

Effectiveness of Continuous Shoulder Rumble Strips in Reducing Single-Vehicle Ran-Off-Roadway Crashes in Nevada

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ABSTRACT

Single-vehicle ran-off-roadway crashes are of significant concern in Nevada. This paper summarizes some findings of a research project to evaluate the effectiveness of continuous shoulder rumble strips to reduce such crashes in Nevada. The efforts evaluated safety records on roadways in Nevada on which continuous shoulder rumble strips had been installed. The roadways studied included interstate freeways, U.S. routes, and state routes. Crash data for the period from 1995 to 2003 were used for the analyses. Key data considered in the analyses presented herein include the locations and dates of installation of continuous shoulder rumble strips on roadway segments, crash data, and roadway characteristics. The frequencies and rates of single-vehicle ran-off-roadway crashes were determined for periods before and after the installation of the continuous shoulder rumble strips. Analyses of the data showed that overall the continuous shoulder rumble strips treatment has been effective in reducing the frequency of single-vehicle ran-off-roadway crashes and the corresponding crash rates.

Key words: crash rates—road safety—rumble strips—single-vehicle ran-off-roadway crashes

INTRODUCTION

Driving safely requires complete attention from the drivers. Fatigue, boredom, and other psychological factors contribute to a lack of attention by drivers. Environmental conditions (e.g., the landscape around the roadway), roadway design characteristics, traffic conditions, and the length (duration) of the drive are factors that affect driver fatigue and boredom. These factors often result in drivers running off the roadway, leading to single-vehicle crashes. Statistics show that a significant proportion of these single-vehicle crashes was fatal (Taylor and Meczkowski 2003). According to the Federal Highway Administration (FHWA), in 2002 ran-off-roadway single-vehicle crashes accounted for more than 120 fatalities and 2,400 injuries in the state of Nevada. The fatalities accounted for more than 30% of total fatalities statewide. Likewise, such injury-related crashes accounted for more than 15% of the total injury crashes statewide. The causes of these crashes include inattentive driving, fatigue, drowsiness, falling asleep, driver distraction, alcohol/drugs, and glare (Haworth et al. 1988). The Nevada Department of Transportation (NDOT) installed continuous shoulder rumble strips along interstate freeways and highways in urban and rural areas of Nevada to alert the drivers and reduce single-vehicle ran-off-roadway crashes. There was a need to evaluate the effectiveness of these continuous shoulder rumble strips in reducing these single-vehicle ran-off-roadway crashes. The types of continuous shoulder strips and the design specifications such as shoulder widths are some factors that might affect the effectiveness of continuous shoulder rumble strips in enhancing safety. This research paper summarizes an evaluation of the effectiveness of continuous shoulder rumble strips in reducing ran-off-roadway single-vehicle crashes in Nevada.

LITERATURE REVIEW

Various types of continuous shoulder rumble strips that have been previously or are currently being used in the United States include the following: milled rumble strips, rolled rumble strips, raised rumble strips, and formed rumble strips. These types of continuous shoulder rumble strips differ in their method of installation, size, shape, and spacing and the noise and vibration they produce (Hickey 1997).

The California Transportation Department (Caltrans) in 1975 added grooved rumble strips to the outside shoulders of a 24-mile section of I-15 next to the Nevada state line. Preliminary results were favorable, and this success led to the installation of shoulder rumble strips in the late 1970s as part of overlaying an additional 130 miles of I-15 and 5 miles of I-40 east of Needles, California. A before-and-after analysis of 1990–1992 crash data on a road network in Utah showed that freeways without shoulder rumble strips experienced a higher rate of run-off-the-road crashes (33.4%) compared to those with shoulder rumble strips (26.9%) (Cheng et al. 1993). An evaluation by Wood (1994) showed that after installation of a sonic nap alert pattern, drift-off-road accidents decreased by 65%. In 1997, Hickey conducted a follow up study to Wood's 1994 observations, in which he added traffic exposure to compare crash volume and crashes per vehicle distance traveled and made adjustments to account for a decline in all crashes during the study years. Perrillo (1998) evaluated the effectiveness of continuous shoulder rumble strips. Griffith (1999) extracted data from California and Illinois and estimated the safety effects of continuous rolled shoulder rumble strips on freeways. The results from this analysis estimated that continuous shoulder rumble strips reduced single-vehicle ran-off-roadway crashes on average by 18.3% on all freeways (with no regard to urban/rural classification) and 21.1% on rural freeways. Chen (1994) performed an analysis of milled, rolled, and formed shoulder rumble strips at 112 locations on two interstate highways in Virginia. The Pennsylvania Department of Transportation researched milled rumble strip patterns that were found to be safe and effective for bicyclists and motorists on nonfreeway roads (Elefteriadou 2000). Spring (2003) conducted a study on the effectiveness of rumble strips in the state of Missouri. The study recommended that the rumble strips only be used on rural roadways and on urban highways in cases where the ran-off-roadway crash history exceeds the acceptable values. Hauer (1997) presents discussions

