
 - iii. During any highway project with a history of run-off-road crashes or where shoulder or edge line rumble strips were overlaid during the paving process.
- b. **Mitigation:** To position a rumble strip program for the best chance of public acceptance, agencies should consider the potential adverse side effects mentioned in this advisory, collaborate with stakeholders, and modify the design and application of rumbles to the extent the agency considers appropriate to meet the safety goal.
- c. **Public Outreach:** When rumble strips are being introduced on a large scale or in a new area, public outreach should be considered to inform the public of the purpose and documented success of rumble strips as a safety countermeasure, and explain how this countermeasure fits into the vision and goals of the implementing agency.

12. REFERENCES: The following resources are available on shoulder and edge line rumble strips.

- a. Torbic, D.J. et al, *Guidance for the Design and Application of Shoulder and Centerline Rumble Strips*, National Cooperative Highway Research Program Report 641, 2009.
- b. Morena, David A., *The Nature and Severity of Drift-Off Road Crashes on Michigan Freeways, and the Effectiveness of Various Shoulder Rumble Strip Designs*, Presented at the 82nd annual Meeting of the Transportation Research Board, 2003.
- c. Perrillo, Kerry, *The Effectiveness and Use of Continuous Shoulder Rumble Strips*, Federal Highway Administration, New York, 1998.
- d. Hickey, John J. Jr., *Shoulder Rumble Strip Effectiveness, Drift-Off-Road Accident Reductions on the Pennsylvania Turnpike*, Transportation Research Record 1573, 1997.
- e. Sayed, T., *Impact of Rumble Strips on Collision Reduction on British Columbia Highways: A Comprehensive Before and After Safety Study*, Transportation Research Record 2148, 2010.
- f. Carlson, Paul J. et al, *Evaluation of Wet-Weather and Contrast Pavement Marking Applications: Final Report*, Texas Transportation Institute, 2007.

- g. Potts, Ingrid B. et al, *Benefit-Cost Evaluation of MoDOT's Total Striping and Delineation Program*, Midwest Research Institute, 2008.
- h. Moeur, Richard C., *Rumble Strip Gap Study, Final Report*, Arizona DOT, 1999.
- i. Elefteriadou, L., et al, *Bicycle-Friendly Shoulder Rumble Strips*, Pennsylvania Transportation Institute, 2000.
- j. American Association of State Highway and Transportation Officials (AASHTO), *Guide for the Development of Bicycle Facilities*, Washington, DC, 1999.

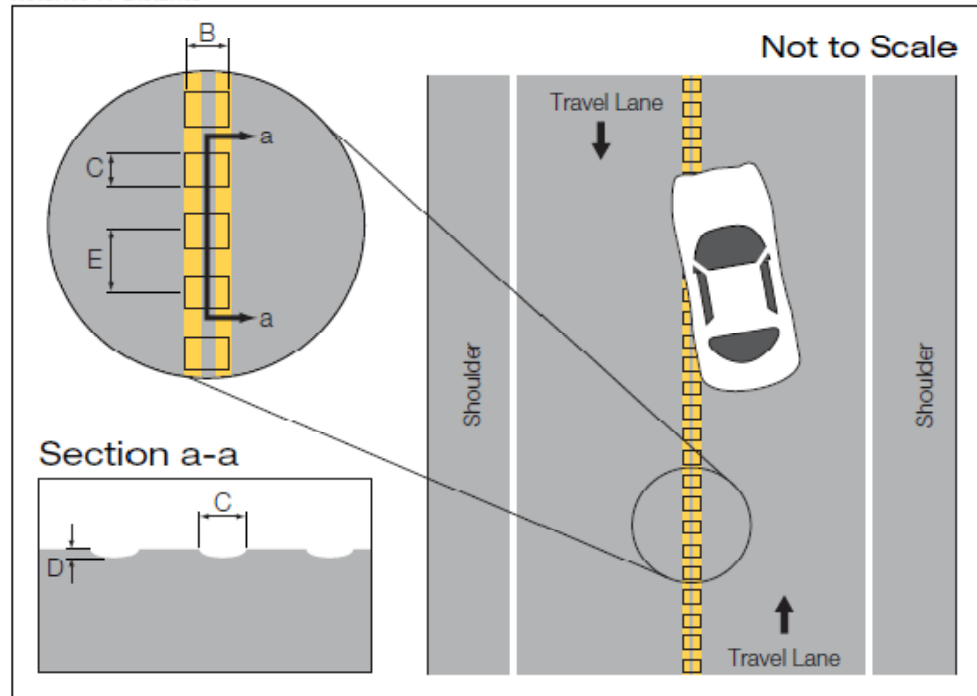
Federal Highway Administration
TECHNICAL ADVISORY
CENTER LINE RUMBLE STRIPS
T 5040.40
April 22, 2011

