

**AC 2007-349: STATE-OF-THE-ART: EFFECTIVENESS OF RUMBLE STRIPES
ON HIGHWAY SAFETY**

Tulio Sulbaran, University of Southern Mississippi

David Marchman, University of Southern Mississippi

Shelton Houston, University of Southern Mississippi

State-of-the-Art: Effectiveness of Rumble Stripes on Highway Safety

Abstract

Traffic deaths are caused by an array of factors and more than half of these roadway fatalities in the United States are caused by roadway departures. In 2003, there were 25,562 roadway departure fatalities, accounting for 55 percent of all roadway fatalities in the United States. Also in 2003, more than 16,700 people died in run-off-the-road crashes (39 percent of all roadway fatalities), and head-on crashes represented 12 percent of all fatal crashes. In short, roadway departures are a significant and serious problem in the United States.

The work presented herein is a part of a project funded by the Mississippi Department of Transportation to determine the safety effectiveness of “Rumble Stripes” in reducing roadway departures in Mississippi. More specifically, this paper presents a series of assessments done nationwide to measure the impact of rumble stripes. The content of this paper will serve as the foundation to establish the method to determine the impact of rumble stripes in Mississippi.

This work followed a descriptive research methodology with a systematic literature review. The results presented in this paper could be used as the foundation for similar studies in other states and it has the potential to directly benefit construction education by serving as an example of good practice in engineering education

Introduction to Roadway Fatalities

The United States (U.S.) heavily relies on the roadway infrastructure. As shown in Table 1 a considerable number of highway vehicle miles are driven every year. Unfortunately, the number of fatalities is staggering with accidents becoming more frequent, resulting in situations as the one depicted in Figure 1.



Figure 1. Crash Sample Picture [Public Roads 2004]

Every year over 40,000 fatalities occur on U.S. highways (See Table 1) with most of these fatalities due to roadway departures. On average, one roadway departure fatality occurs every 23 minutes, and a roadway departure injury occurs every 43 seconds. It is estimated that the annual cost of roadway departure is \$100 billion [FHWA Resource Center 2006]

Table 1. Highway Vehicle Miles and Fatalities from 2001- 2004
[DOT 2007a, DOT 2007b]

Year	Highway Millions Vehicle Miles	Highway Fatalities
2001	2,797,287	42,196
2002	2,855,508	43,005
2003	2,890,450	42,643
2004	2,962,513	Not Available

The Federal Highway Administration (FHWA) indicates that improvements in infrastructure have helped keep the fatalities number from increasing. However, higher traffic volumes have counteracted any real reductions in the number of fatalities due to roadway departure [Public Roads 2005]. These roadway departures are caused by multiple factors. These factors can be categorized into three groups: Environmental, Human and Design. Table 2 shows the three groups with some examples. It is also possible that a combination of these factors cause roadway departures such as: inattentive drivers, poor environmental conditions or poor road designs.

Table 2. Factors that Cause Roadway Departure

Group	Sample
Environment	Weather or animal crossings
Human	Inattention or drowsiness
Design	Substandard curves, unimproved shoulders, travel lanes that are too narrow

Therefore, countermeasures to prevent or lessen the occurrence of roadway departures are important steps towards improving the safety of U.S. roadways. Roadway departure countermeasures must be designed to keep the motorists in lanes and on the roads, enable the drivers to recover and safely return errant vehicles to the roadway, and keep vehicle occupants from greater harm if a vehicle does leave the roadway [Public Roads 2005].

This paper will focus on a project funded by the Mississippi Department of Transportation to determine the safety effectiveness of one roadway departure countermeasure, rumble stripes, in Mississippi. More specifically, this paper presents a series of nationwide assessments that have attempted to measure the impact of rumble stripes on roadway departures. The paper will also present characteristics of rumble stripes, the project research methodology and the findings of meta-analysis on the effect of rumble stripes.

Additionally, based on this project, the research team will develop supplemental modules of instruction for courses in construction safety; cost estimating, project management and

scheduling. Currently at the researchers' University these courses focus on commercial and residential construction and do not include any highway construction topics. Therefore, bringing real life scenarios on highway construction is expected to enhance the students learning experience.

With more construction graduates being employed by highway construction companies, these companies have requested that highway construction exercises be included in these courses. The Rumble Stripes project was determined to be the most cost-effective method of developing case studies that were specific to Mississippi for some of these courses.

