The Effectiveness and Use of Continuous Shoulder Rumble Strips

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NOTICE

A 1995 federal survey estimated that at least 100,000 police-reported motor vehicle crashes are caused by drowsiness and fatigue *(1)*. (It is estimated that less than one-half of all crashes are reported by the police). Due to the driver's falling asleep at the wheel, there are approximately 1,500 deaths and 71,000 injuries per year. Additionally, one million crashes are caused by driver inattention each year, and sleep deprivation and fatigue make attention lapses more likely to occur *(1)*. Fatigue crash reduction efforts include public information and education campaigns about the dangers of driving while fatigued and the signs of fatigue. Training for traffic safety professionals and other education about drowsy driving prevention and the use of fatigue related run-off-road preventive technologies, such as continuous rumble strips on roadway shoulders, have mitigated crashes associated with fatigue related run-off-road crashes.

Previous studies have been performed to determine that continuous shoulder rumble strips are an effective countermeasure to run-off-road crashes. Single vehicle run-off-road crashes are characteristic of drowsy driving and fall-asleep crashes. Continuous shoulder rumble strips have been found to decrease single vehicle run-off-road crashes from 15 to 70 percent *(2)*. New York state has had tremendous success in reducing run-off-road crashes since the installation of over 3140 shoulder-kilometers of rumble strips on the New York State Thruway, and an additional 5086 shoulder-kilometers of rumble strips on Interstate highways and parkways.

Continuous shoulder rumbler strips are being used throughout the country, although the value and knowledge base, while expanding, is still limited. The purpose of this report is to establish the considerations, costs, effects, and benefits of continuous shoulder rumble strips. This research will have a focus on the northeast states, including background information from each state in the northeast region that is currently using continuous shoulder rumble strips. In addition this report will address some other states' experiences with continuous shoulder rumble strips.

BACKGROUND INFORMATION

Continuous shoulder rumble strips are currently being used in 85 percent of states in the United States, however, their use is highly variable and warrants vary from state to state *(3)*. Design considerations have been given to the type of rumble strips used, installation, costs, placement, effects on the environment, and benefits from their use. Currently some states that use continuous shoulder rumble strips are beginning to establish policies for their application, and most states without continuous shoulder rumble strips are considering their installation.

Types of Rumble Strips

There are three different types of rumble strips that have previously been or are currently being used: milled, rolled, and formed. These three types differ by their method of installation, size, shape, spacing, and the noise and vibration they produce. Milled rumble strips are preferred because of their method of installation, their minimal efforts on pavement structures, and the increased noise and vibrations that they produce. Many states that currently use milled rumble strips have historically used rolled rumble strips with varying success *(4)*. This report will focus primarily on milled rumble strips, as they are considered by most to be the preferred rumble strips.

