Evaluation of Rumble Stripes on Low-Volume Rural Roads in Iowa—Phase II

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Final Report
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16. Abstract

Single-vehicle run-off-road crashes are the most common crash type on rural two-lane Iowa roads. Rumble strips have proven effective in mitigating these crashes, but the strips are commonly installed in paved shoulders on higher-volume roads that are owned by the State of Iowa. Lower-volume paved rural roads owned by local agencies do not commonly feature paved shoulders but frequently experience run-off-road crashes.

This project involved installing rumble stripes, which are a combination of conventional rumble strips with a painted edge line placed on the surface of the milled area, along the edge of the travel lanes, but at a narrow width to avoid possible intrusion into the normal vehicle travel paths.

The research described in this report was part of a project funded by the Federal Highway Administration, Iowa Highway Research Board, and Iowa Department of Transportation to evaluate the effectiveness of edge-line rumble strips in Iowa. The project evaluated the effectiveness of rumble stripes in reducing run-off-road crashes and in improving the longevity and wet-weather visibility of edge-line markings.

This project consisted of two phases. The first phase was to select pilot study locations, select a set of test sites, install rumble stripes, summarize lessons learned during installation, and provide a preliminary assessment of the rumble stripes' performance.

The purpose of this report was to document results from Phase II. A before and after crash analysis was conducted to assess whether use of the treatment had resulted in fewer crashes. However, due to low sample size, results of the analysis were inconclusive. Lateral position was also evaluated before and after installation of the treatment to determine whether vehicles engaged in better lane keeping. Pavement marking wear was also assessed.

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EVALUATION OF RUMBLE STRIPES ON LOW-VOLUME RURAL ROADS IN IOWA—PHASE II

Final Report
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Principal Investigator
Shauna Hallmark
Associate Professor
Center for Transportation Research and Education, Iowa State University

Co-Principal Investigator
Tom McDonald
Safety Circuit Rider
Institute for Transportation, Iowa State University

Major Contributor
Robert Sperry
Local Roads Safety Liaison
Institute for Transportation, Iowa State University

Authors
Shauna Hallmark, Tom McDonald, and Robert Sperry

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A report from
Institute for Transportation
Iowa State University
2711 South Loop Drive, Suite 4700
Ames, IA 50010-8664
Phone: 515-294-8103
Fax: 515-294-0467
www.intrans.iastate.edu

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EXECUTIVE SUMMARY

Single-vehicle run-off-road (SVROR) crashes are the most common crash type on rural two-lane Iowa roads. Rumble strips have proven effective in mitigating these crashes, but the strips are commonly installed in paved shoulders on higher-volume roads that are owned by the State of Iowa.

Lower-volume paved rural roads owned by local agencies do not commonly feature paved shoulders but frequently experience run-off-road (ROR) crashes. This project involved installing rumble stripes, which are a combination of conventional rumble strips with a painted edge line placed on the surface of the milled area, along the edge of the travel lanes, but at a narrow width to avoid possible intrusion into the normal vehicle travel paths.

The research described in this report was part of a project funded by the Federal Highway Administration, Iowa Highway Research Board, Iowa Department of Transportation, and Midwest Transportation Consortium to evaluate the effectiveness of edge-line rumble strips in Iowa.

The project evaluated the effectiveness of rumble stripes in reducing ROR crashes and in improving the longevity and wet-weather visibility of edge-line markings. The project consisted of two phases.

In Phase I, candidate locations were selected from a list of paved local rural roads that were most recently listed in the top five percent of roads for ROR crashes in Iowa. Horizontal curves were the most favored locations for rumble stripe installation because they commonly experience roadway departure crashes. Rumble stripes were installed at five tests sites in 2008. In addition, rumble stripes were installed independently at one site by a county during the installation period and it was included as an evaluation site.

A preliminary assessment of the rumble stripes’ performance was conducted and lessons learned during installation were summarized. This information was included the Phase I report (http://www.intrans.iastate.edu/reports/HallmarkTR-577_report.pdf).

The purpose of the second phase was to provide a more long-term assessment of the performance of the pavement markings, conduct preliminary crash assessments, and evaluate lane keeping. Phase II results are presented in this report.