1. **PURPOSE:** To transmit information and guidelines for the design and installation of center line rumble strips on appropriate segments of paved roads in the United States.
2. **CANCELLATION:** This Technical Advisory supersedes the information on centerline rumble strips contained in Section 9f of T 5040.35, Roadway Shoulder Rumble Strips, dated December 20, 2001.
3. **DEFINITIONS:** A ***center line rumble strip*** is a longitudinal design feature installed at or near the center line of a paved roadway. It is made of a series of indented or raised elements intended to alert inattentive drivers through vibration and sound that their vehicles have left the travel lane. In most cases the center line pavement marking is placed over the rumble strip, which is sometimes referred to as a ***center line rumble stripe***.
4. **BACKGROUND:** One of Federal Highway Administration's (FHWA's) primary safety goals is to reduce the number and severity of roadway departure crashes, which include both run-off-road and cross center line or cross median crashes. Safety improvements intended to address this goal include those that are intended to keep the vehicles on the roadway, those that improve the likelihood of a safe recovery after a roadway departure, and those that reduce the severity of those crashes that do occur. Center line rumble strips are one of the proven countermeasures that reduce the risks of cross center line crashes.
 - a. ***The problem:*** Recent crash data indicates nearly 20 percent of Roadway Departure fatal crashes involve an opposing direction collision. The NCHRP 500 volume on head-on collisions found similar statistics and further indicated that "75 percent occur on undivided two-lane roads," and that "most head-on crashes result from a motorist making an unintentional maneuver."
 - b. ***The target driver:*** Center line rumble strips are designed primarily to assist distracted, drowsy or otherwise inattentive drivers who may unintentionally stray over the center line. For this set of drivers, the audible and vibratory warning provided by center line rumble strips greatly improves the chances of a quick and safe return to their lane. Where drivers don't safely recover, the warning provided may at least decrease the severity of the crash.
 - c. ***Development of center line application:*** Audible and vibration treatments produced through surface texture on pavements have been in use for over fifty years as a means to alert errant drivers leaving the roadway; however, it was not until the 1990's that this strategy was applied to prevent head-on collisions on two-lane roads. Lessons learned in the development of shoulder rumble strips have been applied to center line rumble strips, which have consequently been almost exclusively milled-in. Initial studies placed the rumbles in corridors with a history of opposite direction collisions and were found to be very effective.
 - d. ***Striping the rumble strip:*** A variety of rumble strip patterns have been used, typically placing the center line markings over the rumble strip. This practice improves wet nighttime marking visibility; the back wall of each rumble enhances bead reflection of headlight beams back to the driver with or without the presence of water in the rumble. The practice also increases the longevity of the markings (within the rumble) due to tire wear or plowing activity.