on conducting before-and-after studies for road safety. Building upon the aforementioned items from the literature, this paper reports some findings from a study to evaluate the effectiveness of continuous shoulder rumble strips deployed along roadways in Nevada.

METHODOLOGY

Based on the literature review, metrics were adopted to evaluate the effectiveness of continuous shoulder rumble strips in Nevada. The metrics used in the analyses include those based on individual roadway sections as well as for composite sections. Specific metrics include frequencies and rates of single vehicle ran-off-roadway crashes. A before-and-after study approach was used to evaluate the effectiveness of the rumble strips. The analysis began with the identification of individual roadway segments. The individual segments served as the basic units for the analysis. Data pertaining to the individual sections of a roadway were aggregated to evaluate the roadway. The analysis was based on single-vehicle ran-off-roadway crashes in Nevada recorded by law enforcement agencies.

Data Identification, Collection, and Analysis

The data required to support the analyses consisted of information pertaining to crashes, roadway design, and operational characteristics. Data elements of interest in this regard included the following:

- Road network data (for locations with continuous shoulder rumble strips)
 - Functional classification of roadway
 - Identification of roadway segments
- Rumble strip data
 - Rumble strip installation location
 - Date of rumble strip installation
 - Type of rumble strips
 - Shoulder width
- Single-vehicle ran-off-roadway crash data

NDOT maintains 5,400 centerline miles of highways in the state of Nevada. At the commencement of this study, more than 1,455 centerline miles (both directions accounted for on divided roadways) of these roads had been treated with continuous shoulder rumble strips. These roadway segments consisted of the following types of roadways: interstates, U.S. routes, and state routes. They included roadways distributed across the state of Nevada. The continuous shoulder rumble strips considered for the analyses spanned installations from the year 1998 to 2004. Of these, 1,017 centerline miles had rumble strips installed during the year 1999.

For the purposes of performing the analyses in this study, the roadway sections with continuous shoulder rumble strips were divided into smaller segments. A total of 370 segments were thus identified for the study. The sections with continuous shoulder rumble strips were located on different functional classes or types of roadways, such as interstate freeways, U.S. routes, and state routes. The before-and-after analysis required data for periods prior to and following the construction of continuous shoulder rumble strips on each segment to be evaluated. Among the 370 roadway segments identified for evaluation, 64 segments had their continuous shoulder rumble strips installed in the year 2003 or 2004. Thus, they did not have any after condition data. The remaining 306 roadway segments had at least one year of crash data for each of the before and after conditions with respect to the continuous shoulder rumble strips' installation. These segments, which account for 1,303 centerline miles of roadway, were considered for evaluation and analyses in this study. The segments range in length from less than one mile to several miles, depending

on roadway characteristics. A geographic information system layer was developed to identify segments based on the dates of installation of the rumble strips.

Key data pertaining to the road segments with continuous shoulder rumble strips were obtained from NDOT. These included the following: the date of continuous shoulder rumble strips' installation, traffic volumes, crash data, posted speed limits, shoulder width, and section lengths. In order to study the effectiveness of continuous shoulder rumble strips, it was necessary to compile and evaluate data related to single-vehicle ran-off-roadway crashes that occurred on the road segments of interest for time periods before and after the installation of rumble strips. Such crash data for the roadway network in Nevada for the years from 1995 to 2003 were obtained from NDOT. This amounted to a total of 33,117 single-vehicle ran-off-roadway crashes, for an average of 3,680 crashes/year during the nine-year period under consideration. About 2.3% (772) of the 33,117 crashes resulted in one or more fatalities. About 35.7% (11,812) of the crashes involved human injuries or fatalities. The remaining 62% (20,532) of the crashes involved property damage. The 4,173 single-vehicle crashes reported in the year 1998 was the highest number of crashes in any year during the analysis period; the 2,817 crashes for 2003 was the lowest number of crashes. The 33,117 crashes were geographically located with reference to the road network using a geographic information system program.