The first evaluation was pavement marking wear. One of the advantages that has been attributed to rumble stripes is additional visibility of the pavement marking. It is thought that the shape of the rumble stripe itself provides a raised (vertical) surface so that the markings are more visible at night and particularly when some amount of precipitation is on the pavement surface.

In addition, the depression protects part of the pavement marking which can lead to improved wear. Consequently, part of the evaluation was to monitor wear over time. Iowa receives a significant amount of snow from December through March. Road maintenance in Iowa is aggressive and includes scraping and the use of salt and sand. As a result, winter maintenance is harsh on pavement markings.

Several sites were visited two years after application of the rumble stripes and a qualitative assessment of pavement marking wear was conducted. At all of the sites, a significant portion of the regular pavement markings, which were flush with the pavement surface, had been worn away by the snowplows, while much of the marking within the rumble stripe remained. As a result, the rumble stripe was successful in preserving the pavement marking, which will lead to improved visibility. One problem that was noted with the rumble stripes is that material (sand, gravel, and dirt) tends to accumulate within the stripe.

A before and after crash analysis was also conducted. A set of control sites were included. Results of the analysis were inconclusive. However, only seven treatment sites were tested and only a short after-period (two years) was available. In addition, even though the locations were considered to be “high-crash,” given the majority of the sections were less than two miles long and volumes were less than 1,500 vehicles per day (vpd), the actual number of crashes was low. Consequently, due to the low sample size and number of crashes, it was difficult to conduct a statistically-valid crash analysis.

Lane position was evaluated before and after installation of edge-line rumble stripes as a surrogate measure of safety given only a short after-period was available for a crash analysis. Lateral position data were collected using a Z-configuration setup with road tubes at six locations. Data were collected over several days before and, then, approximately one month after installation of the edge-line rumble stripes. Lateral position from the right roadway edge was measured using the road tubes. Distance from the lane center was calculated using lateral position and lane width. Data were evaluated for day and nighttime periods separately.

Average offset from the lane center decreased by more than 1 ft for two locations during the daytime period. Average offset decreased by 0.2 to 0.6 ft for three sites and increased at one site by 0.4 ft. As indicated, the vehicle wheel path moved closer to the lane center for all six sites for the nighttime period but was not statistically significant at the 95 percent level of confidence for the County Road W-13 south and P-53 locations. The change was around 1.5 ft for three of the sites. On average, improvement in offset from the lane center was higher for the nighttime period than for the daytime period.

Average and 85th percentile speeds were also compared from the before to after period. In general both mean and 85th percentile speeds increased after installation of the treatments. Average speed increases ranged from 0.1 to 6.5 mph and changes in 85th percentile speeds increased from -2.5 to 6.9 mph. It is not known if speed changes were due to better delineation of the roadway or if the speed increase was unrelated to the treatment.

1. BACKGROUND

1.1 Introduction

Run-off-road (ROR) crashes are a serious traffic safety concern. ROR crashes account for 38 percent of U.S. highway fatalities and one million injuries annually. It is also estimated that 24 percent of highway fatalities occur on two-lane undivided rural roads (Taylor and Meczkowski 2003). Neuman et al. (2003) also estimated that 39 percent of national fatal crashes are single-vehicle run-off-road (SVROR) crashes.

Lane departure crashes are the single largest category of fatal and major injury crashes in Iowa. The Iowa Department of Transportation (DOT) estimates that 52 percent of roadway-related fatal crashes are lane departures and that 39 percent of Iowa's fatal crashes are SVROR.

A number of strategies have been employed to address roadway departure, including installation of rumble strips on paved shoulders, which has proven very effective in reducing the incidence of roadway departure crashes. However, the strategy can only be used on roadways with paved shoulders.

High-visibility edge-line markings have also been found to be key elements for guiding drivers during nighttime hours and can be applied on roadways with no shoulders. However, visibility of these markings is commonly adversely affected by wet conditions, which tend to obscure the encapsulated retroreflective beads. In addition, snowplow operations, routine shoulder maintenance, and even wear from vehicular traffic can be detrimental to the life of surface-applied pavement markings.

For roads where paved shoulders are not a viable option due to cost, narrow shoulders, and right-of-way restrictions, an alternative process has been devised, which involves milling narrow-width rumble strips directly along the existing pavement edge, followed by placement of standard edge line pavement markings over the milled areas, resulting in rumble stripes. (These edge-line rumble strips are sometimes called rumble stripes.)

