Transverse Rumble Strips at Rural Intersections: Literature Search
July 18, 2019

Prepared for: Brent Rusco

Prepared by: Karen Neinstadt

Resources searched: Transport, TRID, RiP, MnDOT Catalog, Web

Summary: There were not many results that specifically addressed the use of transverse or in-lane rumble strips and/or their efficacy in the last five years. Most of the results were on centerline and shoulder applications and a few that focused on noise levels of various types. If the abstract indicated performance or safety statistics, I included it. A number of the "least relevant results" cover the specific use of transverse rumble strips to deter wrong-way drivers. I have added some of the older results to the category “Results from 2010-2014”.

Most Relevant Results

Title: Rumble Strips: Existing Literature and the State of the Practice in New Mexico, Final Report: URL: http://dot.state.nm.us/content/dam/nmdot/Research/NM12SP-07-001_Rumble%20StripsFINAL2.pdf

Title: Evaluating the Effects of Transverse Bar on Vehicle Speed at an Arterial Road in Kuala Lumpur. Author: MOHD Nur Shuhadah; KADAR HAMSA Abdul Azeez Source: Asian Transport Studies. 2017. 4(4) pp 723-740 (Figs., Refs., Tabs.) Publisher: Eastern Asia Society for Transportation Studies

Abstract: Road safety is a major concern for road users. Vehicles traveling at speeds higher than the speed limit are one of the main reasons for the increased number of accidents along arterial roads in Malaysia. Transverse bars are considered as an effective measure in addressing the increased speed of traffic along arterial roads. This paper investigates the effects of transverse bars on the speed of the vehicles at a road segment along an arterial road in Kuala Lumpur. Two sets of transverse bars at an arterial road in Kuala Lumpur were selected. The design profiles and spot speed of the vehicles at the two selected transverse bars were measured. The speed of the vehicles before, on and after the transverse bars was analysed. The findings show despite the speed of the vehicles having decreased when approaching towards transverse bars, the speed still remains higher than the permissible speed limit.

Publication Year: 2017

Title: Effects of Speed-Control Measures on the Safety of Unsignalized Midblock Street Crossings in China.
Author: Wang Chao; Ye Zhirui; Wang Xinyi; Li Wenting
Publisher: Taylor & Francis
Abstract: The primary objective of this study was to evaluate the effects of different speed-control measures on the safety of unsignalized midblock street crossings. In China, it is quite difficult to obtain traffic crash and conflict data for pedestrians using such crossings, mainly due to the lack of traffic data management and organizational issues. In light of this, the proposed method did not rely on such data, but considered vehicle speed, which is a leading contributing factor of pedestrian safety at mid blocks. To evaluate the speed reduction effects at different locations, the research team utilized the following methods in this study: (1) testing speed differences--on the basis of the collected data, statistical analysis is conducted to test the speed differences between upstream and crosswalk, upstream and downstream, and downstream and crosswalk; and (2) mean distribution deviation--this value is calculated by taking the difference in cumulative speed distributions for the two different samples just mentioned. In order to better understand the variation of speed reduction effects at different distances from speed-control facilities, data were collected from six types of speed-control measures with a visual range of 60 m. The results showed that speed humps, transverse rumble strips, and speed bumps were effective in reducing vehicle speeds. Among them speed humps performed the best, with reductions of 21.1% and 20.0% from upstream location (25.01 km/h) and downstream location (24.66 km/h) to pedestrian crosswalk (19.73 km/h), respectively. By contrast, the speed reduction effects were minimal for stop and yield signs, flashing yellow lights, and crossings without treatment. Consequently, in order to reduce vehicle speeds and improve pedestrian safety at mid blocks, several speed-control measures such as speed humps, speed bumps, and transverse rumble strips are recommended to be deployed in the vicinity of pedestrian crosswalks.
ISSN: 1538-9588
Publication Year: 2017
Title: Driving Simulator Study on the Influence of Speed-Reducing Measures at Highway Interchanges

Authors: Cornu, Joris; Brijs, Kris; Daniels, Stijn; Hermans, Elke; Brijs, Tom; Wets, Geert