ANALYSIS

Computation of Safety Indicators

A comparison of the number of crashes during the period before the continuous shoulder rumble strip treatment and after the continuous shoulder rumble strip treatment was a good indicator of the effectiveness of continuous shoulder rumble strips. To account for a variety of factors, which might have a bearing on the increase/reduction of the number of crashes, the analyses were carried out based on two indicators of safety for each segment:

- Crash frequency, in Crashes/Year
- Crash density, in Crashes/Mile/Year

Computation of Crash Frequency

Crash frequency was computed by dividing the total number of crashes recorded on each segment during the before or after period by their respective duration expressed in years. It was computed using the following equations:

$$\text{Crashes/Year}_{\text{before}} = C_{ij \text{ before}} / P_{i \text{ before}} \quad (1)$$

$$\text{Crashes/Year}_{\text{after}} = C_{ij \text{ after}} / P_{i \text{ after}} \quad (2)$$

where,

- $C_{ij \text{ before}}$ = Total number of crashes recorded on segment i in year j during the before period
- $C_{ij \text{ after}}$ = Total number of crashes recorded on segment i in year j during the after period
- $P_{i \text{ before}}$ = duration of the before period of segment i in years
- $P_{i \text{ after}}$ = duration of the after period of segment i in years

The total number of crashes on each facility was obtained by the simple addition of the number of crashes on each constituent segment. Since different roadway segments have different construction periods, it was

implied that the before periods and after periods were also different for many of these roadway segments. In order to compute the crash rate in terms of crashes/year, a weighted average of the before and after period was computed separately, as described next:

$$\text{Average before period (P}_{\text{before}}) = \frac{L_i * P_{i \text{ before}}}{L_i} \quad (3)$$

where,

L_i is the length of each segment

P_i is the before period of each segment

A similar computation was used to obtain the average after period (P_a). The crashes per year for each facility were computed as follows:

$$\text{Crashes/Year}_{\text{before}} = \frac{\sum_i \sum_j C_{ij \text{ before}}}{P_{\text{before}}} \quad (4)$$

$$\text{Crashes/Year}_{\text{after}} = \frac{\sum_i \sum_j C_{ij \text{ after}}}{P_{\text{after}}} \quad (5)$$

Computation of Crash Density

The safety indicator in terms of crash density was computed as the crashes/year divided by the length of each segment. To compute the crash rates in terms of crashes/mile/year for each facility as a single unit, the following expression was used:

$$\text{Crashes/Mile/Year}_{\text{before}} = \frac{\sum_i \sum_j C_{ij \text{ before}}}{(L_i * P_{i \text{ before}})} \quad (6)$$

where,

C_{ij} = Number of crashes of segment i in year j

L_i = Length of Segment i

$P_{i \text{ before}}$ = “before” period of analysis of segment i

RESULTS

Crash Frequency (Crashes/Year)

The first type of analysis was performed by computing the crash rate in terms of the number of crashes that occurred per year during the before and after periods. The number of crashes on each segment was divided by the number of before or after period years to obtain the crash rate in terms of crashes/year. Once the crash rate was computed, the percent change in crash rates was computed to determine if the safety condition on the roadway had improved or deteriorated after the continuous shoulder rumble strip treatment. When the crashes/year values of each of the 306 segments were compared, it was observed that about 66% of the segments showed a decline in the number of crashes/year. These segments accounted for 81% of the total centerline miles of roadway. Likewise, 12% of the segments (about 4% of centerline miles) showed no change in crashes/year, and 23% of the segments (15% of the centerline miles) showed an increase in the number of crashes/year. The results suggested that overall the continuous shoulder rumble strip treatment was effective in reducing the number of single-vehicle ran-off-roadway crashes. The two major interstate facilities in Nevada, I-15 and I-80, recorded 23% and 36% reductions, respectively, in the number of single-vehicle ran-off-roadway crashes/year. The two major U.S. routes, US-95 and US-93, also showed reductions in the crashes/year, registering 32% and 38% reductions, respectively. Although not very high, it was observed that US-6 experienced a slight increase in the number of crashes/year, and SR-160 showed a significant increase in the crashes/year.