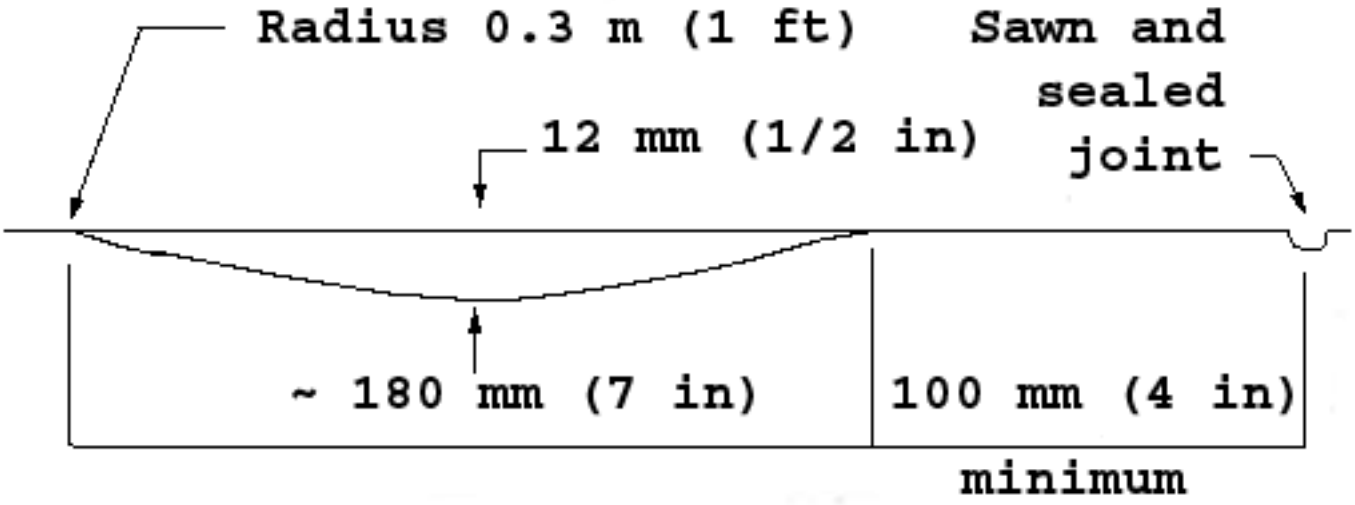
Milled Rumble Strip Installation

Milled rumble strips can be installed on existing, new, or reconstructed asphalt shoulders, therefore allowing greater flexibility for installation. Milled rumble strips are produced using a mechanical device with a rotary cutting head which results in a smooth, uniform, and consistent cut *(4)*. The produced rumble strips are 180 millimeters (mm) wide (plus or minus 13 mm) in the direction of travel and 400 mm long (perpendicular to the direction of travel). The depressions have concave circular shapes with minimum depths in the center at 13 mm deep *(4)*. Due to the width of the rumble strips, the resulting tire drop is approximately 13 mm when passing over the milled rumble strip.

The installation of milled rumble strips is as follows: the machine (that is used to mill in the rumble strips) has a blade that is programed to cut the same shape, depth, width, and length into the pavement. The impressions are made at a pre-determined offset distance from the outer edge of the roadway edge line. This offset can be altered to accommodate variations in the roadway segments *(5)*. After the machine has cut the shape, the resulting debris is swept, collected, and discarded appropriately. (If the debris is left on the roadways for any period of time, it will meld back into the pavement.) Because the rumble strips are "cut" into the pavement, they can be made equally well on new, existing, or reconstructed shoulders. A photo of the installation of a milled rumble strip can be seen in Figure 1. Typical dimensions of milled rumble strips can be seen in Figure 2.

FIGURE 1. Installation of a Milled Rumble Strip

FIGURE 2. New York State's Milled Rumble Strip Design



Rolled Rumble Strip Installation

To install rolled-in rumble strips a roller with steel pipes uniformly welded to drums passes over the pavement pressing narrow depressions into the new or reconstructed hot asphalt. The excess pavement is concurrently pushed to the sides of the newly formed strip and hardens. The rolled rumble strips are kept narrow to indent the asphalt, having typical dimensions of 38 mm wide and 31.9 mm deep *(4)*. The resulting tire drop is approximately 0.76 mm, which is approximately 1/26 of the resulting vertical tire drop of the milled rumble strips. The lower tire drop is a result of the decreased width in the direction of travel; it results in less noise and vibration than that of the milled rumble strips.

The rolled rumble strips have considerable maintenance and construction problems. For example, rolled rumble strips cause a reduction in shoulder asphalt density due to the non-uniform compaction during construction. The increased voids formed along the joint trigger premature degradation of the shoulder *(4)*. Additionally, the excess material resulting from the installation may increase maintenance problems after the pavement stabilizes, particularly when traversed by vehicles and plow machines. Also, the rolled rumble strips are typically inconsistent in depth due to many variables (for example, pavement temperature and asphalt density) during resurfacing that affect the rate of the hardening of the asphalt. Finally, after rolled rumble strips have become worn, they typically have long sections of smoothed out patterns which exhibit less noise and have little or no effect on fatigued drivers *(4)*.

Formed Rumble Strip Installation

Formed rumble strips are installed into Portland Cement Concrete (PCC). They were installed in the late 1980's in several locations by being formed in the surface of fresh PCC. Formed rumble strips are no longer installed in the region due to the commonly used asphalt shoulder, however, they were very effective in producing loud noises and strong vibrations *(5)*.

Costs

Costs in the installation of milled rumble strips have dramatically decreased over the years with increased installation and technological advances. For example, in 1990 the New York State Department of Transportation reported paying $6.18 per linear meter as compared to $0.49 per linear meter in 1998. Table 1 provides additional cost data for milled rumble strip installation on the New York State Thruway from 1993 to 1996. These costs do not include the maintenance and protection of traffic (M&PT). The trend is apparent that throughout the years the price of installation has decreased. Additionally, the cost of installation is also dependent on the project size; e.g., the larger projects result in lower dollar values per meter.

TABLE 1. Milled Rumble Strip Installation Costs (New York State Thruway Authority)

Year	Cost ($/meter)
1993	3.63
1994	0.98-1.31
1995	0.48
1996	0.38

ROADWAY CONSIDERATIONS

Several considerations have been made about the placement of continuous shoulder rumble strips on roadways, including the roadway environment (rural versus urban), the functional classification of the roadways, and the physical location on the roadways. Additional considerations were made to take into account the environmental conditions (for example, the typical weather and pavement conditions), noise effects, the effects on bicyclists, and the possible migration of crashes caused by continuous shoulder rumble strips.

Placement of Rumble Strips

Rumble strips have been installed in several different locations within the cross section of the roadway, depending upon their purpose and location (urban, suburban, rural). Variations also exist between the location and/or continuity of the rumble strips, partially due to the difference in environments (width of shoulder) that exist and the intended purposes.