Abstract: The most important and immediate cause of accidents on highways is speed. Interchanges are an essential part of this highway network. Belgium has about 40 interchanges representing 5.5% of the total number of casualties on highways. However, relatively little attention is given to interchanges on highways. Therefore, the primary objective of this study is to examine the effectiveness of speed reducing measures in the vicinity of highway interchanges. A driving simulator is used to monitor the driving behavior of 51 participants (36 men) at 14 measurement points in the vicinity of the curve area. A real world location is rebuilt in the driving simulator environment by use of the procedure called geo-specific database modeling. The parameters ‘average speed’ and ‘acceleration/deceleration’ are examined. All three scenarios (1/ baseline; 2/ C43 speed limit sign 90km/h; and 3/ transverse markings) are driven in random order. Based on the results of the simulator study the authors conclude that both the introduction of a lower speed limit of 90km/h, as well as applying transverse markings (i.e. rumble strips) reduce the average speed of the drivers significantly compared to the baseline condition. This reduction in speed is mainly realized before the curve. Concerning the deceleration behavior, it can be concluded that rumble strips generate less abrupt braking maneuvers. Compared to the other scenarios, drivers slow down more gradually which leads to a safer deceleration behavior.

Supplemental Notes: This paper was sponsored by TRB committee AND30 Standing Committee on Simulation and Measurement of Vehicle and Operator Performance.

Monograph Title: TRB 96th Annual Meeting Compendium of Papers

Corporate Authors: Transportation Research Board

Pagination: 18

Conference: Transportation Research Board 96th Annual Meeting

Location: Washington DC, United States

Date: 2017-01-08 to 2017-01-12

Publication Date: 2017-00-00

Report/Paper Numbers: 17-05417

Title: Change of Road Integrated Design Consistency due to Antiskid Transverse Rumble Strips on High-Speed Federal Road FT050.

Authors: Prasetijo Joewono; Zhang Guohui; Guntor Nickholas Anting Anak; Siang Alvin John Lim Meng; Daniel Basil David; Sanik Mohd Erwan

Source: Advances in Civil Engineering Materials. 2018. 7(3) pp 460-472

Abstract: Malaysia is one of many developing countries that have a high rate of road accidents. Most accidents happen to motorcyclists and car users, and motorcycles are deemed 17 times more dangerous than passenger cars. One of the most common accident types are collisions between motorcycles and passenger cars due to a lack of geometric design consistency on roads, wherein drivers make errors because of geometric features. Therefore, this study is conducted to develop a consistency model for motorcycle-car collisions based on the characteristics of the geometric design on the roads and vehicle continuous speed profiles. The study was conducted on the FT050 federal road in Malaysia, from km 31 to km 35. Use of a DG-200 global positioning system (GlobalSat, New
Taipei City, Taiwan), the continuous speed profile was extracted to develop road design consistency profiles based on the following parameters: the bounded area between the profile, the average speed, and the standard deviation of speed along the road. Furthermore, the study investigated the effects of antiskid transverse rumble strip treatment along the section of km 34 to km 35 after the rumble strip treatment. The installation of antiskid transverse rumble strips generally produced a significant reduction in vehicle speeds on the Federal Road FT050, which has posted speed limits of 60 km/h. The mean speed along the sections with antiskid rumble strips declined by 3.4 km/h on federal roads with a speed limit of 60 km/h. The 85th percentile speed declined to 3.8 km/h with a speed limit of 60 km/h. The profiles show that the influence area of antiskid rumble strips would be generally less than 0.5 km. The km 34 to km 35 road section, which is justified based on the design consistency of the area and on the integrated design consistency model between car and motorcycle, is found to be acceptable.