Specifically, case studies will be developed to evaluate the effectiveness of a roadway departure countermeasure such as rumble stripes, and its impact on reducing highway accidents. The case study will also be evaluated to determine cost for developing highway bids and developing a workable schedule as part of a total overlay project. Other topics under consideration include but are not limited to:

- 1) Safety counter measures for winter road maintenance operations: locating depots, routing service vehicles, scheduling vehicles, and configuring a vehicle fleet.
- 2) Scheduling and managing a natural disaster such as estimating debris removal, emergency road repairs, supply chain management and management of network and transportation service data.
- 3) Estimating life cycles for roadway departure countermeasures such as rumble stripes.
- 4) Estimating, scheduling, and safely managing a hazardous materials event.
- 5) Developing, estimating, scheduling and managing wildlife deterrence plans in high traffic and urban areas.
- 6) Environmental impact of rumble stripes and/or other run off road (ROR) countermeasures toward noise pollution, pedestrians and bicyclists.
- 7) Developing "Work Zone" highway safety plans.

Characteristics of Rumble Strips and Stripes

Two of the countermeasures used to increase roadway safety by deterring roadway departures are Rumble Strips and Rumble Stripes. Although in many cases Rumble Strips and Rumble Stripes have been used interchangeable, they do not have the same design characteristics.

Rumble strips are raised or grooved patterns on the roadway shoulders or center lines. Figure 2 shows the dimensions and a schematic profile of Rumble Strips used by the Alaska DOT. Figure 3 provides a picture of a Rumble Strip on a Roadway segment. Rumble strips provide both an audible warning (rumbling sound) and a physical vibration to alert drivers as they are leaving the driving lane [FHWA 2006a]. Noise and vibration produced by shoulder rumble strips are effective alarms for drivers who are leaving the roadway. They are also helpful in areas where motorists battle rain, fog, snow, or dust [FHWA 2007b]. Rumble strips also help reduce highway

hypnosis-a condition where white lines and yellow stripes on long, monotonous stretches of straight freeway can mesmerize and wreak havoc with a driver's concentration [FHWA 2007b].

- . **Lateral Width:** 400mm (16")

- . **Longitudinal Milling Pattern:** 175mm (7") cut, 13mm (½") deep, 125mm (5") flat

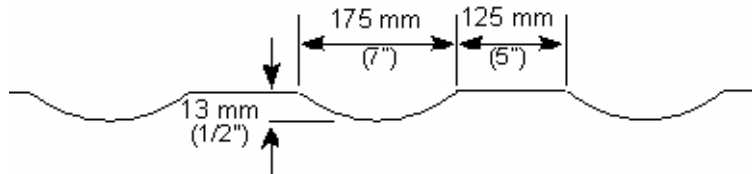


Figure 2. Dimensions and Schematics Profile of Rumble Strips [FHWA 2007c]



Figure 3. Rumble Strip on a Roadway [Safe Roads 2003]

Rumble Strips can be grouped in three types: continuous shoulder, centerline and transverse rumble strips. The most common type of strip is the continuous shoulder rumble strip. These are located on the road shoulder to prevent roadway departure crashes on expressways, interstates, parkways, and two-lane rural roadways. Centerline rumble strips are used on some two-lane rural highways to prevent head-on collisions. Transverse rumble strips are installed on approaches to intersections, toll plazas, horizontal curves, and work zones [FHWA 2007a].

Rumble Stripes are a combination of pavement markings and rumbles strips. Pavement markings are applied on top of the rumble strips. Rumble Stripes enhance visibility as the vertical face of the rumble strip provides a raised texture that enhances the retroreflectivity performance of the striping material [Public Roads 2004] as presented in Figure 4. Because the vertical edges of the strips are painted, the paint line is more visible at nighttime and during wet conditions [Public Roads 2005].



Figure 4. Rumble Stripe Sample on Roadways
 [Amparano, Morena, 2006] & [ATSSA 2006 - Picture by Jim Willis-MDOT]

Research Methodology

A descriptive research methodology was followed to summarize the available literature on the effectiveness of rumble stripes on highway safety. As part of the research methodology, a systematic literature review and a meta-analysis were performed. The meta-analysis combined the results from a number of previous studies, in an attempt to summarize the evidence of rumble stripes impact on highway safety. The meta-analysis included a qualitative component (pre-determined search criteria) and a quantitative component (integration of numerical information) [CHP, 2005].

The qualitative component (search criteria) of the meta-analysis is challenging for most research projects. Various factors, such as very general keywords, can generate an unbearable amount of data to be analyzed. Using very specialized or precise technical keywords can produce zero results or very limited data. Combining the correct keywords with different databases will have a significant impact on the results of the research.