Transverse Rumble Strips

Transverse rumble strips are used to alert drivers of an upcoming change or hazard in the roadway *(6)*. Additionally they are used to warn drivers of needed lane changes, the need to slow down or stop, or changes in the roadway alignment. Typical locations for these rumble strips are on approaches to intersections, toll plazas, horizontal curves, and work zones *(7)*. Sometimes nearby resident may complain of being disrupted when travel lane rumble strips are traversed. Additional concerns are the additional maintenance that may be required, motorcyclists and bicyclists concerns, and motorists using opposing lanes to avoid rumble strips.

Centerline Rumble Strips

Several states have installed rumble strips on the centerline of two lane rural roadways to prevent crossover crashes. In particular, rumble strips are being installed where there are high incidents of crossover crash locations. The centerline rumble strips are applied using the milled technology and applying painted centerline strips on top of the rumble strips. Delaware, Maryland, and Pennsylvania have used centerline rumble strips and have collected before and after crash data. The data from Pennsylvania showed a large reduction in head-on crashes, however, many other roadway improvements were concurrently made. Thus, the crash reduction can not be attributed solely to the addition of rumble strips, but can be concluded as an elemental effect of other roadway enhancements. Delaware installed center line rumble strips on a two lane undivided rural highway to reduce the number of head-on crashes. For 36 months before the use of rumble strips there were six of these crashes resulting in fatalities, 14 crashes resulting in injuries, and 19 crashes resulting in property damage. Data were collected for 24 months after the installation of rumbles strips; the number of crashes resulting in fatalities decreased from six to zero, injury crashes decreased from 14 to 12, and property damage crashes were reduced from 19 to six. Therefore, the total number of crashes were reduced from 39 crashes (in 36 months) before the rumble strips to 18 crashes (in 24 months) after the installation of rumble strips *(8)*.

Continuous Shoulder Rumble Strips

Rumble strips are commonly placed continuously on the shoulder of roadways to alert drivers that they are leaving the roadway. The strips have been primarily used on expressways, Interstates, and parkways, although

in some states they are also used on two lane rural roadways. Their effects on reducing crashes due to driver fatigue or inattention in both rural and urban environments are similar. Since the introduction of continuous shoulder rumble strips, there has been a reduction in the total number of crashes, total injuries, and total fatalities for single vehicle run-off-road crashes in New York state *(9)*.

There is concern about the placement of continuous shoulder rumble strips across bridge decks, areas with narrowing lateral clearance on roadways (i.e., approaching a bridge), and acceleration/deceleration lanes. New Jersey's policy on the installation and application of continuous shoulder rumble strips describes areas where continuous shoulder rumble strips should not be installed. These areas include bridge decks and 30.5 meters in advance and beyond all intersections and driveways. New Hampshire and Connecticut have reported that they do not use continuous shoulder rumble strips on bridge decks or acceleration and deceleration lanes. Massachusetts, Maine, and New York install continuous shoulder rumble strips on acceleration/deceleration lanes, but not on the ramp proper. New Jersey's policy states that continuous shoulder rumble strips are needed when the shoulder approaching a bridge overpass or underpass is reduced or eliminated. In this situation the continuous shoulder rumble strips should be provided at a minimum of 152.5 meters in advance of the bridge.

The distance between the continuous shoulder rumble strips and the edge of the traveled way varies from state to state and transportation agencies depending upon factors such as the width of the shoulder and noise concerns. In Maine the minimum shoulder requirements are 1.8 meters (m) for the median shoulder and 3.05 m for the right shoulder on divided highways. This standard size for shoulders may differ only in a very small number of sections where guardrail is located closer to the travel lane. New Hampshire, which has wide shoulders (up to 3.67m), places continuous shoulder rumble strips further from the edge of the travel way. For shoulders 1.83 m or wider, an offset of 770 m is used from the edge of the traveled lane pavement markings. For shoulders less than 1.83 m wide, a 153 mm offset is used. Placing the continuous shoulder rumble strips further from the traveled way results in less "hits" and therefore fewer noise complaints. Additionally, because the continuous shoulder rumbles strips are further from the traveled way, the plow operators comfort level increases and there are decreases in the wear on the rumble strips. Because the shoulders are very wide, there is still a large recovery distance for the vehicles after they have traversed the rumble strip, allowing time for the driver to correct their vehicles' path. Table 2 illustrates the distances between the edge of the rumble strip and the edge of the traveled way for each state.

There is concern about where the continuous shoulder rumble strips should be installed. Limitations have been made to determine the minimum shoulder needed for the installation of continuous shoulder rumble strips. Each state in the region provided their minimum requirements for shoulder widths as detailed in Table 2. These width requirements are generally based upon the width needed for the milling machines.