Publisher: ASTM International
Publication Year: 2018
Title: The Temporary Portable Rumble Strip: Road Safety Reinvented
Authors: Jamieson W; Cox T; Mettler C
Conference Title: Twenty-Fourth Canadian Multidisciplinary Road Safety Conference
Citation: Held: 00000-00000. 2014. 1 PDF file, 915 KB, 16p.
Abstract: The scourge of distracted driving is not limited to any one demographic group or nation. It is global, and affects every victim and their families. The dire situation, caused largely by technology, requires technological solutions, including new traffic safety countermeasures. The transverse rumble strip, a countermeasure reinvented as the Temporary Portable Rumble Strip (TPRS) in 2009, is already proving a significant, innovative addition to work zone safety processes and procedures. This device is designed to reduce accidents and save lives by alerting drivers to changing road conditions. The rumble strip provides significant vibration and sound alerts to drivers, forcing them to refocus attention on driving and, most often, reduce their speed. Though not widely known, 85% of work zone fatalities are suffered by drivers, not construction workers. Drivers cause accidents in work zones by following too closely to the car ahead, changing lanes improperly, or driving too fast for conditions. The temporary rumble strip can reduce all three occurrences. Our presentation will show and discuss: design criteria of the temporary portable rumble strip; how the device alerts drivers; work zone applications in which to install temporary rumble strips; specifications from governing agencies. The audience will understand the development of the Temporary Portable Rumble Strip (TPRS) as an effective countermeasure; how TPRS alerts drivers to changing road conditions, like work zones; speed reductions shown with use of TPRS.
Publication Year: 2014
Title: Operational Effects of Transverse Rumble Strips on Approaches to High-Speed Intersections
Authors: Yang, Lingling; Zhou, Huaguo; Zhu, Lingxi; Qu, Hongyang
Abstract: The objective of this study was to determine whether the application of transverse rumble strips was an effective warning device for drivers approaching high-speed intersections. Performance was evaluated for attention-getting characteristics, driver speed choice, and braking behavior. Five intersection approaches on US-280 in Alabama were selected and monitored during both daytime and nighttime conditions. Acoustic and tactile signatures were measured by a specially equipped passenger car under different speed ranges. To examine effectiveness on speed changes, vehicle mean speeds were recorded by radar measurements along the approach to the intersections: 400 ft (122 m) upstream of the transverse rumble strips, right before the transverse rumble strips, and right after the transverse rumble strips. Video cameras were also in place to survey the brake lights of
vehicles driving over the transverse rumble strips to quantify driver behavior. An analysis of variance
F-test and Tukey’s honest significance test revealed that the strips created a recognizable amount of
interior noise and vibration when an automobile crossed over the transverse rumble strips. The
installation of transverse rumble strips generally produced statistically significant (p ≤ .05) reductions
in approach speeds. During daytime and at night, drivers drove at lower speeds through the
intersections compared with the initial upstream speed. The transverse rumble strips also exerted
certain effects on driver braking behavior.

Monograph Title: Human Performance, User Information, and Simulation
ISBN: 9780309441384
Serial: Transportation Research Record: Journal of the Transportation Research Board
Publisher: Transportation Research Board
ISSN: 0361-1981
Issue: 2602
Pagination: pp 78–87
Publication Date: 2016-00-00
Report/Paper Numbers: 16-1552

Title: Human Performance, User Information, and Simulation
Abstract: This issue contains sixteen papers concerned with human performance, user information,
or simulation. Specific topics addressed in this issue include the following: total eyes-off-road time
glance criterion; older drivers’ scanning patterns at intersections; overtaking on two-lane rural roads;
caffeinated chewing gum as a countermeasure to driver fatigue; cell phone restrictions for young
drivers; gap acceptance behavior of mobile phone-distracted drivers; attitudinal determinants of
aberrant driving behaviors; and user acceptance of driverless podlike vehicles. Additional topics
addressed in this issue include: trajectory prediction for turning vehicles; operational effects of
transverse rumble strips; legacy highway advisory systems; collision avoidance behavior; a low-cost
driving simulator; transfer of control from an automated driving suite; a PC-based attention
maintenance training program; and safety and operation performance at a freeway toll plazas.
ISBN: 9780309441384
Serial: Transportation Research Record: Journal of the Transportation Research Board
Publisher: Transportation Research Board
ISSN: 0361-1981
Issue: 2602
Pagination: 145p
Publication Date: 2016-00-00

Title: Speed reduction treatments for high-speed environments
Author: Levasseur, M
Abstract. This report examines the performance of different types of speed-reducing treatments (or
combinations of treatments) in high-speed environments. The project also considered how desired
speed can be aligned with a safe, anticipated operating speed with the goal of making high-speed
roads more self-explanatory. Treatments reviewed included: treatments to support development of
road hierarchies in line with the concept of self-explaining roads; perceptual countermeasures;
transverse rumble strips; vehicle activated signs; gateway treatments; route-based curve treatments;
wide median centrelines; and sight distance adjustments on intersection approaches. Based on the
outcomes of this review, these treatments may merit further consideration for future Austroads
research and guidance.
Least Relevant Results