Rumble stripes are a relatively new innovation that combine the beneficial effects of edge lines and rumble strips while enhancing the longevity and wet-condition visibility of painted markings. With rumble stripes, the edge-line paint markings are applied directly over the rumble strip indentations, resulting in a near-vertical painted face for improved wet condition visibility.

Some agencies are using edge-line rumble strips on two-lane paved roadways with unpaved shoulders. Rumble strips grooved into the pavement edge can provide some alert to drivers crossing the edge line. In addition, when the edge-line pavement marking is painted through the rumble strip, the grooved surface of the rumble strip facing the driver can provide a near-vertical surface, which enhances edge-line pavement marking visibility at night and during rainy conditions. Figure 1.1 shows an example of this treatment.

Figure 1.1. Completed edge-line rumble stripe on a rural highway in Iowa

Edge-line shoulder rumble strips/stripes increase edge-line marking visibility and longevity because part of the line paint is located within the rumble strip/stripe depression. This feature is particularly advantageous in climates where ice and snow are present, where raised pavement markers cannot be used due to probable snowplow damage.

1.2 Effectiveness of Rumble Stripes

Although it is believed that using rumble strips/stripes can decrease lane departures, limited information is available that demonstrates the effectiveness of the treatment. The Mississippi DOT (MDOT) installed edge-line rumble stripes on a two-lane roadway and conducted a before and after crash study (ATTSA 2006). The study found that right-side ROR crashes were reduced by 25 percent after installing the rumble stripes.

The Texas Transportation Institute (TTI) evaluated the impact of edge-line rumble stripes on traffic operations. The evaluation found that shoulder encroachment decreased by 46.7 percent after installing edge-line rumble stripes (Miles et al. 2005).

Pratt et al (2006) evaluated centerline and edge-line rumble strips (ERS) where the RS was placed directly on the marked edge line along a five-mile segment. The RS was 0.5 in. deep, 7 in. long, and 12 in. wide at 12 in. spacing with a 4 in. edge line. The researchers evaluated shoulder usage and lateral position within the lane line before and after installation using a Z configuration of road tubes and video. Encroachments were only included for daytime hours. Shoulder encroachments were classified as emergency vehicles, turning, passing, and inadvertent. Encroachments were assessed on both curved and tangent sections. The authors found a reduction of 46.7 percent for all categories of encroachments. Inadvertent shoulder encroachments decreased from 616 to 359 from the before to after period.

Lateral encroachment onto the shoulder was also recorded. A decrease in shoulder encroachment from 10.6 to 18.5 in. was noted. A 71.8 percent decrease in number of vehicles striking the right edge line was also noted.

A recent study of Missouri's Smooth Roads Initiative (SRI) included 61 sites and more than 320.5 miles of both edge-line rumble stripes and shoulder rumble strips. The authors conducted a before and after analysis using an empirical Bayesian analysis. Overall, they found that the SRI program showed a statistically-significant eight percent decrease in fatal and disabling injury crashes and a six percent decrease in fatal and all injury crashes. However, the analysis only included one year of after data (Potts et al. 2008).

Anund et al (2008) studied the effect of four types of rumble strips on sleepy drivers in an advanced moving driving simulator in Sweden and Finland. One set of rumble strips was roughly similar to what is used as edge-line rumble stripes with dimensions of 7 in. wide by 0.8 in. long at a spacing of 11.2 in. apart and a depth of 0.6 in. Thirty-five subjects who had worked the night shift before participating in the study were evaluated over a straight section of road alternating a particular type of rumble strips.

Lateral position, eye blinks, and other medical measures of sleepiness were evaluated. The study reported that all of the rumble strips evaluated, including the edge-line rumble stripes, exhibited similar alerting effects as measured by reduced variability in lateral position and a decreased physiological sleepiness level. However, the effect in all cases was only moderate and the decrease in sleepiness was only sustained for two to three minutes after the rumble strip was encountered.

1.3 Other Impacts of Rumble Stripes

Drivers may be surprised when their vehicle tires contact the edge line and, when they experience aural and vibratory warnings, they may respond by engaging in erratic maneuvers such as hard braking, swerving, rapid alignment, lane shifting, correcting the their vehicle trajectory into the wrong direction, losing control, or engaging in avoidance maneuvers (intentionally straddling or shifting around rumble strips).