TABLE 2. Minimum Shoulder Width and Offset Requirements

State	Offset from Travel Way		Minimum Shoulder Width	
	Right	Median	Right	Median
	(meters)	(meters)	(meters)	(meters)
Connecticut	0.31	0.15	0.92	0.92
Maine	0.10	0.10	3.06	1.22
Massachusetts	0.25	0.10	1.50	1.50
New Hampshire	0.76*	0.76*	1.83	1.83
New Jersey	0.10	0.10	2.44	1.52
New York (DOT)	0.25	0.10	1.22	0.92
New York (Thruway Authority)	0.41	0.31	**	**

* if shoulder is 1.83 meters or wider, otherwise 0.15 is the minimum
** no written policy exists because the Thruway only has limiting shoulder within urban areas, where rumble strips are not installed

Weather

There is concern about the effects of inclement weather on continuous shoulder rumble strips, such as the collection of ice and snow in the rumble strips. Some have hypothesized that when water is trapped in the rumble strips and then freezes, icy conditions may occur and cause a threat to drivers. On the contrary, it has been noted that the down slope drainage of the shoulders and the proximity of the rumble strips to the traveled way prevent water build up. The speed, turbulence, and vibrations from the passing vehicles tend to knock the debris, ice and water from the cut of the rumble strip *(10)*. Additionally, since a typical rumble strip is 12.7 mm deep and usually does not completely fill with rain or snow, there most likely will not be ice build-up.

Although there is not a great risk of ice forming within the rumble strips, problems arise with rolled rumble strips when snow and ice is removed (plowed) from the shoulders and nearby roadway. As a result of the rumble strips being rolled into the pavement, excess asphalt is pushed up above the pavement surface (both in front and behind the rumble strips). Therefore, when the plow passes over the rumble strips, the excess pavement is scraped off reducing the effectiveness of the rumble strips *(6)*.

Continuous shoulder rumble strips provide an advantage in inclement weather by acting as a guide for the travel lanes. Truck drivers have stated that the continuous shoulder rumble strips serve as an aid in determining the edge of the traveled way in low visibility conditions, such as heavy snow, fog, and ice *(11)*. They provide a roadway delineation in conditions where the roadway edges would otherwise not be distinguishable *(10)*. Additionally, in mountainous terrain they have provided tread for vehicles traveling up large slopes *(10)*.

Degradation of Pavement

There has been no indication of premature degradation of pavement resulting from the installation and use of milled rumble strips on new pavement. It was noted that installation of milled rumble strips on older shoulder pavements with previous degradation and cracking, results in the rumble strip island being more likely to wear away more rapidly due to the hits that the rumble strips receive. However, in New York milled rumble strips were applied to previously deteriorated pavement, and the rumble strips were noted to be in good condition, producing loud noises and strong vibrations. In areas where the milled rumble strips were deteriorated they still produced high audible levels and strong vehicle vibrations.

Rolled rumble strips must be installed on new or reconstructed pavements thereby reducing the concerns with previously degraded pavements. There is concern about the degradation of pavement as a result of the installation method of rolled rumble strips. The installation of rolled rumble strips tends to leave a pavement with higher air voids which may lead to premature pavement degradation.

Type of Pavement

Concerns have been given to the type of pavement where the rumble strips are being installed. In particular, concerns were displayed about the installation of rumble strips on open-graded asphalt pavement. Massachusetts has installed milled rumble strips on their open-graded pavement within the past three years. They reported having no problems with installation, and no evidence of pavement degradation within the past two years.

Pavement Thickness

The pavement thickness must be thick enough to provide depth to mill out the rumble strips. New York State Department of Transportation includes in their policy a minimum requirement for pavement thickness regarding rumble strip installation. Their policy states that, "SAFE-STRIPS (continuous shoulder rumble strips) should only be installed on shoulders in reasonably good condition, and in the case of asphalt shoulders, having a minimum thickness of 2 1/2 inches (60 mm). They should not be milled into existing shoulders that are rated as either deformed or having moderate to high degrees of deformation and/or cracking distress as defined by the Pavement Rehabilitation Manual. They should also not be installed on Type 1 Optional Flexible Shoulders or other asphalt shoulders with less than 1 inch (25 mm) of top course. [Pavement surfaces less than one inch in depth have been found to cause debonding.] *(12)*."

Pavement Overlay

Massachusetts has had experience filling in rumble strips to help promote traffic flow through work zones. When performing work on an area approaching a bridge deck, the state diverted traffic from the travel lanes onto the roadways shoulders. To help move traffic smoothly the state paved over the rumble strips. To pave the rumble strips a trench was milled along the shoulder rumble strips (removing the rumble strip islands) and the trench was filled with asphalt. This aided in providing for uniform compaction along the area of the strip. Traffic then temporarily drove on the shoulder once the rumble strips were filled in. Once the construction was completed and the traffic was moved back onto the roadways, the shoulder was resurfaced and rumble strips were milled into the new asphalt overlay.