Title: New Concept Design of Directional Rumble Strips for Deterring Wrong-Way Freeway Entries.
Author: Yang Lingling; Zhou Huaguo; Zhu Lingxi
Source: Journal of Transportation Engineering, Part A: Systems. 2018/5. 144(5) Content ID 04018010(Refs.)
Abstract: Drivers who make wrong-way entries onto freeways pose a serious risk to the safety of other motorists and themselves. As a new countermeasure to mitigate the wrong-way entry issue, directional rumble strips (DRSs) were designed to generate elevated noises and vibrations to warn against wrong-way drivers and a normal level of stimuli to slow down right-way traffic. Five conceptual designs were developed based on Department of Transportation (DOT) guidelines, existing transverse rumble strips implementations, and input from rumble strip vendors. A national survey and extensive field tests were performed to verify the effectiveness of the proposed configurations. Acoustic and tactile signatures of the DRSs were measured by a specially equipped passenger car under different speed categories. The results indicated that the tested patterns could provide similar sound and vibration levels in the wrong-way direction as the existing transverse rumble strips (61.8-80.0 dBA sound signals and 1.1-1.4 g vibrations). The statistical and comparative analyses identified three DRS configurations that could produce greater audible and tactile signals in the wrong-way direction than the right-way direction, thereby serving the purpose of alerting inattentive wrong-way drivers while offering good visual attentiveness and applicability.
Publisher: American Society of Civil Engineers
Publication Year: 2018
speed ranges. The results show that the tested patterns created 61.8 to 80.0 dBA sound signals and 1.1 to 1.4 g vibration in the wrong-way direction when coming into contact with the DRS, indicating that all of the configurations were able to generally provide similar sound and vibration levels as the existing Transverse Rumble Strips (TRS). The statistical and comparative analysis identified three configurations that produced greater audible effect and slight tactile signals for the wrong-way driver than the right-way direction.

**Supplemental Notes:** This paper was sponsored by TRB committee AHB50 Standing Committee on Traffic Control Devices.

**Monograph Title:** TRB 96th Annual Meeting Compendium of Papers

**Corporate Authors:** Transportation Research Board
500 Fifth Street, NW
Washington, DC 20001 United States

**Pagination:** 17p

**Conference:** Transportation Research Board 96th Annual Meeting
Location: Washington DC, United States
Date: 2017-01-08 to 2017-01-12

**Publication Date:** 2017-00-00

**Report/Paper Numbers:** 17-03895

**Title:** Field Verification of Directional Rumble Strips to Deter Wrong-Way Freeway Driving

**Authors:** Xue, Chennan; Zhou, Huaguo; Xu, Dan; Liu, Pan

**Abstract.** This paper summarizes the results of Phase II of a research project developing a novel design of directional rumble strips (DRSs) to deter wrong-way driving (WWD) onto freeway off-ramps. In Phase I of this project, five concept designs of the DRS (named from A to E) were developed to generate elevated sound and vibration to warn against WWD and to generate normal sound and vibration to slow down the right-way (RW) traffic. After initial field tests in Phase I, three final conceptual DRS designs were selected for further field verification, specifically, Patterns C, D3, and E1. Pattern C was designed based on traditional transverse rumble strips (TRSs), but the spacing between the strips was changed to generate different rhythms of sound and vibration. Pattern D3, which was modified based on the advance warning markings for speed humps, increases in thickness and length in each strip. Pattern E1 has a right-angled triangle cross section that can produce the most recognizable sound and vibration from the WWD direction among the three patterns. The objective of this paper was to document the field verification results of the final three patterns and to develop implementation recommendations for applying them on off-ramps. Overall, the field verification results indicated that the tested DRS can generate recognizable interior sound and a moderate amount of vibration to alert wrong-way drivers. Recommendations for implementation were also developed for transportation agencies to identify proper locations for installing them to achieve the best performance based on type and length of off-ramp.

**Supplemental Notes:** © 2019 American Society of Civil Engineers.

**Serial:** Journal of Transportation Engineering, Part A: Systems
Publisher: American Society of Civil Engineers

**ISSN:** 2473-2907

**EISSN:** 2473-2893

**URL:** http://ascelibrary.org/journal/jtepbs

**Volume:** 145

**Issue:** 8
Title: Field Implementation and Verification of Directional Rumble Strips to Deter Wrong-Way Freeway Entries
Authors: Xue, Chennan; Zhou, Huaguo; Xu, Dan; Liu, Pan
Abstract. This paper summarizes the results of Phase II of a research project developing a novel design utilizing directional rumble strips (DRS) to deter wrong-way entries onto freeway off-ramps. In Phase I of this project, five concept designs of the DRS were developed to generate elevated sound and vibration to warn against wrong-way driving (WWD) and to generate normal sound and vibration to slow down the right-way (RW) traffic. After initial field tests in Phase I, three final conceptual DRS designs were selected for further implementation and verification, specifically Patterns C, D3, and E. Pattern C was designed based on traditional transverse rumble strips (TRS), but the spacing between the strips was changed to generate different rhythms of sound and vibration. Pattern D3 had increasing thickness and length for each strip, which also visually warned potential wrong-way (WW) drivers. Pattern E was a right-angled triangle with a different length for the side cross-section which produced the most recognizable sound and vibration from the WW direction among the three patterns. The objective of this paper is to document the field verification results of the final three patterns and to develop an implementation guideline for applying them on off-ramps. Overall, the field verification results indicated that the tested DRS can generate recognizable interior sound and a moderate amount of vibration to affect driver behavior. An implementation guide was also developed for transportation agencies to identify proper locations for installing these patterns to achieve the best performance based on length and type of off-ramps.
Supplemental Notes: This paper was sponsored by TRB committee AHB50 Standing Committee on Traffic Control Devices.