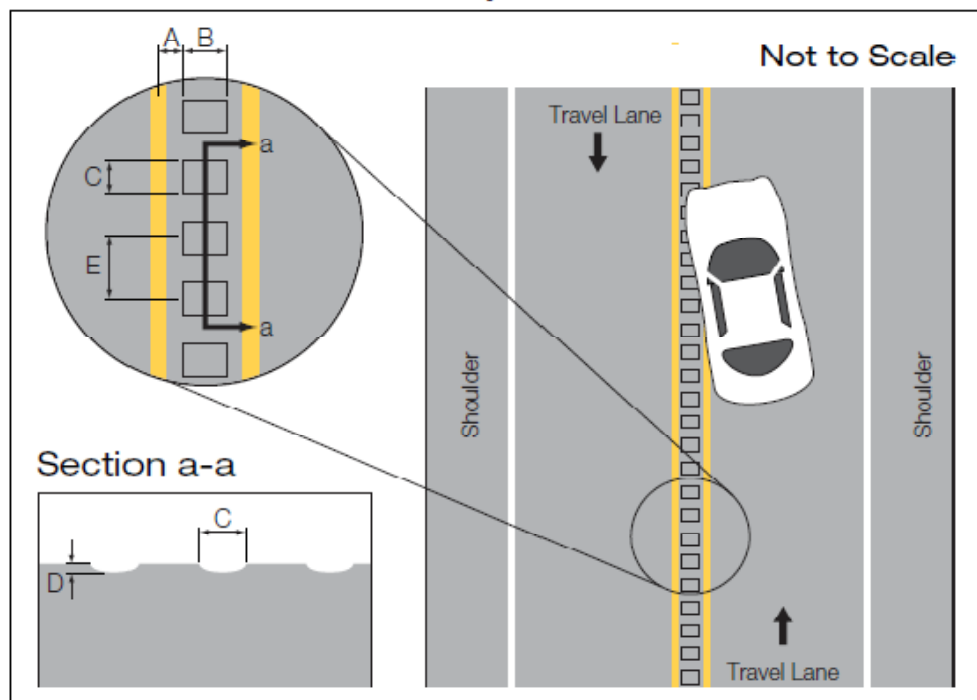
- e. **Benefits to other road users:** The noise that is generated when a vehicle begins to cross a rumble strip has the additional benefit of providing warning to bicyclists, pedestrians, or highway workers who may be in the path of the straying vehicle.
5. **EFFECTIVENESS:** The target crashes for center line rumble strips are head-on and opposite direction sideswipe collisions and single vehicle run-off-road crashes to the left. For these crash types, center line rumble strips are among the most cost-effective safety features available.
- a. **Head-on and opposite direction sideswipe collisions:** For these two crash types, NCHRP Report 641 documents milled center line rumble strip provide statistically significant reductions in injury crashes of 38 to 50 percent on rural two-lane roads and 37 to 91 percent on urban two-lane roads. Reductions were also shown on other types of roadways, but the estimates are not as reliable.
 - b. **Navigational aid in bad weather:** Center line rumble strips may also serve as an effective means of locating the travel lane during inclement weather. Fog, snow or blinding rain often covers pavement markings. The vibration provided by rumbles can assist drivers avoid unintentionally crossing the center line in these conditions. In addition to vibration, there are improved striping benefits. Even a light rain can seriously reduce the retroreflective capacity of pavement markings. When the pavement marking is placed in the rumble strip, the vertical component of the center line rumble stripe will often still be visible under these adverse conditions.
6. **APPLICATION CONSIDERATIONS:** Center line rumble strips have the potential to reduce opposing direction crashes on any undivided, paved road with a marked center line. A summary of rumble strip practices and policies as of 2005 is included in NCHRP Report 641.
- a. **Corridor vs. spot treatment:** It is recommended that center line rumble stripes be installed in corridors or long sections, prioritized by the frequency of target crash types. In the type of opposing direction crash for which rumbles are most effective, the location of the event is typically random, related more to when the driver became distracted or drowsy than to where the vehicle was on the road system. Spot installations are not expected to be as effective. However, within a corridor application, there may be spots where discontinuing the center line rumble strip installation may be prudent. Some of these issues are covered under Section 9 below.
 - b. **Urban vs. rural:** While rumble strips have been extensively used in rural areas, use in urban areas is also effective in producing safety benefits. It is more common for other issues such as low speed or noise issues to limit the need for or use of rumble strips in urban areas.
 - c. **Pavement width:** Centerline rumble strips have been shown to result in vehicles moving 3 to 6 inches away from the rumble strip, which could increase the potential for right-side roadway departures on narrow pavements.
 - d. **Combination of shoulder and center line rumble strips:** The practice of installing both center line and shoulder rumble strips along the same segments of road is becoming more common with no noted detrimental effects. A Missouri study of the installation of rumble strips with wider markings during resurfacing showed the greatest reduction in serious injury crashes were found when both center line and edge line rumble strips were installed with the wider markings.
7. **DESIGN:** The design of rumble strips factors into their effectiveness. The terminology used in this technical advisory is shown in Figure 1.