Miles et al (2006) investigated driver behavior when encountering rumble stripes. They installed rumble stripes along the edge of a five-mile rural two-lane highway with a posted speed limit of 70 mph where passing was permitted for more than 75 percent of the section length. The rumble stripes were milled to 0.5 in. and were 7 in. long by 12 in. wide with the edge line repainted along the outside left edge of the RS.

Lateral position was collected using traffic counters and type of encroachment was determined using video footage. No erratic maneuvers were observed for the 120 hours of data that were collected.

The study also assessed whether drivers intentionally avoided the rumble stripes by observing the number of vehicles that straddled the lane line before and after installation of the treatment. The researchers found a 71.4 percent increase in the proportion of vehicles with three or more axles straddling the edge line and a 35.7 percent reduction in the rate of straddling by vehicles with two axles. The authors felt that drivers of large vehicles were intentionally straddling the ERS to avoid continuous contact with them.

1.4 Purpose for Research

As noted in the previous section, edge-line rumble stripes may be a potentially effective strategy for keeping vehicles on the roadway. However, the effectiveness of the strategy is not well documented. While installing edge-line rumble stripes on sections with narrow or no paved shoulders is listed in the National Cooperative Highway Research Program's Report 500, Volume 6: A Guide for Addressing Run-Off-Road Collisions as a strategy to keep vehicles on the road, it is considered an experimental strategy (Neuman et al. 2003). As a result, additional information on its effectiveness is necessary.

The research described in the this report was part of a project funded by the Federal Highway Administration (FHWA), Iowa Highway Research Board (IHRB), and Iowa DOT to evaluate the effectiveness of edge-line rumble strips in Iowa.

The project evaluated the effectiveness of rumble stripes in reducing ROR crashes and in improving longevity and wet-weather visibility of edge-line markings. This project consists of two phases. The first phase was to select pilot study locations, select a set of test sites, install rumble stripes, summarize lessons learned during installation, and provide a preliminary assessment of the rumble stripes' performance. This information is summarized in the Phase I report (Hallmark et al. 2009).

The purpose of the second phase was to provide a more long-term assessment of the performance of the pavement markings, conduct preliminary crash assessments, and evaluate lane keeping. This effort is documented in this Phase II report.

If proven effective, rumble stripes will provide another relatively low-cost tool for local agencies to use in reducing ROR incidences, the highest crash type in rural Iowa areas.

2. DESCRIPTION OF SITES

A full description of how sites were selected and a discussion on how the milling was undertaken is provided in the Phase I report (Hallmark et al. 2009). A brief discussion of the site selection process is provided below. The Iowa DOT crash database was used to identify sections of two-lane paved roadways with unpaved shoulders in 10 counties in Iowa that had a large number of ROR crashes.

The top five percent of all locations that had the largest number of ROR crashes were selected for further analysis, resulting in a list of 11 initial sites. Individual sections varied in length from less than three miles to more than 11 miles. The 10 counties were considered because county engineers from the majority of these counties indicated interest in participating in the project.

The sites were reviewed by an evaluation team and site visits were made to each of the initial sites. Information such as pavement condition, relevant surrounding features (intersections, roadside objects, etc.), presence of horizontal or vertical curves, etc. was gathered during the site visits. A final list of feasible locations was selected based on several factors.

The first criterion was characteristics of the test site. Sections where a major intersection, a railroad crossing, or some other feature was present that would have made installation and evaluation difficult were removed from further analysis. The second criterion was the pavement condition and type. Rumble stripes are easier to cut into hot mix asphalt (HMA) than Portland cement concrete (PCC) pavement; however, it was also desired to have a site for each pavement type. Locations where the pavement edge had any amount of deterioration were also not included because milling the rumble strips in this situation may have further compromised the pavement quality. After removing sites that were not ideal based on these conditions, seven feasible sites in six counties remained and were viable for the study.

Once a final list was developed, sites were ranked based on agreed participation of local agencies, crash history, site characteristics, and potential for improvement. Sites were carefully selected to maximize potential effectiveness. The installation cost was based on linear foot, and there was not enough funding to complete all of the projects selected. As a result, the sites were ranked by number of crashes. Sites were selected from the list in descending order until funds were expended.