Noise

The desired results from continuous shoulder rumble strips are the vibrations and noise produced to alert drivers that they are leaving the travel lane. Adversely, high levels of noise can be a significant concern for nearby residential environments. Complaints have been made from residents living in close proximity to roadways equipped with continuous shoulder rumble strips about the noises produced. Although the rumble strips are rarely driven over (only by those vehicles leaving the roadways), some complaints have been made even based on infrequent events.

Ideally, the desired effect of a vehicle passing over a continuous shoulder rumble strips should be a sound loud enough to be heard inside any type of vehicle, and a strong vibration serving as the main indicator for drivers. The sound inside of an operating passenger vehicle is approximately 60 decibels, and the Office of Motor Carrier set the maximum permissible noise emission level inside of an operating cab of a large truck at 90 decibels *(13)*. Therefore, rumble strips should create noise levels that can be heard inside of an operating commercial motor vehicle cab, in addition to the strong vibrations produced. Noise levels produced by rolled and milled rumble strips were recorded while a truck passed over the rumble strips. The volumes within the cab traveling 105 km/h were 86 decibels for rolled rumble strips and 89 decibels for milled rumble strips. The 3 decibel difference is a perceptible difference *(14)*. Due to the increased noise and vibrations, milled rumble strips are noted to be more effective.

As mentioned, complaints have been made about the noise that is created from vehicles that are driving on the continuous shoulder rumble strips. Continuous shoulder rumble strips located in urbanized areas (or rural areas with some residences) tend to generate noise complaints even though the rumble strips ideally should not have many hits. A possible suggestion for compromise with the residents are the use of noise barriers between the roadway and the residential areas. Another suggestion is to move the rumble strips further from the traveled lane, however, this results in less time and distance for drivers to react and correct their vehicle's path after they have passed over the rumble strips *(15)*. A larger offset between the travel lane and the rumble strips may not always be an effective method of alleviating noise problems. In Wisconsin there were noise complaints reported even after the continuous shoulder rumble strips were removed from the edge of the roadway to 0.75 meters from the edge of the traveled way. Some of these hits may be due to the novelty of rumble strips, resulting in drivers "test-riding" them. It is suggested that the problem has or will lessen when the novelty of "hitting" the rumble strips wears off.

An additional noise concern reported by police officers is that some people who are unfamiliar with the sounds produced by continuous shoulder rumble strips mistake the noise for car troubles *(11)*. This problem can be addressed by the public information and education campaigns on rumble strips. As shoulder rumble strips become a more standard design application, people will become familiar with the rumble strips and this problem should subside.

Bicycles

Bicycles are generally not a concern on freeways, Interstates, and parkways, as most states prohibit bicycles on such facilities. However, considerations are made for bicycle and motorcyclist riders with respect to continuous shoulder rumble strips on other roadways. Previous research was performed to determine that bicyclists and motorcyclists do not have an increased risk of losing control when riding across or along milled rumble strips *(16)*. The riders who tested the rumble strips reported that it was annoying riding over the rumble

strips, but at no time did they lose control.

The milled rumble strips do not use as large a space on the shoulder as the other types of rumble strips, therefore allowing more room for bicyclists *(6)*. Because of the smaller width of shoulder that milled rumble strips require (as opposed to rolled rumble strips), the bicyclists are provided more shoulder room and an additional level of separation from dangerous situations due to inattentive drivers. It is noted that on some roadways the spacing between the rumble strips and the edge of the shoulder can be cluttered with debris. Therefore, some concern is still noted about using rumble strips on roadways that allow bicyclists and have limited shoulder space.

Crash Migration

There has been some concern about crash migration, transferring the problem of run-off-road crashes downstream where there are no continuous shoulder rumble strips or onto a cross road of a lesser design standard. It is suggested that by preventing fatigue related crashes on one section of roadway, it may be transferring the problem downstream to a section of roadways without continuous shoulder rumble strips, or off of the roadway system. With educational efforts, it should be promoted that fatigued drivers (particularly those who ride over the rumble strips and recover their vehicle from running off road) should stop and rest before continuing on the roadway. No data was found from states in the northeast region to support or dispel the theory that run-off-road crashes are migrating to non-continuous shoulder rumble strip sites.

CURRENT RESEARCH

This section will provide regional information about the current uses of continuous shoulder rumble strips on roadways in several states. Information includes policies for installation, considerations regarding placement, current status of several states, and before and after crash data to help determine the effectiveness of continuous shoulder rumble strips on roadways. Additionally, benefits and costs will be discussed and detailed.

Current New York Status

There are two state agencies in New York that install continuous shoulder rumble strips. The New York State Department of Transportation (NYSDOT) currently installs the milled rumble strips, as they have been proven to be more effective in New York. Continuous shoulder rumble strips have been an effective countermeasure to combat driver inattention, fatigue, and drowsiness crashes in New York resulting in a 65 percent reduction in ROR crashes *(17)*. Many of the continuous shoulder rumble strips have been installed with regular construction projects let by the NYSDOT, while others are let as stand alone projects. NYSDOT has also implemented seven specific continuous shoulder rumble strip projects dedicated to installing rumble strips along their existing rural Interstate highways and parkways throughout the state. In 1993 NYSDOT installed only 148 shoulder-kilometers, as compared with 2777 shoulder-kilometers in 1995 and 5071 shoulder-kilometers in April 1998.