A slight variation in the search criteria (keyword and database) could result in differences in the outcome. Therefore, it is important to explicitly state the search criteria used. The keywords used in this project are presented in Table 3. These two keywords were used after several preliminary searches with a variety of keywords related to the subject. The databases used in this project were limited to the seven databases presented in Table 4. These databases were based on the studied subject and recommendations from the Mississippi Department of Transportation.

Table 3. Keywords/Phrases Used for the Search

Keywords
Rumble Stripes
Rumble Strips (<i>Only used in some databases</i>)

Table 4. Databases: Name, URL Location and Information used to Search

Database's Name	URL	Information
Transportation Research Board (TRIS)	http://trisonline.bts.gov/	TRIS Online provides links to full text and to resources for document delivery or access to documents where such information is available. These may include links to publishers, document delivery services, and distributors.
Federal Highway Administration (FHWA)	http://www.fhwa.dot.gov/search.html	FHWA search provides information regarding the outcomes of partnerships with the state and local agencies to meet the nation's transportation needs. The information provided relates to the FHWA work done cooperatively with governmental agencies, industry, and research community partners to research, develop, test, and implement the latest proven technological advancements including intelligent transportation systems.
National Cooperative Highway Research Program (NCHRP)	http://safety.transportation.org/Default.aspx	This web site offers access to a Safety Portal, where parties engaged in developing and implementing comprehensive state highway safety plans can exchange information, ask questions, and get expert advice from the developers of the AASHTO Strategic Highway Safety Plan implementation guides
National Highway Traffic Safety Administration (NHTSA)	http://www.nhtsa.dot.gov/nhtsasearch/index.asp	NHTSA site has valuable information and statistics related to the many ways that NHTSA works to reduce deaths, injuries and economic losses resulting from motor vehicle crashes. The site is organized by three major sections: 1- Vehicles and Equipment, 2- Traffic Safety and Vehicle Occupants, and 3- General Information.
Transportation Research Board - Research In Progress (TRB-RiP)	http://rip.trb.org	TRB-RiP database contains over 7,800 current or recently completed transportation research projects. Most of the RiP records are projects funded by Federal and State Departments of Transportation. University transportation research is also included.
The National Work Zone Safety Information Clearinghouse (WZSRD)	http://wzsafety.tamu.edu/searches/research.stm	WZSRD database contains 1686 records of journal articles, research reports, research projects, and other types of publications that are related to work zone safety. Each publication record includes bibliographic information, a summary, and a link to full text if available. Each project record includes a description, sponsor, and contact information.
American Traffic Safety Services Association (ATSSA).	http://www.atssa.com/	ATSSA site contains tools to discover the latest news on technology in the roadway safety community and an electronic clearing house of technical issues that affect road safety.

Impact of Rumble Strip/Stripes Nationwide

For a number of years, the Federal Highway Administration (FHWA) has actively endorsed the use of rumble strips as a way to reduce roadway departure crashes [Public Roads 2005]. There have been a number of Rumble Strip and Rumble Stripe projects implemented across the United States. A FHWA report indicates that the following states have implemented extensive rumble strip programs: Kansas, Michigan, Minnesota, Mississippi, Oklahoma, and Pennsylvania, among others [Public Roads 2005]. Some studies have been performed documenting the roadway safety improvements due to the Rumble Strip and Rumble Stripes installation. This section provides a synthesis of studies on Rumble Strip and Rumble Stripes with their outcomes.