A total of five sites had rumble stripes installed. One additional site was added to the list for evaluation: Linn County had independently installed edge-line rumble stripes on County Road E-16 under a separate contract. They had used the same rumble-stripe design, so the project was consistent with those installed as part of this research.

These were the final sites:

- County Road W-13 in Buchanan County (PCC pavement; project length: 7,400 linear ft; 840 vpd)
- County Road P-53 in Dallas and Madison Counties (PCC pavement; project length: 8,600 linear ft; 1,140 vpd)
- County Road F-70/Vandalia in Polk County (HMA pavement; installed in two segments with a total length of 32,737 linear ft; 1,317 vpd)
- County Road F-29 in Poweshiek County (HMA pavement; project length: 9,560 linear ft; 1,100 vpd)
- County Road B-30 in Sioux County (HMA pavement; project length: 8,500 linear ft; 780 vpd)
- County Road E-16 in Linn County (PCC pavement; project length: 5,500 linear ft; 1,000 vpd)

The project involved milling narrow-width (4 to 6 in.) rumble strips that were a maximum of approximately 5/8 in. deep along the pavement edge of the selected roadway sections. A narrow width was necessary because most sections did not have paved shoulders. Following placement of the rumble strips, painted edge lines were applied directly over the milled areas, resulting in finished rumble stripes. The rumble stripe design is shown in Figures 2.1 through 2.3.