Overall, when the effectiveness of the continuous shoulder rumble strip treatment based on individual facilities was considered, all state routes except SR-160 showed improvement after the continuous shoulder rumble strip treatment. A summary of the crash rates before and after installation of rumble strips with their corresponding percent changes is presented in Figures 1 through 3. Figure 1 shows the results for roadways with crash frequencies ranging between 0 and 250 crashes/year, while Figure 2 provides the results for facilities whose crashes/year value varies between 0 and 60 crashes/year. Results of the analyses based on roadway class are shown in Figure 3.

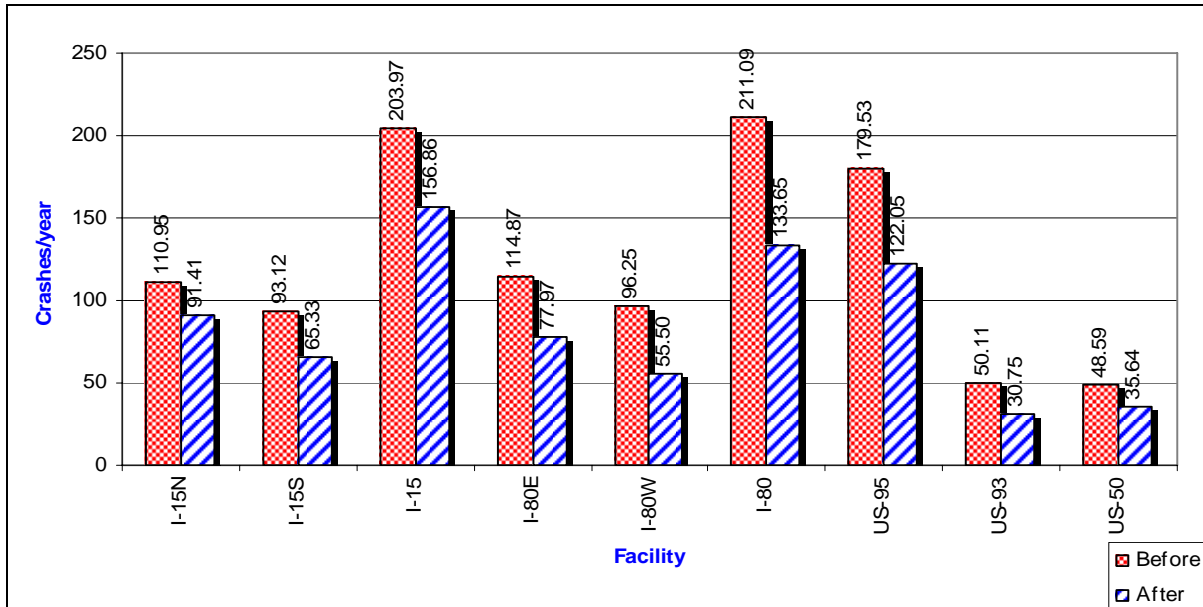


Figure 1. Single-vehicle ran-off-roadway crashes/year before and after continuous shoulder rumble strip treatment