The New York State Thruway Authority (NYSTA) owns and operates the private toll road which extends approximately 966 kilometers (3,864 shoulder-kilometers) across the state. Continuous shoulder rumble strips are installed on 3131 shoulder-kilometers of the Thruway. The NYSTA installed the milled rumble strips on the Thruway between the years of 1992 and 1996. They have a dedicated troop of the state police force that records information about each reported crash on their roadways, providing complete and uniform information. Due to the limited number of roadway miles, functional classification, and police reports, the before and after data from the New York Thruway are easy to use to determine the effectiveness of the continuous shoulder rumble strips.

Both agencies, NYSTA and NYSDOT, have collected before and after data to help determine the effectiveness of continuous shoulder rumble strips in the state. The data from the NYSTA provides one year (1991) of data before the rumble strips and one year of data after the completion of the rumble strips (1997). Additionally, in 1992 there were a very limited number of roadways sections with continuous shoulder rumble strips, as the construction did not begin until late in the year. Continuous shoulder rumble strips on the Thruway were near completion midway through 1996. NYSDOT has very similar data, with a limited amount of data from before and after the installation. Both agencies have noted a reduction in crashes of at least 65 to 70 percent.

The data illustrated in Table 3 and Figure 3 represent the number of single vehicle run-off-road crashes for the years of 1991-1997 on the New York Thruway. Crashes represented in the table are due to the following causes:

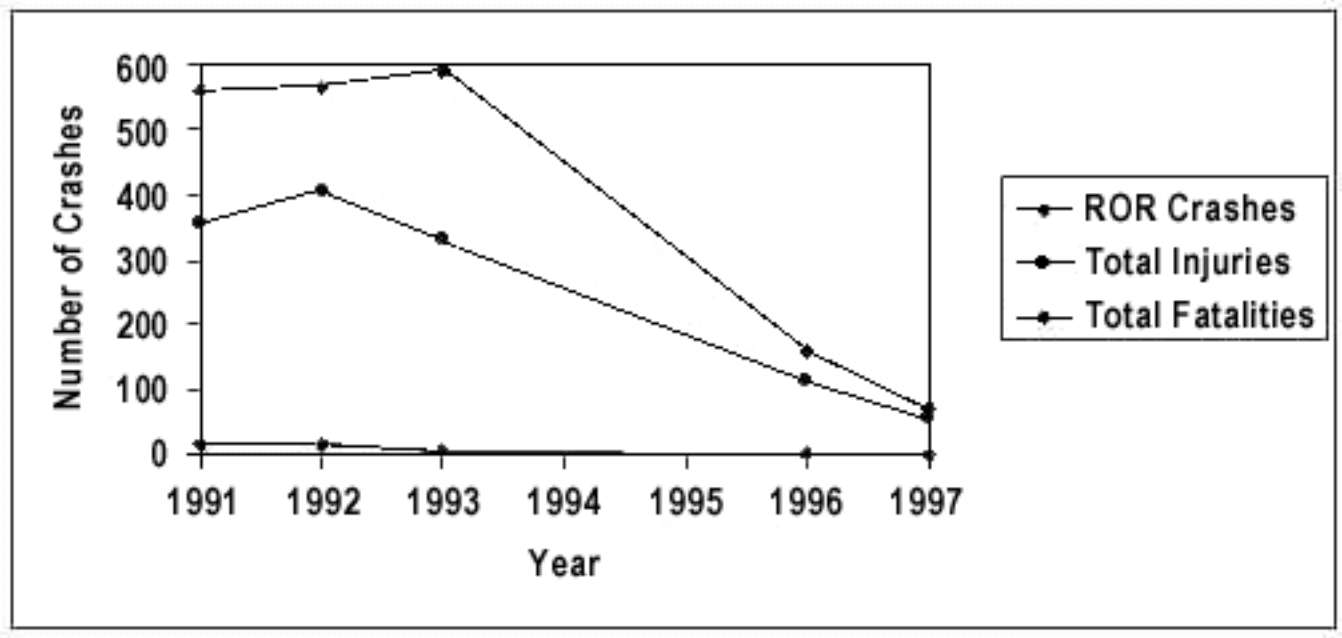
- Alcohol Involvement
- Driver Inattention
- Driver Inexperience
- Drugs (Illegal)
- Fell Asleep
- Illness
- Passenger Distraction
- Prescription Medication
- Fatigue, Drowsiness
- Glare

It was believed that these specific run-off-road crashes were indicative of those that could be mitigated by the use of continuous shoulder rumble strips and correcting the driver's behavior. Crashes cause by other factors were not included in this database. The data included only single vehicle crashes that were reported by the Thruway police. The data are collected from the sections of roadway now equipped with continuous shoulder rumble strips on the New York Thruway. During the years of 1992 and 1993 there were some continuous shoulder rumble strips installed, however not a significant percentage. By eh end of 1996 the entire Thruway continuous shoulder rumble strip installation was completed.