Center Line Rumble Stripes

Note: No "A" Distance



Center Line Rumble Strips



Legend

→	= Direction of Travel	B	= Length	E	= Spacing
ooo	= Rumble Strip	C	= Width		
A	= Offset	D	= Depth		

Figure 1

- a. **Types:** There are four basic rumble strip designs or types: milled-in, raised, rolled-in, and formed. Typically, only milled rumble strips are used in center line applications.
 - b. **Dimensions:** Optimum dimensions for milled center line rumble strips depend on operating conditions, cross-sectional characteristics, and potential road users. Two key dimensions to increase sound and vibration, and thereby effectiveness, are depth (D) and width longitudinal to the road (C). Most crash studies referenced here evaluated center line rumble strips of 7 inches long by 16 inches wide with a depth of one-half to five-eighths inch. One study showed the variation in length transverse to the road (B) had the least effect on noise produced compared to the other dimensions. The same study indicated that a rumble acting on the driver side tires, such as a center line rumble strip, produced more noise in the vehicle than rumbles to the right, indicating a center line rumble strip may not need to be as deep as a shoulder rumble strip to provide the same audible warning to the driver.
 - c. **Location:** Center line rumble strips are typically placed at the center of 2-lane or 4-lane undivided roads and may lap across a longitudinal pavement joint. A few agencies have design details to avoid cutting the strip across the joint – typically by narrowing the rumble strip and placing the strip on each side of the joint, if the remaining pavement width is adequate. Where pavement width is available, this may provide a small amount of additional buffer between vehicles moving in opposite directions.
 - d. **Continuous vs. intermittent application:** To maximize the effectiveness of this countermeasure in a given corridor, it is desirable for the rumble strips to be installed on as much of the roadway length as feasible. Therefore, most center line rumble strips are installed without any breaks or gaps except at intersections and major commercial driveways. Many agencies use center line rumble strips in passing zones and there has been no indication that this inhibits passing activities among vehicles, including motorcycles.
8. **INSTALLATION:** Typically center line rumble strips are placed so that the center line pavement markings, which may consist of one or two lines, are contained within the rumble. Monitoring to ensure the proper depth and center to center spacing is maintained throughout the length of the installation is also recommended.
- a. **Milled center line rumble:** Most North American transportation agencies mill rumble strips into their asphalt or concrete pavement. The milling operation can be performed at any time, either in small quantity as part of a construction project, or in large quantity, taking advantage of the economy of scale by installing rumble strips for long sections or a number of corridors.
 - b. **Other types:** Raised rumble strips using raised pavement markers or other available products are sometimes used in climates where snow-plowing is not a practice. Effectiveness of these depends on the patterns and dimensions, but some do provide an audible and vibratory effect. Rolled-in and formed rumble strips are not typically used in the U.S. for center line rumble strip applications due to limited applications and concerns which are discussed further in T 5040.39, Shoulder and Edge Line Rumble Strips.
 - c. **Complications caused by normal crown:** When milling into crowned pavements, agencies should be aware of several challenges. First, the milling machine should be equipped with a vertical alignment guide to orient the rumbles on the horizontal, rather than tilted level with the crown on one side of the joint or the other. Second, since the rumble strip depth will vary across the length of the rumble transverse to the roadway (B); specify the desired maximum and minimum depth. Lastly, clearly indicate in project documents where the rumble strip depth will be measured and acceptable tolerances.

- d. **Rumble Stripes:** Milling over existing pavement markings initially reduces the area of the marking visible to the motorist. Proper installation of a center line rumble stripes includes the step of applying the pavement marking over the top of the rumble strips.

9. MITIGATING ADVERSE EFFECTS: A balance between the safety of motorists and the potential adverse effects on the life of the pavement, other road users and nearby residents should be considered when installing rumble strips.