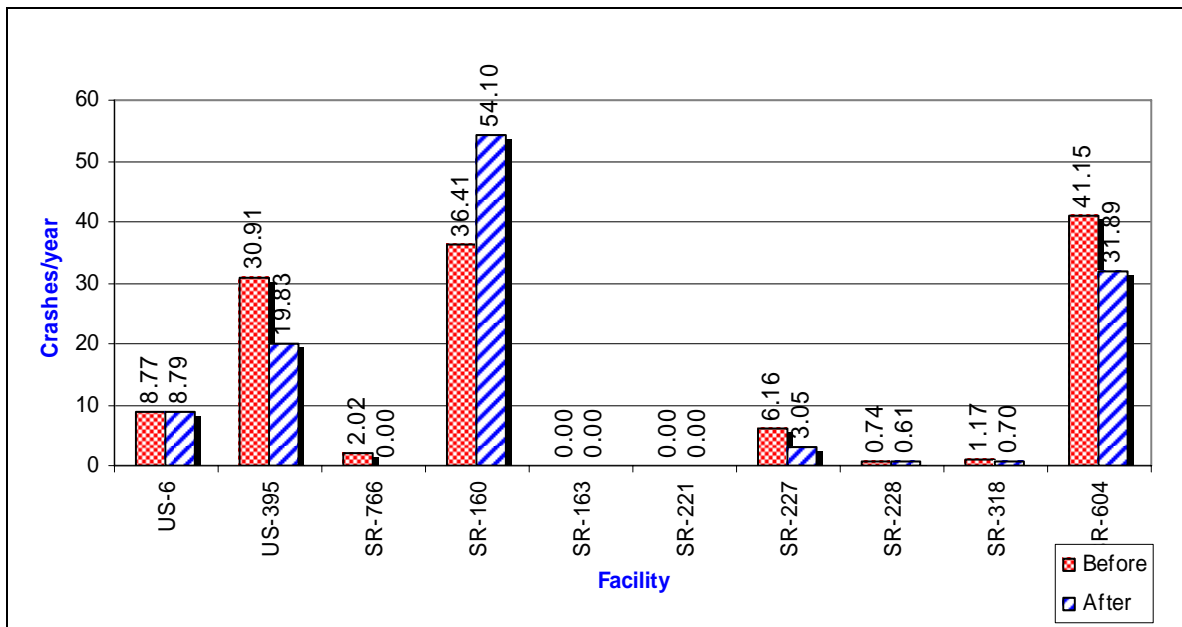


Figure 2. Single-vehicle ran-off-roadway crashes/year before and after continuous shoulder rumble strip treatment

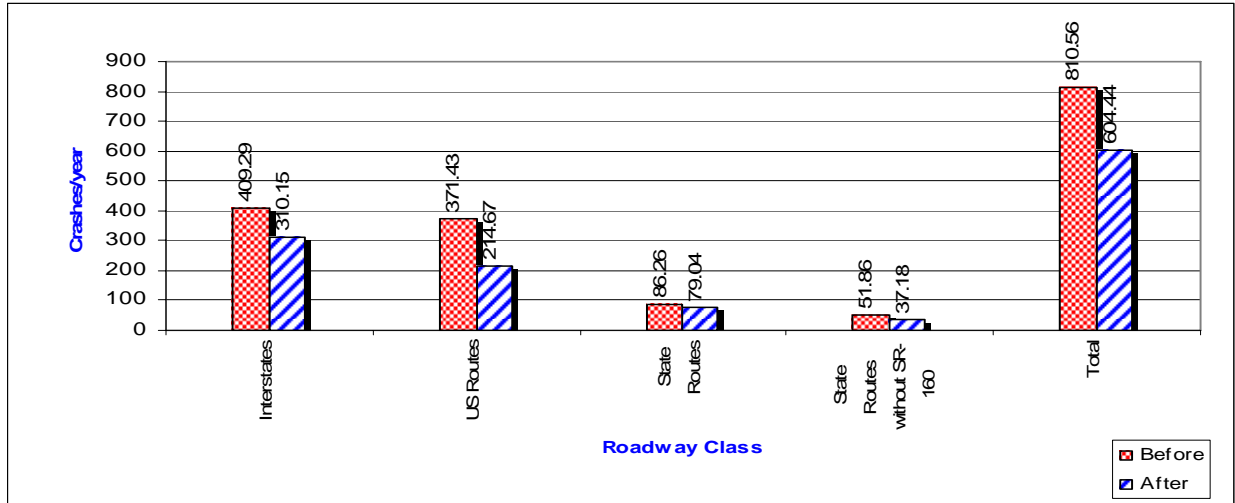


Figure 3. Single-vehicle ran-off-roadway crashes/year before and after continuous shoulder rumble strip treatment

Observations showed that over 142 of the 181 centerline miles of I-15 (78%) with continuous shoulder rumble strip treatment saw a decline in the number of single-vehicle ran-off-roadway crashes/year after the treatment. Similarly on I-80, 281 miles of the 366 centerline miles (about 77%) with continuous shoulder rumble strip treatment recorded a decline in the number of single-vehicle ran-off-roadway crashes after the continuous shoulder rumble strip treatment. On US-95, 320 miles of the 380 centerline miles evaluated (about 84%) showed improvement. Likewise, on US-93, about 91% of the 143 centerline miles studied showed a decline in the number of single-vehicle ran-off-roadway crashes/year after the installation of continuous shoulder rumble strips. Overall, of the 1,303 miles of roadways with continuous shoulder rumble strip treatment, 1,051 miles (80%) experienced a reduction in the number of single-vehicle ran-off-roadway crashes /year. This is a clear indication that, based on crash frequencies, the continuous shoulder rumble strip treatment was effective.