Title: Evaluation of Alternative Intersection Treatments at Rural Crossroads Using Simulation Software.
Author: Peiris Sujanie; Corben Bruce; Nieuwesteeg Michael; Gabler Hampton C; Morris Andrew; Bowman Diana; Lenn Michael G; Fitzharris Michael
Source: Traffic Injury Prevention. 2018/3. 19(sup2) pp S1-S7 (Refs.)
Source Notes: copyright 2018 Monash University Accident Research Centre.
Publisher: Taylor & Francis
Abstract: Rural roads are characterized by hazardous roadsides and suboptimal geometry yet allow for high travel speeds and unfavorable impact angles. In Victoria, 25% of persons seriously injured and 52% of fatalities occur on rural roads, with 30% occurring at intersections. In the United States, almost twice the number of traffic fatalities occur in rural areas than in urban areas, while accounting for less than half of all vehicle miles traveled and 21% of the population. The choice of safety countermeasure is therefore paramount. Simulation software provides a cost-effective means of analyzing alternative intersection treatments with a view to identifying their effectiveness in mitigating
crashes. The aim of this research was to assess the safety benefits of 4 alternative intersection treatments using in-depth crash data with an advanced crash reconstruction process. Using a single serious injury real-world crash from the Monash University Accident Research Centre Enhanced Crash Investigation Study and crash reconstruction software, an exemplar rural crash was reconstructed and validated against real-world data. The crash involved a passenger vehicle (European New Car Assessment Programme 5-star) approaching from a minor road and failing to yield at a give-way sign; the posted speed limit was 80 km/h. The vehicle was struck on the right/driver side by a rigid truck (B-vehicle; 1990) traveling on the major approach (100 km/h). The driver of the case vehicle was seriously injured. Four alternative intersection treatments appropriate for the crash site were constructed in computer-aided design software (Rhinoceros Ver. 5): roundabout; rumble strips; a reduced speed limit; and the combination of lower speed limit and rumble to determine the reduction in crash forces in the presence of the countermeasures. The hypothetical scenarios demonstrate substantial reductions in impact force and different points of impact, resulting in a significantly lower injury severity for the struck driver. Speed limit reduction to 80 km/h on the main approach (from 100 km/h) in combination with rumble strips on both intersection approaches had the most favorable outcome with the crash avoided entirely, assuming speed compliance. The findings have implications for understanding the role of speed in crashes and hence the design of effective countermeasures. Simulation software, validated using real-world data, provides a cost-effective means of evaluating alternative intersection treatments for rural intersections. Scaled up, implementing these treatments would have significant safety benefits and reduce the road trauma currently associated with rural roads.

ISSN: 1538-9588
Publication Year: 2018

Title: Investigation of Exterior Noise Generated by Vehicles Traveling over Transverse Rumble Strips.
Authors: An Deok Soon; Kwon Soo Ahn; Lee Jaejun; Suh Young Chan
Abstract: This study focuses on the impact of vehicle speed, vehicle type, and transverse rumble strip (TRS) design on the sound pressure level perceived by drivers when they traverse a TRS. TRSs are commonly installed on approaches to toll plazas and at intersections, etc. The ability of a TRS to capture a driver's attention is directly related to the magnitude of the sound and vibration. However, the traffic noise generated by TRS creates a problem for adjacent residences and businesses near the roadway. Thus, the aim of this study is to quantify the level of traffic noise and verify the effects of TRS shapes. The research team measured the exterior noise, inner noise, and vibration generated by three types of vehicles (sedan, minivan, and truck) traveling over four types of transverse rumble strip applications (Types A, B, C, and D) with speed range between 40 and 100 km/h. In general, the increase in the exterior noise generated was greater at 100 km/h than at 40 km/h and lower for a sedan than for a truck. Type A generated the highest exterior noise and Type C generated the highest inner noise. The sound level clearly changed according to TRS dimension such as shape, width, and length, etc. Type C showed the best performance with a lower sound pressure level, effective ability to alert the driver, and reduced complaints from adjacent residents after implementation on a highway road in Korea.
Publisher: American Society of Civil Engineers
Publication Year: 2016

Title: Prototyping and Field Testing of a Demand-Responsive Rumble Strip Mechanism
**Authors:** Paz, Alexander; Trabia, Mohamed