- a. **Maintenance:** Pavements are typically constructed with a longitudinal joint along the center of the road. For asphalt pavements, poorly constructed joints or degradation over time may allow the entry of water, leading to early pavement deterioration. Rumble strips provide another potential reservoir to hold water, and is perceived to accelerate this joint deterioration. Experience has shown that traffic flow near the rumble keeps water from accumulating in the strip. Where there are deterioration concerns, an asphalt fog seal can be placed over milled-in strips to preserve them from oxidation and moisture.
- b. **Bicycle compatibility:** Where pavement width on two-lane roads is narrow; some drivers may align their vehicles further to the right within the lane to avoid the rumbles, thereby crowding the space available to bicyclists. For this reason, it is recommended that on routes with heavy bicycle traffic, the rumble strip design provide 13 ft of pavement beyond the edge of the rumble strip.
- c. **Noise to adjacent residents:** Citizen acceptance of a state or local agency safety countermeasure should be taken into consideration as it can affect the long-term viability of that strategy. The noise produced by vehicles impacting a rumble strip generally is not pleasant to residents along the roadway. While residents would not normally complain about a rumble noise that averted a traffic crash, most rumble noise results from incidental impacts in which the impacting vehicle might not have been heading toward a crash. Agencies can slightly affect the volume of the noise generated by rumble impacts through design modifications; however, they can greatly control the frequency of incidental hits by attention to placement details. For instance, gaps in the rumbles are commonly provided in the vicinity of intersection and driveways, where they would be crossed by left-turning traffic. Some other placement features are more difficult to deal with. Horizontal curvature can produce incidental hits from off-tracking. These hits can be reduced with spiral transitioning or curve widening. Placement of rumbles in no-passing zones will result in expected impacts from passing vehicles, for which there is no easy solution. Most agencies mitigate what they can, but still install the rumbles at these locations.

10. PUBLIC OUTREACH: Public outreach should be considered by any agency that is introducing center line rumble strips into an area for the first time or on a large scale. The outreach goals should make a case to the public for the expenditure of public funds for this safety treatment, explain how the treatment works, document historical success, and attempt to allay any fears that individuals may have about adverse side effects. Proactive newspaper articles, explanatory brochures, web-based videos, agency websites, and a variety of other outreach efforts have been used by many state DOTs and local agencies for this purpose.

11. RECOMMENDATIONS:

- a. **Installation:** Continuous (including passing zones) milled center line rumble strips should be installed:
 - i. Along rural and urban two-lane road corridors where significant number of opposing direction crashes that involve any form of motorist inattention have been identified.

- ii. System-wide on undivided rural roads with travel speeds of 50 mph or greater where the lane plus shoulder width beyond the rumble strip will be at least 13 feet, particularly roads with higher traffic volumes, poor geometrics, or a history of opposing direction crashes.
 - iii. During any highway project with a history of head-on and opposing direction sideswipe collisions, or where center line rumble strips were overlaid during the paving process.
- b. **Mitigation:** To position a rumble strip program for the best chance of public acceptance, agencies should consider the potential adverse side effects mentioned in this advisory, collaborate with stakeholders, and modify the design and application of rumbles to the extent the agency considers appropriate to meet the safety goal.
- c. **Public Outreach:** When rumble strips are being introduced on a large scale or in a new area, public outreach should be considered to inform the public of the purpose and documented success of rumble strips as a safety countermeasure, and explain how this countermeasure fits into the vision and goals of the implementing agency.

12. REFERENCES: The following resources are available on center line rumble stripes.

- a. Torbic, D.J. et al, *Guidance for the Design and Application of Shoulder and Centerline Rumble Strips*, National Cooperative Highway Research Program Report 641, 2009.
- b. Sayed, T., *Impact of Rumble Strips on Collision Reduction on British Columbia Highways: A Comprehensive Before and After Safety Study*, Transportation Research Record 2148, 2010.
- c. Russell, Eugene R. and Margaret J. Rys, *Centerline Rumble Strips – A Synthesis of Highway Practice*, National Cooperative Highway Research Program Synthesis 339, 2005.
- d. Persaud, B.N., *Crash Reduction Following Installation of Centerline Rumble Strips on Rural Two-Lane Roads*, Insurance Institute for Highway Safety, 2003.
- e. Miller, Kenneth W., *Effects of Center-Line Rumble Strips on Non-Conventional Vehicles*, Minnesota Department of Transportation, January 2008.
- f. Mahoney, K.M. et al, *Evaluation of Centerline Rumble Strips on Lateral Placement and Speed on Two-Lane Highways*, Pennsylvania Transportation Institute, 2003
- g. Carlson, Paul J. et al, *Evaluation of Wet-Weather and Contrast Pavement Marking Applications: Final Report*, Texas Transportation Institute, 2007.
- h. Potts, Ingrid B. et al, *Benefit-Cost Evaluation of MoDOT's Total Striping and Delineation Program*, Midwest Research Institute, 2008.