- 1- The Missouri Department of Transportation (MoDOT) has been implementing numerous countermeasures to address visibility issues with older drivers. The MoDOT identified eight essential strategies to improve roadway safety, one of which was the installation of shoulder, edgeline and centerline rumble strips/rumble stripes. MoDOT has already installed several miles of center and edgeline rumble strips and rumble stripes [State of Missouri 2007]. However, no information was found regarding studies to quantify the safety impact of rumble stripes on Missouri roadways.
- 2- The Michigan Department of Transportation has evaluated rumble stripes by placing a pavement marking over pre-existing shoulder rumble strips, creating a double edge line system [Filcek et al 2004]. Retroreflectivity of both the standard flat line, and the shoulder rumble stripe, were measured after one year of service, including the winter maintenance activities. The results indicate that dry and wet rumble stripe markings provide 6 and 20 times more retroreflectivity, respectively, than the standard flat edge line markings. These results demonstrate that rumble stripes have higher wet retroreflectivity than the standard flat lines, and that the rumble stripe may be protected from snow removal equipment as indicated by the higher dry retroreflectivity values. A pavement marking protected from snow removal equipment will increase the durability of the marking, extending its service life, and reducing yearly pavement marking costs. [ATSSA 2006]
- 3- The Michigan Department of Transportation through a research project revealed that the milled-in rumble strip demonstrates a design advantage by allowing vehicle tires to partially drop into them, providing a vibration to the vehicle that translates up to the steering wheel. Whereas rolled and concrete intermittent designs can provide some outside noise to alert a drifting driver, the milled-in design produces a louder noise and adds a vehicle vibration that most certainly increases the potential for alerting a drowsy or distracted driver [Public Roads 2005].
- 4- The Michigan Department of Transportation reports that milled-in rumble strips installed on Michigan roadways have reduced drift-off-the-road crashes by 40 percent, through the entire range of traffic volumes studied [Morena 2003]
- 5- The Mississippi Department of Transportation has also experimented with rumble stripes on edge lines at several sites. They concluded that in addition to the excellent audible warning, rumble stripes provide increased retroreflectivity of pavement markings similar to that of profiled markings [Willis and Dean, 2004]

- 6- The Texas Department of Transportation is currently evaluating the wet night visibility of various types of pavement marking materials, including rumble stripes [Carlson, et Al 2005] The results of the first year of the project indicate an overall advantage of a rumble stripe versus a standard flat line of the same marking material with the rumble stripe providing an additional 25 ft of visibility distance. The study indicated that the rumble stripe provides similar visibility to the standard flat line in low rainfall events, but better visibility in medium and heavy rainfall events [ATSSA 2006].
- 7- The Nevada Department of Transportation indicates that the installation of milled-in rumble strips, adjacent to the travel way, is a surefire way to warn drivers that their vehicles are about to leave the travel lane so they can take corrective action. [ATSSA 2002]. Nevada found that with a cost benefit ratio ranging from more than 30:1 to more than 60:1, rumble strips are more cost effective than many other safety features, including guardrails, culvert-end treatments, and slope flattening [FHWA 2007a]. The Nevada department of transportation is currently funding a project to evaluate the effectiveness and feasibility of centerline rumble strips installed in Nevada with respect to placement, operational and safety effects, cost, and service life, and develop guidelines for installations of centerline rumble strips in Nevada [TRB-RiP 2007a].
- 8- The Kentucky Department of Transportation has installed several miles of Rumble Strips and as reported in the Growing Traffic in Rural America [The Road Information Program 2005] Rumble Strips have been found to reduce run off the road crashes by between 25 to 43 percent [Agent et al 2003].
- 9- The Maine Department of Transportation surveyed 50 State DOTs and identified a cost benefit ratio of 50:1 for milled-in rumble strips on rural interstate roadways nationwide [FHWA 2007a]
- 10- The Delaware Department of Transportation has installed several miles of rumble strips. One Delaware case worth noting was the Rumble Strips project on U.S Route 301 (a two-lane, undivided rural highway with a high fatality rate). After the rumble strips were installed, the head-on collision rate decreased 90 percent, and fatalities decreased to zero. These dramatic safety improvements were achieved despite a 30 percent increase in traffic. [FHWA 2007a]
- 11- The New York Department of Transportation has been installing rumble strips for many years. A New York study showed a significant change in the number of roadway departure crashes, injuries, and fatalities after rumble strips were installed on the New York State Thruway. Roadway departure crashes were reduced 88 percent, from a high of 588 crashes in 1993 to 71 in 1997. Total injuries were reduced 87 percent, from a 1992 high of 407 to 54 in 1997. Fatalities were reduced 95 percent, from 17 in 1991 and 1992 to 1 fatality in 1997 [FHWA 2007a].
- 12- The Virginia Department of Transportation won the 2001 National Highway Safety Award for its experiment with continuous shoulder Rumble Strips on the State's 917-mile interstate highway system from 1997 to 2000. During this project, the roadway departure crashes were reduced by 51.5 percent, saving an estimated 52 lives. It is estimated that continuous Rumble Strips technology has prevented 1,085 injuries and 1,150 ROR crashes, with a total cost savings of \$31.2 million in the state of Virginia. [FHWA 2007a].