TABLE 3. Before-After Data for Rumble Strips in New York State (NYSTA)

Year	Total ROR Crashes	Total Injuries	Total Fatalities	Vehicle-Miles Traveled (millions)
Before and During Rumble Strip Installation				
1991	557	358	17	6,744
1992	566	407	17	7,612
1993	588	328	8	7,792
After Rumble Strip Installation Completed (Percent Reduction from 1991)				
1996	161 (74)	113 (72)	4 (75)	8,512
1997	74 (88)	54 (87)	1 (95)	8,692

FIGURE 3. Before and After Single Vehicle Run-off-Road Crashes



Each year there was an increase in the number of vehicle-miles traveled on the Thruway. There is a significant reduction in the total number of run-off-road crashes from the period 1991-1993 (before/during installation) as compared to the period 1996-1997 (after installation). There is a continued decrease in the number of crashes, injuries, and fatalities between 1996 and 1997, and/or additionally the completion of continuous shoulder rumble strip installation on the Thruway during the year of 1996. The Thruway's single vehicle run-off-road crash data is consistent with the data from the New York State Department of Transportation. NYSDOT reports that their 5071 shoulder-kilometers of continuous shoulder rumble strips have reduced run-off-road crashes due to driver inattention, fatigue, and/or drowsiness by 65 percent *(17)*.

Other Experiences in the Region

Currently the states of Region 1 have had various experiences with continuous shoulder rumble strips. Each state has different policies and uses involving continuous shoulder rumble strips. Each of the state's programs are detailed below.

Connecticut

Connecticut does not currently have a written policy for the use of continuous shoulder rumble strips on new freeways and/or overlays. The state has been installing rumble strips for the past five years on sections of freeway that have shoulders that are at least 915 millimeters wide and are being resurfaced. Connecticut does not install rumble strips on any type of facility besides freeways, therefore, bicycles are not a concern in the state.

Maine

Maine does not have any written policies on the installation of continuous shoulder rumble strips, but they do have practices that are routinely followed. Rumble strips are not currently installed as part of regular maintenance activities or any other special programs, but they are installed on all rural complete rehabilitation projects on the Interstate. The state is also beginning to consider installing rumble strips on urban Interstate rehabilitation projects, but have not yet begun to do so. Since rumble strips are applied only to the Interstate, there are no considerations given to bicyclists.

Massachusetts

Massachusetts has a policy that requires continuous shoulder rumble strips to be installed along edge lines on all Interstate and National Highway System (NHS) limited access roadways and other roadways with a speed limit of 65 Km/h or greater during resurfacing or reconstruction. Exceptions to these policies include areas where the shoulder is used as a travel lane during certain hours (rumble strips should be installed along the

median edge line only), bridge decks, acceleration/deceleration lanes without a parallel paved shoulder, any area with a shoulder less than 610 millimeters in width, and for accommodations for bicyclists.

New Hampshire

New Hampshire does not currently have any written policies for the application or installation of continuous shoulder rumble strips, however rumble strips are being installed on the Interstate. Rumble strips are not being installed on any roadway besides the Interstates, therefore they do not have concerns about the effects of rumble strips on bicyclists.

New Jersey

New Jersey has existing policies on the installation of continuous shoulder rumble strips. It states that, "Rumble strips shall be constructed on the inside shoulders that 1.52 meters or greater and outside shoulders that are 2.44 meters or greater in width along the mainline on all Interstate highways, freeways, and other limited access highways *(18)*." For other land service highways with high crash locations (due to nighttime run-off-road crashes) or land service highways with reduced or eliminated shoulders near or approaching a bridge overpass, rumble strips are also suggested. A minimum length of 30.5 meters is suggested for longitudinal measurements along the shoulder for effectiveness. Additionally, it is required that rumble strips are not constructed across bridge decks or 30.5 meters in advance and beyond all intersections. New Jersey is currently working on a policy involving considerations for bicyclists.

Benefit-Cost Ratios

Analyses were performed using assumptions to determine a minimum benefit-cost ratio of continuous shoulder rumble strips for the New York State Thruway. The cost assumptions used in this analysis were provided by a current manufacturer and include estimates of the cost of installation and maintenance and protection of traffic. These values are:

- The cost of installation per roadway kilometer of rumble strips: $2477 (equivalent to $0.62 per meter). This cost includes the installation of each of the four shoulders, including the costs to mill the rumble strips, to sweep and discard the excess asphalt, and for maintenance and protection of traffic *(10)*.

The Thruway has approximately 783 kilometers of roadway that have rumble strips installed on each of the four shoulders. The total cost of installation using the cost per kilometer value shown above is calculated to be $1,939,491.