Crash Density (Crashes/Mile/Year)

An evaluation based solely on the number of crashes does not accurately reflect the changes in safety, since it does not address factors related to measures of exposure. If a roadway segment of short length experienced a high number of crashes, then the number of crashes/unit length of roadway would be high. On the other hand, if a longer roadway segment had the same number of crashes, then the number of crashes/unit length of roadway would be lower. Hence, to address such scenarios, crashes/mile was computed for each segment. By computing the number of single-vehicle crashes/mile, segments with relatively high crash densities or concentrations (expressed in terms of crashes/centerline mile) were identified. Once the crashes/mile was computed for the before and after periods, the rates were compared to evaluate the effectiveness of rumble strips in reducing the ran-off-roadway crashes. The results show that overall 201 of the 306 segments studied (i.e., 65.7%) showed a reduction in crashes/mile (i.e., improvements in safety). These segments accounted for 1,051 centerline miles (80.7%) of the roadways studied. Likewise, 36 segments (11.8%) showed no change in the number of crashes/miles. These segments accounted for 4.3% of the centerline miles of the roadways studied. Further, 69 segments (22.6%) experienced increased crash rates after the continuous shoulder rumble strip treatment. They constituted about 15% of the centerline miles studied. Figures 4 and 5 show results based on the number of segments for each facility. Similarly, Figures 6 and 7 show results based on centerline miles for each facility.

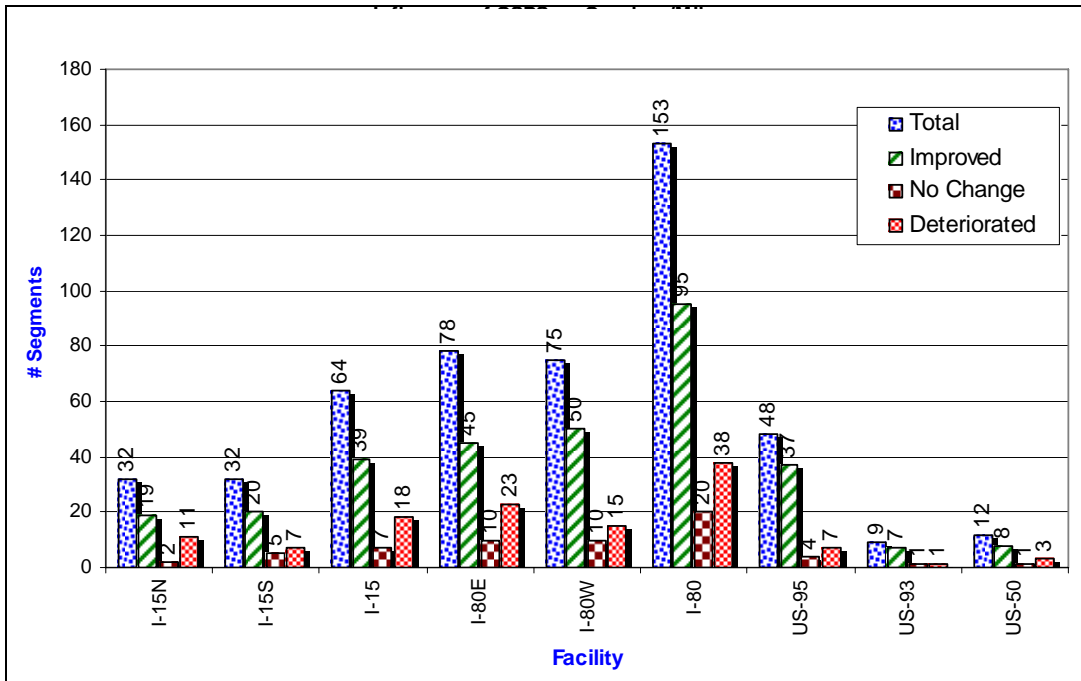


Figure 4. Influence of continuous shoulder rumble strips on crashes/mile/year (#segments)