- 13- The Minnesota Department of Transportation has also begun exploring rumble strips as a potential solution to high crash rates on the State's rural roads. Today, the state has instituted a comprehensive policy that mandates placing edgeline rumble strips on all rural multilane and two-lane highway projects where shoulders are constructed, reconstructed, or overlaid, and where the posted speed limit is 80 kph (50 mph) or greater and shoulders are 1.8 meters (6 feet) or greater in width. According to Gary Dirlam, District 3 traffic engineer for the Minnesota Department of Transportation (Mn/DOT), the department reviewed several reports, including the 1999 FHWA summary report, *Safety Evaluation of Rolled-In Continuous Shoulder Rumble Strips Installed on Freeways* (FHWA-RD-00-032), which estimated that approximately one single-vehicle, run-off-the-road incident (at an average cost of \$62,200) could be prevented every 3 years based on an investment of \$217 to install continuous shoulder rumble strips for 1 kilometer of roadway [Public Roads 2005]
- 14- The California Department of Transportation has also installed several miles of rumble strips on highways including centerlines to replace the double yellow strips as stated by Fitzpatrick [NCHRP 2005].
- 15- The Alaska Department of Transportation conducted a research study to document the success and problems of Rumble Strips with the intent of making recommendations concerning future installations. At the time of the study (2003), "before" crash data was not included because the data collection was ongoing. From the study the following observations were made: 1- Appear to be effective as lane delineations; 2- Snow and ice buildup in rumble strips is generally not a problem; 3- Rumble strips do not appear to produce an external, measurable volume (db) increase over general traffic noise; 4- Pavement deterioration is not a problem [NCHRP 2005].
- 16- The Kansas Department of Transportation is currently conducting a project with the primary objective of investigating and testing in the field the human factors and safety aspects of center-of-lane and center-line rumble strips on two-lane Kansas state rural highways without shoulders. The advantages and disadvantages, including potential legal liability issues, of using a rumble strip on the centerline of two-lane roads will be investigated. A two-stage study will take place. The first stage will assess the feasibility, potential legal, operational and driver expectancy problems, installation, and the impact of rumble strips on various vehicles. Stage two of the study will focus on the design, implementation and evaluation of field tests on center-of-lane rumble strips on two-lane rural highways in Kansas. The hundreds of miles of Kansas highways with no shoulder would result in a payoff of millions of dollars in reduced crash costs [TRB-RiP 2007b].
- 17- The Kentucky Department of Transportation is currently funding a research project to determine the safety benefits of shoulder and centerline rumble strips [TRB-RiP 2007c].

The Development of the Instructional Modules based on Rumble Strips/Stripes

The predominant setting for teaching at Universities is classroom settings. These classroom settings include activities such as: study groups, classroom discussions, project teams and cooperative teaching/learning methods [Schmuck 1988, Slavin 1995]. However, generally in classroom settings students are passive observers and recorders of the events [Penner 1996].

These classroom settings also have a series of constraints directly related to the number of students in the class, number of classes taught by a faculty, percentage of class time expended in non-teaching/learning activities, technology available in the classrooms, students' aptitude towards the classroom environment, time of the class and curriculum design among others.

The classroom constraints describe previously and many other changes in education (such as: technology, accreditations and funding just to mention a few) have inspired faculty to explore other avenues to educate the construction and engineering professionals of the future. One of these avenues is capstone experience. The capstone experience is intended to integrate the knowledge gained within the major and extend, critique, and apply this knowledge to real world applications.

Historically, at the researchers' university this has been accomplished through a field experience. In lieu of this field experience, students working on support of this project will develop modules of instructions based on information collected. Students will be asked to develop learning objectives, project outcomes, analyze incident data, study cost information, etc. The students will be provided with instructional templates which they will complete with a estimated time effort of approximately 300 hours. During these 300 hours the students will implement, document and demonstrate a learning module that considers at least one aspect of the rumble strips/stripes. The materials prepared by the students will then be given to an information technology specialist who will convert them to on-line assessable material. This on-line material will be disseminated in the construction program courses at the researchers' university and available upon request to other universities.

Summary

It can be summarized that, as documented in the literature, fatalities due to roadway departure are at staggering levels. Therefore, it is critical to expedite the assessment of safety countermeasures (such as Rumble Strips and Stripes), especially in Mississippi which has one of the worst safety records in the nation.

In this paper the characteristics of Rumble Strips and Rumble Stripes supported by the Federal Highway Administration studies were presented. Then, based on a systematic literature review of the nationwide implementation and studies on Rumble Strips and Stripes, a synthesis of the current state-of-the-art knowledge regarding the safety impacts of these countermeasures was provided.

The results presented in this paper are very important for the scholarly community, because they can be used as the foundation for similar studies in other states and it has the potential to directly benefit construction education by serving as an example of good practice in engineering education

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