**Abstract.** This project involved the development, design, prototyping and testing of a Demand-Responsive Transverse Rumble Strip (DRTRS) mechanism, which becomes active (lowers an array of strips) only when necessary in order to alert drivers of downstream risks. Three alternative mechanisms for the deployment of DRTRS designed and evaluated. A first prototype using an electric actuator was tested. Results illustrate the vibration and noise generated by the prototype. The authors’ evaluation concluded that an innovative hydraulically-activated design is the best approach to deploy the DRTRS. The proposed DRTRS apparatus is modular, and the mechanical components of the DRTRS units are reliable having few components. The hydraulic system will need regular maintenance. However, this system is placed in a cabinet outside of the travel lanes. The DRTRS deployment cost is comparable to existing solutions for intersections, school zones, toll lanes, and speed control zones. A second prototype based on the hydraulic system was built and it is about to be tested on a public facility at the University of Nevada Las Vegas. Results from this testing will provide information about its effectiveness and potential insights to further improving our design to make it even more cost and safety effective.

**URL:** [https://www.nevadadot.com/home/showdocument?id=16054](https://www.nevadadot.com/home/showdocument?id=16054)

**Supplemental Notes:** This document was sponsored by the U.S. Department of Transportation, University Transportation Centers Program.

**Edition:** Final Report

**Corporate Authors:**
Nevada Department of Transportation  
1263 South Stewart Street  
Carson City, NV 89712 United States  
Office of the Assistant Secretary for Research and Technology  
University Transportation Centers Program  
Department of Transportation  
Washington, DC 20590 United States

**Pagination:** 189p

**Publication Date:** 2018-07-00

**Report/Paper Numbers:** 224-14-803 TO 17

**Title:** Design, Prototyping and Field Testing a Demand-Responsive Rumble Strip Mechanism

**Authors:** Paz, Alexander; Trabia, Mohamed

**Abstract.** This project involved the development, design, prototyping and testing of a Demand-Responsive Transverse Rumble Strip (DRTRS) mechanism, which becomes active (lowers an array of strips) only when necessary in order to alert drivers of downstream risks. Three alternative mechanisms for the deployment of DRTRS were designed and evaluated. A first prototype using an electric actuator was tested. Results illustrate the vibration and noise generated by the prototype. The authors’ evaluation concluded that an innovative hydraulically-activated design is the best approach to deploy the DRTRS. The proposed DRTRS apparatus is modular, and the mechanical components of the DRTRS units are reliable having few components. The hydraulic system will need regular maintenance; however, this system is placed in a cabinet outside of the travel lanes. The DRTRS deployment cost is comparable to existing solutions for intersections, school zones, toll lanes, and speed control zones. A second prototype based on the hydraulic system was built and it is about to be tested on a public facility at the University of Nevada Las Vegas. Results from this testing will provide information about its effectiveness and potential insights to further improving our design to make it even more cost and safety effective.
Title: Safety Effects of Portable End-of-Queue Warning System Deployments at Texas Work Zones
Author: Ullman, Gerald L; Iragavarapu, Vichika; Brydia, Robert E
Abstract. The reduction of upstream end-of-queue (EOQ) crashes at work zone lane closures has been a focus of the Texas Department of Transportation, Austin, for several years. An ongoing widening effort on Interstate 35 through central Texas prompted officials to examine and implement technologies to mitigate the impacts of EOQ warning crashes. An EOQ warning system was established, which consisted of a highly portable work zone intelligent transportation system of easily deployable radar speed sensors linked to one or more portable changeable message signs and highly portable transverse rumble strips. The EOQ system was deployed upstream of nighttime lane closures, where queues were expected to develop. Although the sample sizes were relatively small, the trends did suggest that the systems were having a positive effect to reduce crashes. Overall, the EOQ warning system was estimated to have reduced crashes 44% from what they otherwise would have been if the system had not been used. The crashes that did occur were less severe, which was most likely because fewer of them were of the high-speed, rear-end-collision variety. With traditional societal crash cost values updated to 2014 dollars, the use of the EOQ warning system at nighttime lane closures reduced crash costs by $1.36 million over the analysis period. This figure equated to $6,313 in crash cost savings per night of deployment. Compared with the approximate costs of procurement and deployment of these systems, a break-even point was achieved after 95 to 190 nights of use.
Monograph Title: Visibility and Work Zone Traffic Control
Results from 2010-2014