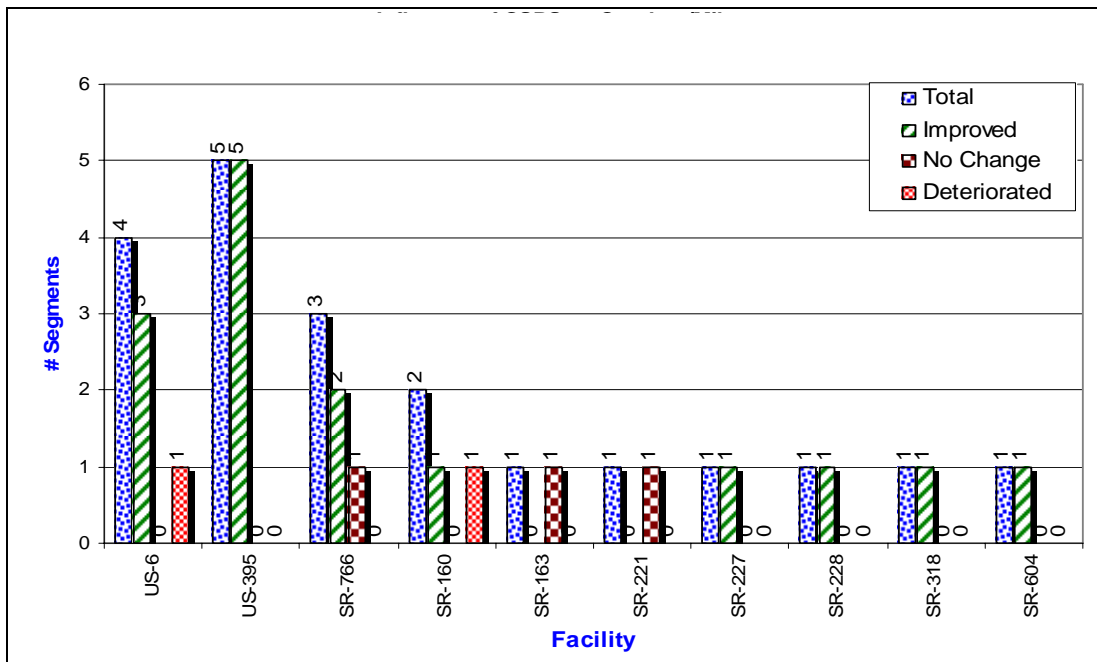


Figure 5. Influence of continuous shoulder rumble strips on crashes/mile/year (#segments)