The benefits of the rumble strips resulted from the savings in fatalities, injuries, and property damage crash costs. Values for these three degrees of crashes were referenced from the Federal Highway Administration's "The Cost of Highway Crashes" *(19)*. These values are:

- Fatalities $2,723,000
- Nonincapacitating Crash $48,000
- Property Damage Crash $4,500

Data from before (1991) and after (1997) the installation of the rumble strips were used. The total savings per year resulting from the reduction in the three different types of crashes is $58,893,500. It is also assumed that the life of the rumble strips is at least six years. (Currently Massachusetts has not seen any degradation in the past three years on their open graded pavement nor has New York on their regular asphalt pavement). Calculating the benefit-cost ratio, assuming identical savings for each of the six years (using the above value per year) and the installation costs, determines a value of 182. The Thruway experience has demonstrated a high benefit-cost ratio due to the low installation costs, no maintenance costs, and resulting reduction in crashes. Individual states are encouraged to collect and review their before and after data (if available) and calculate their benefit-cost ratios. Additional costs may be required if a state is resurfacing previous rumble strips.

Summary of Calculations

- Total Cost of Rumble Strip Installation: **$1,939,491**

- Total Savings per Year: **$58,893,500**
- Assumed Life of Rumble Strips (maintenance free): **6 years**
- Total Benefit/Cost Ratio: **182**

SUMMARY

The many issues regarding the installation and placement of continuous shoulder rumble strips have been discussed and the region's experiences have been detailed. Continuous shoulder rumble strips placed on roadway shoulders have reduced the number of crashes, injuries, and fatalities on roadways in New York state by nearly 70 percent. The cost of installing continuous shoulder rumble strips is very low as compared to the costs that are saved by the prevention of crashes, injuries, and fatalities. There are some advantages and disadvantages to consider about the use of continuous shoulder rumble strips, which are:

Advantages

As previously stated, there are many advantages and positive effects with the installation and use of continuous shoulder rumble strips. These are:

- Rumble strips appear effective in reducing the number of run-off-road crashes due to driver inattention, driver error, and fatigue
- Rumble strip installation costs are low
- There is no noticeable degradation of pavement due to rumble strips
- Rumble strips require little or no maintenance
- Milled rumble strips can be installed on new or existing pavements
- Rumble strips are effective in snow and icy conditions and may act as a guide in inclement weather for truck drivers
- Rumble strips are easily and comfortably traversed by bicyclists
- There is flexibility in the placement of rumble strips on the roadway shoulder depending upon the roadway environment and traffic

Due to the low installation cost and little maintenance needed, continuous shoulder rumble strips are an effective method of reducing single vehicle run-off-road crashes. High benefit-cost ratios are due to the amount of lives saved and injuries prevented in comparison to the low cost of installation of rumble strips.

Disadvantages

There are also genuine and perceived disadvantages associated with the continuous shoulder rumble strips. These concerns are:

- The noise produced by rumble strips may be disruptive to nearby residents
- Bicycle operations may be hampered with the limitation in shoulder room due to the installation of rumble strips on non-Interstate roadways
- The potential problem of migration of crashes further down the roadway without rumble strips or off the system

Although there is a concern about the noise, bicyclist concerns, and potentially the migration in crashes, there is a proven noticeable positive effect that continuous shoulder rumble strips are having on the roadways where they are installed. The number of crashes, injuries, and fatalities has been greatly reduced on roadways equipped with continuous shoulder rumble strips. Efforts need to be made to educate the public on the advantages of continuous shoulder rumble strips and the dangers of driving while drowsy. Also, alternate designs or compromises with concerned parties should be considered (for example, nearby residences) so that continuous shoulder rumble strips can continue to save lives and prevent crashes. The benefit-cost ratio reveals that continuous shoulder rumble strips are inexpensive to install as compared to the benefits that they produce.

CONCLUSIONS

Due to the successfulness of continuous shoulder rumble strips in reducing run-off road crashes, injuries, and fatalities in New York and other states in the nation, continuous shoulder rumble strips should be considered on multi-lane roadways in the nation, if appropriate. The cost of continuous shoulder rumble strips is low and continues to decrease as popularity grows. Many states are beginning to equip their roadways with continuous shoulder rumble strips and create policies for their installation and use. Unlike other safety measure that have, over time, decreased in effectiveness due to the "novelty" effect, rumble strips novelty effects are surely not an issue for drowsy drivers. Issues that need to be addressed are the noise produced in relation to the proximity of residences, and the concern for roadways that allow bicyclists. Additionally, the more roadways equipped with continuous shoulder rumble strips, the less of a concern for crash migration on surrounding roadways. Barriers need to be broken to allow areas to introduce continuous shoulder rumble strips without hesitation. Continuous shoulder rumble strips can be a benefit for roadway safety; they are a low cost effective method of reducing crashes and saving lives.

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