Title: Safety Evaluation of Transverse Rumble Strips on Approaches to Stop-Controlled Intersections in Rural Areas.
Author: Srinivasan Raghavan; Baek Jongdae; Council Forrest
Citation: 2012. 8p
Abstract: Transverse rumble strips (TRSs) (also called in-lane rumble strips) have been used by some agencies to warn drivers in rural areas that they are approaching a stop sign. The strips typically consist of grooves crossing the roadway surface to provide a tactile and audible warning for drivers. Many studies have focused on the effect of TRSs on driver behavior, and there is some evidence that TRSs are effective in reducing the intersection approach speeds. However, the results from these crash-based studies are not reliable due to the lack of rigor in the accident evaluation designs. The objective of this effort was to examine the impact of TRSs on crashes, specifically total crashes, injury crashes, and specific crash types, such as right-angle and run stop sign crashes. The effort also included an economic analysis to investigate the tradeoffs between different crash types. Data on rural intersections with minor-leg stop control where TRSs were introduced was provided by the Iowa Department of Transportation (Iowa DOT) and Minnesota Department of Transportation (MnDOT).
Publication Year: 2012

Title: Effects of transverse rumble strips on safety of pedestrian crosswalks on rural roads in China.
Authors: Liu Pan; Huang Jia; Wang Wei; Xu Chengcheng
Citation: Accident Analysis & Prevention. 2011/11. 43(6) pp 1947-1954(10 Figs., Refs., 2 Tabs.)
Abstract: The primary objective of this study is to evaluate the impacts of transverse rumble strips in reducing crashes and vehicle speeds at pedestrian crosswalks on rural roads in China. Using crash data reported at 366 sites, the research team conducted an observational before-after study using a comparison group and the empirical bayesian method to evaluate the effectiveness of transverse rumble strips in reducing crashes at pedestrian crosswalks. It was found that transverse rumble strips may reduce expected crash frequency at pedestrian crosswalks by 25%. The research team collected more than 15,000 speed observations at 12 sites. The speed data analysis results show that transverse rumble strips significantly reduce vehicle speeds in vicinity of pedestrian crosswalks on rural roads with posted speed limits of 60 km/h and 80 km/h. On average, the mean speed at pedestrian crosswalks declined 9.2 km/h on roads with a speed limit of 60 km/h; and 11.9 km/h on roads with a speed limit of 80 km/h. The 85th percentile speed declined 9.1 km/h on roads with a speed limit of 60 km/h; and 12.0 km/h on roads with a speed limit of 80 km/h. However, the speed reduction impacts were not found to be statistically significant for the pedestrian crosswalk on the road with a speed limit of 40 km/h. The study also looked extensively
at the influence area of transverse rumble strips on rural roads. Speed profiles developed in this study show that the influence area of transverse rumble strips is generally less than 0.3 km.

**Publisher:** Elsevier  
**Publication Year:** 2011  
**Title:** Effects of Transverse Rumble Strips on Safety of Pedestrian Crosswalks on Rural Low-Volume Roads in China.  
**Authors:** Liu Pan; Huang Jia; Wang Wei; Xu Chengcheng  
**Conference Title:** Transportation Research Board 90th Annual Meeting.  
**Location:** Washington  
**Citation:** 20110123-20110127. 2011. 17p(Figs., Photos., 11 Refs., 2 Tabs.)  
**Abstract:** The primary objective of this study is to evaluate the impacts of transverse rumble strips in reducing crashes and vehicle speeds at pedestrian crosswalks on rural low-volume roads in China. Using crash data reported at 366 pedestrian crosswalks, the research team conducted an Empirical Bayesian (EB) before-after study using comparison groups to evaluate the effective of transverse rumble strips in reducing crashes at pedestrian crosswalks. It was found that the deployment of transverse rumble strips may reduce expected crash frequency at pedestrian crosswalks by 24%. The research team collected more than 15,000 speed observations at 12 sites in Jiangsu and Guangdong Provinces in China. The speed data analysis results show that transverse rumble strips significantly reduce vehicle speeds in vicinity of pedestrian crosswalks on rural low-volume roads with posted speed limits of 60 km/hr and 80 km/hr. On average, the mean speed at crosswalks declined 9.2 km/hr on roads with a speed limit of 60 km/hr; and 11.9 km/hr on roads with a speed limit of 80 km/hr. The 85th percentile speed declined 9.1 km/hr on roads with a speed limit of 60 km/hr; and 12.0 km/hr on roads with a speed limit of 80 km/hr. However, the speed reduction impacts were not found to be statistically significant for the pedestrian crosswalk on the road with a speed limit of 40 km/hr. The study also looked extensively at the influence area of transverse rumble strips on rural low-volume roads. Speed profiles developed in this study show that the influence area of transverse rumble strips is generally less than 0.3 km.