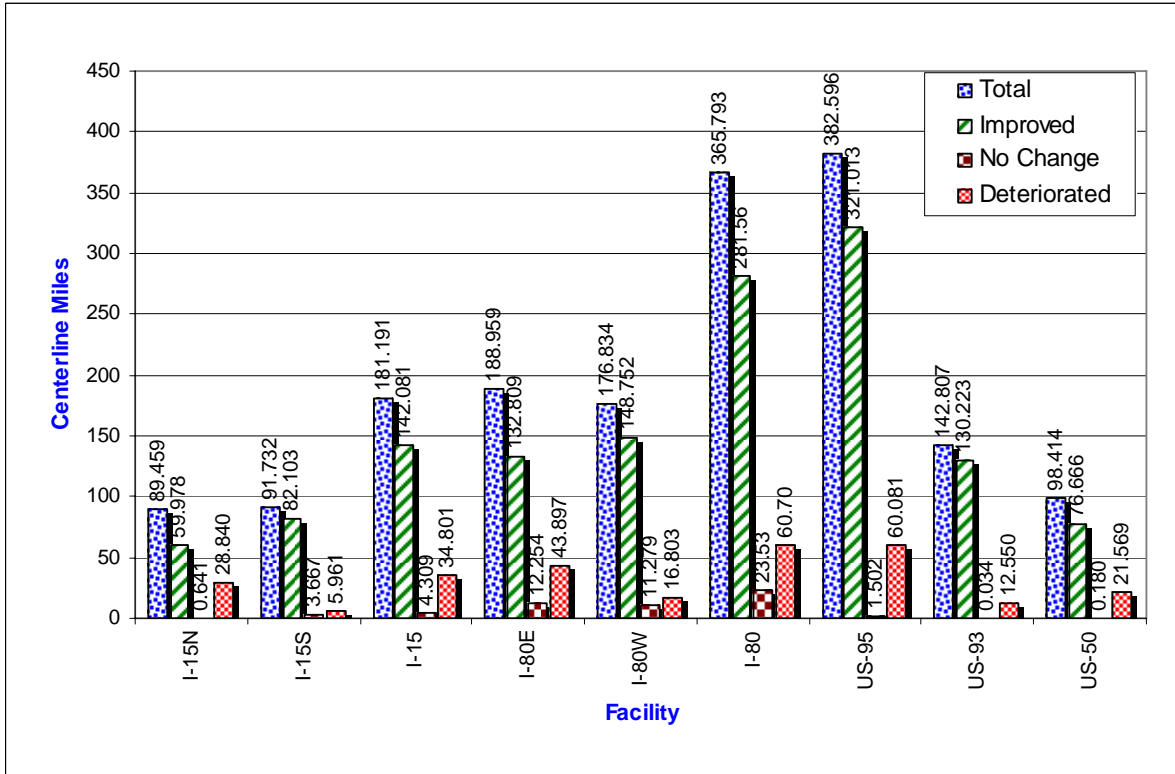


Figure 6. Influence of continuous shoulder rumble strips on crashes/mile/year (centerline miles)

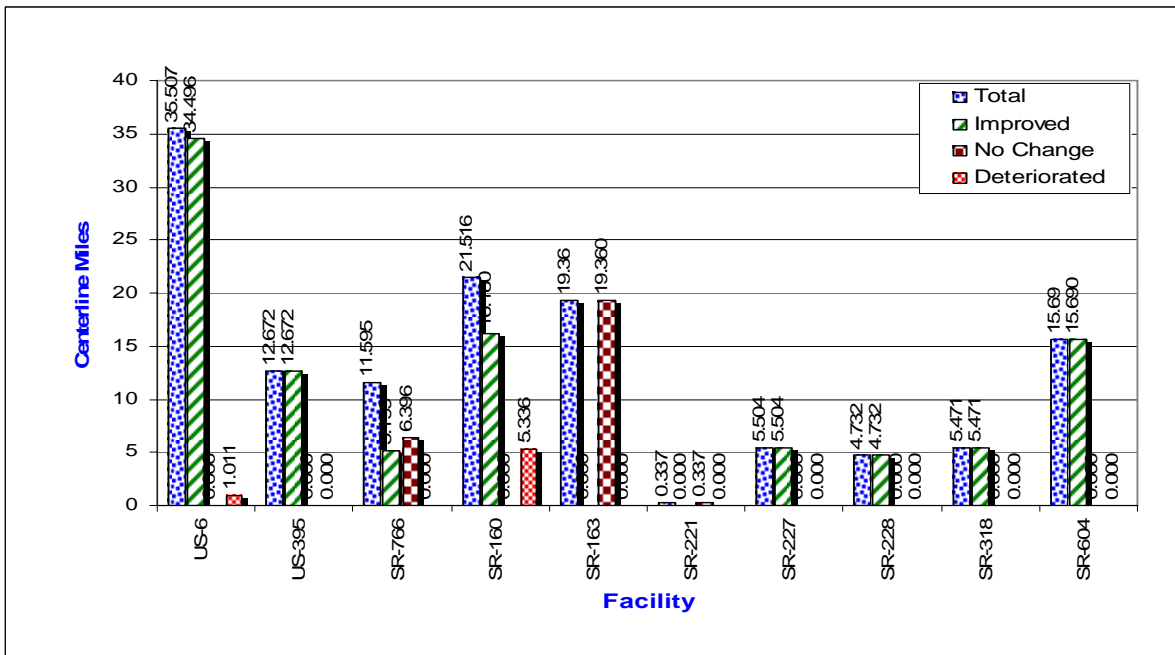


Figure 7. Influence of continuous shoulder rumble strips on crashes/mile/year (centerline miles)

SUMMARY

This paper has summarized a simple evaluation of the effectiveness of continuous shoulder rumble strips in enhancing road safety. The analyses were based on before-and-after studies comparing crash data on roadway segments and roadways before and after the installation of rumble strips. The analyses accounted for the length of individual roadway segments in determining crash rates. The results clearly show that such rumble strips on roadways in the state of Nevada have been effective in reducing the frequency of single-vehicle ran-off-roadway crashes and the corresponding crash rates. However, the analyses did not include information related to traffic volumes or vehicle miles of travel. They, too, need to be included in the analyses. Further, the changes in crash rates over time need account for normal effects, as opposed those that could be attributed to the rumble strips.

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