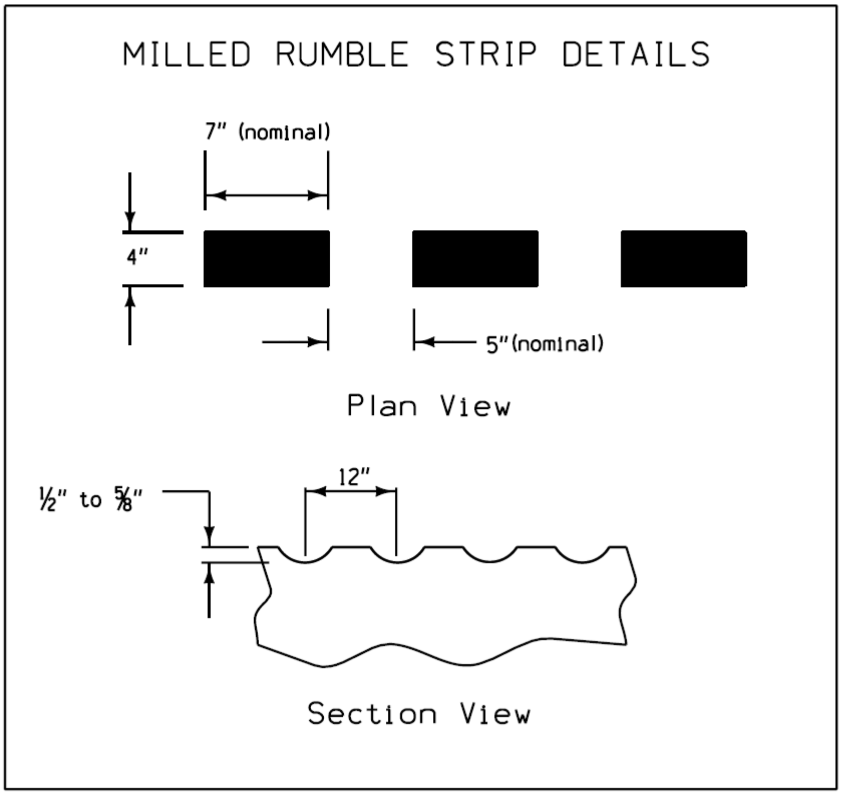

Figure 2.1. Rumble strip detail

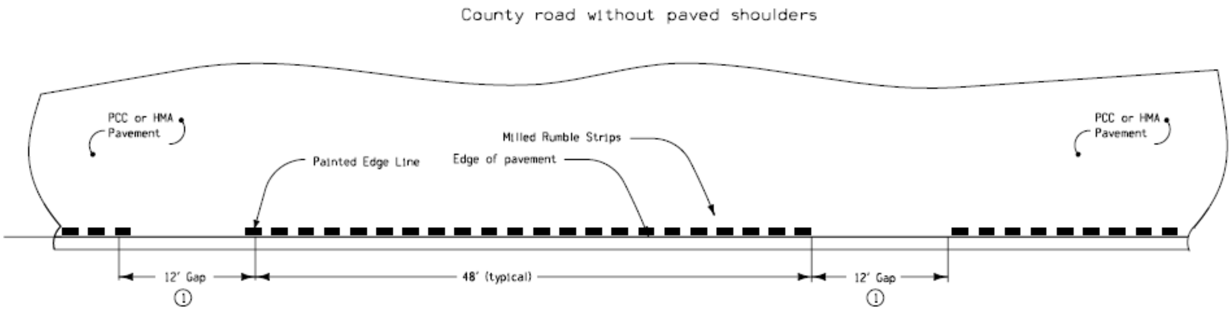

Figure 2.2. Rumble stripe layout for sections with no paved shoulders

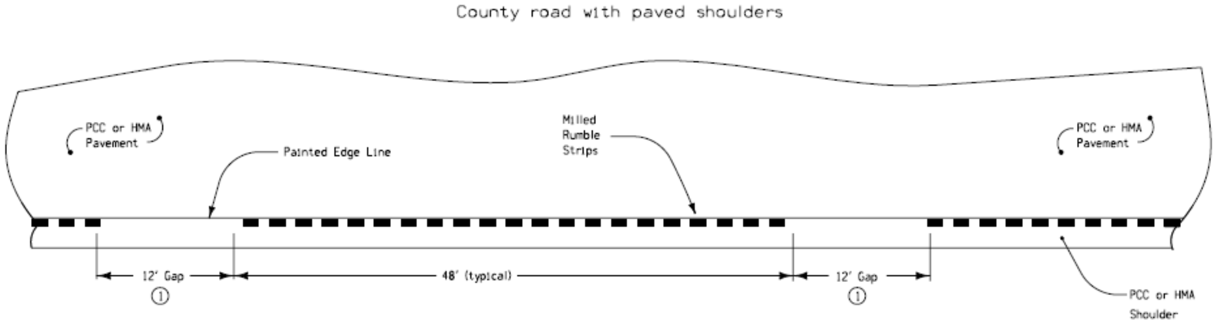

Figure 2.3. Rumble stripe layout for section with paved shoulders

Rumble stripe placement varied among road sections with some continuous and others only in specific areas such as curves or other high-crash locations. Work commenced in June 2008 and was completed in November 2008.

3. EVALUATION METHODOLOGY AND RESULTS

Several methods were used to evaluate the edge-line rumble strips. In Phase I, several short-term measures were used to assess the safety and performance of the rumble stripes. The first evaluation was to assess retroflectivity. A retrometer was used to measure the R1 parameter, which was the coefficient of retroreflected luminance, for pavement markings.

The R1 parameter represents the brightness of road markings illuminated by headlights as seen by motor vehicle drivers. Readings were taken of pavement markings on the regular pavement surface and within the rumble stripes for several periods after installation and painting of the rumble strips. A visual assessment of general wear was conducted after one year. Finally a follow-up with user groups was conducted. Results for each of these assessments was provided in the Phase I report (Hallmark et al. 2009).

In Phase II, three types of assessment were conducted. General wear of the rumble stripes was assessed two years after installation. Lateral position was measured for six locations over four sites and compared before and after installation. Finally a before and after crash analysis was conducted. Each is described in the following sections.

3.1 General Wear

One of the main benefits of the rumble stripes is that they provide additional visibility. It is thought that the shape of the rumble stripe itself provides a raised (vertical) surface so that the markings are more visible at night and particularly when some amount of precipitation is on the pavement surface.

In addition, the depression protects part of the pavement marking which can lead to improved wear. Consequently, part of the evaluation was to monitor wear over time. Iowa receives a significant amount of snow from December through March. Road maintenance in Iowa is aggressive and includes scraping and the use of salt and sand. As a result, winter maintenance is harsh on pavement markings.

Several sites were visited in May 2011, two years after application of the rumble stripes, and pavement markings were reviewed for wear. At all of the sites, a significant portion of the regular pavement markings that were flush with the pavement surface had been worn away by the snowplows. Much of the marking within the rumble stripe remained. A qualitative assessment of the wear is shown in Figures 3.1 through 3.3.