**Publication Year:** 2011  
**Title:** Practice of Rumble Strips and Rumble Stripes  
**Citation:** TRB NCHRP Synthesis 490  
**URL:** [http://www.trb.org/Publications/Blurbs/174393.aspx](http://www.trb.org/Publications/Blurbs/174393.aspx)  
**Title:** Design Guidance for High-Speed to Low-Speed Transitions Zones for Rural Highways  
**Citation:** TRB NCHRP Report 737  
**URL:** [http://www.trb.org/Main/Blurbs/168309.aspx](http://www.trb.org/Main/Blurbs/168309.aspx)  
**Title:** Evaluation of Transverse Rumble Strips for Work Zones  
**Abstract:** Plastic Safety Systems has developed RoadQuake, a portable rumble strip, which is 11-feet in length, 12-inches wide and 0.8125-inches in height. This rumble strip has a profile twice the height of any rumble strip previously evaluated. The University Transportation Center at Cleveland State University and the Department of Civil Engineering at Ohio University proposes to evaluate the effectiveness of Plastic Safety Systems RoadQuake transverse rumble strips with regard to delineation and safety.  
**Project Contract Numbers:** DUFFY18E  
**Status:** Active
Title: Designing safer roads to combat driver errors: rural crashes
Authors: Candappa, N; Devlin, A; Logan, D; Corben, B
Abstract. The incidence of serious casualty run-off-road crashes in rural Western Australia is significant. Driver behaviour including inadvertent error and deliberate unsafe behaviour compound this issue. Many countermeasures were identified in the literature to address driver error in WA along remote and regional areas. These ranged from perceptual countermeasures such as transverse lines and wide centreline marking to physical measures such as rumble strips and increased lighting. A taxonomy was developed to link the areas of concern with respect to road design and driver error, with available countermeasures.

Corporate Authors: Curtin-Monash Accident Research Centre
GPO Box U1987, Perth, WA 6845, Australia
Perth, Western Australia
Pagination: 57p
Publication Date: 2013-09-00
Source Agency: ARRB
Melbourne, Victoria Australia

Title: Toolbox of Countermeasures for Rural Two-Lane Curves
Authors: Hallmark, Shauna; Hawkins, Neal; Smadi, Omar
Abstract. The Federal Highway Administration (FHWA) estimates that 58 percent of roadway fatalities are lane departures, while 40 percent of fatalities are single-vehicle run-off-road (SVROR) crashes. Addressing lane-departure crashes is therefore a priority for national, state, and local roadway agencies. Horizontal curves are of particular interest because they have been correlated with increased crash occurrence. This toolbox was developed to assist agencies address crashes at rural curves. The main objective of this toolbox is to summarize the effectiveness of various known curve countermeasures. While education, enforcement, and policy countermeasures should also be considered, they were not included given the toolbox focuses on roadway-based countermeasures. Furthermore, the toolbox is geared toward rural two-lane curves. The research team identified countermeasures based on their own research, through a survey of the literature, and through discussions with other professionals. Coverage of curve countermeasures in this toolbox is not necessarily comprehensive. For each countermeasure covered, this toolbox includes the following
information: description, application, effectiveness, advantages, and disadvantages. Countermeasures covered are as follows: speed signs, chevrons, widening/adding paved shoulders, reflective barriers, high-friction treatments, raised pavement markers, edge lines, transverse pavement markings, vertical delineation, rumble strips, rumble stripes, on-pavement curve signing, flashing beacons, dynamic curve warning systems, and pavement inset lights.

http://www.dot.state.mn.us/research/TS/2013/201325.pdf

Supplemental Notes: This research was sponsored by the U.S. Department of Transportation, University Transportation Centers Program. A Final Report was published in June 2012, and the Revised Final Report was published in October 2013.

Edition: Revised Final Report

Corporate Authors: Iowa State University, Ames
Center for Transportation Research and Education, 2711 South Loop Drive
Ames, IA 50011-8664 United States

Iowa Department of Transportation
Office of Traffic and Safety, 800 Lincoln Way
Ames, IA 50010 United States

Midwest Transportation Consortium
Iowa State University, 2711 South Loop Drive, Suite 4700
Ames, IA 50010-8664 United States

Research and Innovative Technology Administration
1200 New Jersey Avenue, SE
Washington, DC 20590 United States

Pagination: 81p

Publication Date: 2013-10-00

Report/Paper Numbers: IHRB Project TR-579; InTrans Projects 07-311; InTrans Projects 08-320