Figures 3.1 and 3.2 show wear images for County Road (CR) F-29 and Vandalia/CR F-70. Both are HMA pavement. As noted, most of the pavement marking on the regular surface has been worn away. Most of the marking within the rumble stripe is still intact. Figure 3.3 provides images for CR P-53, which is PCC. Similar wear is noted.

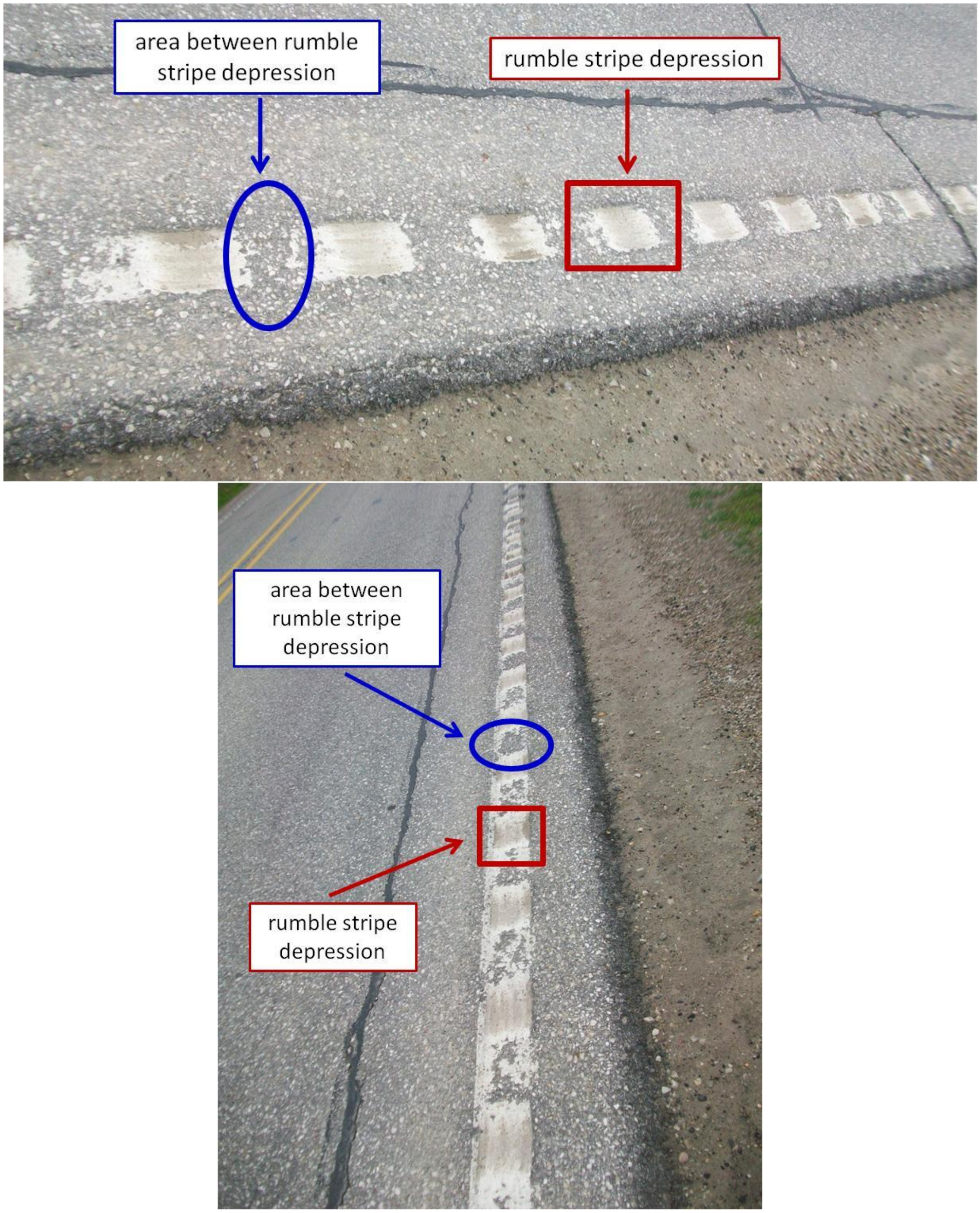

Figure 3.1. Wear at CR F-29 after two years (HMA)

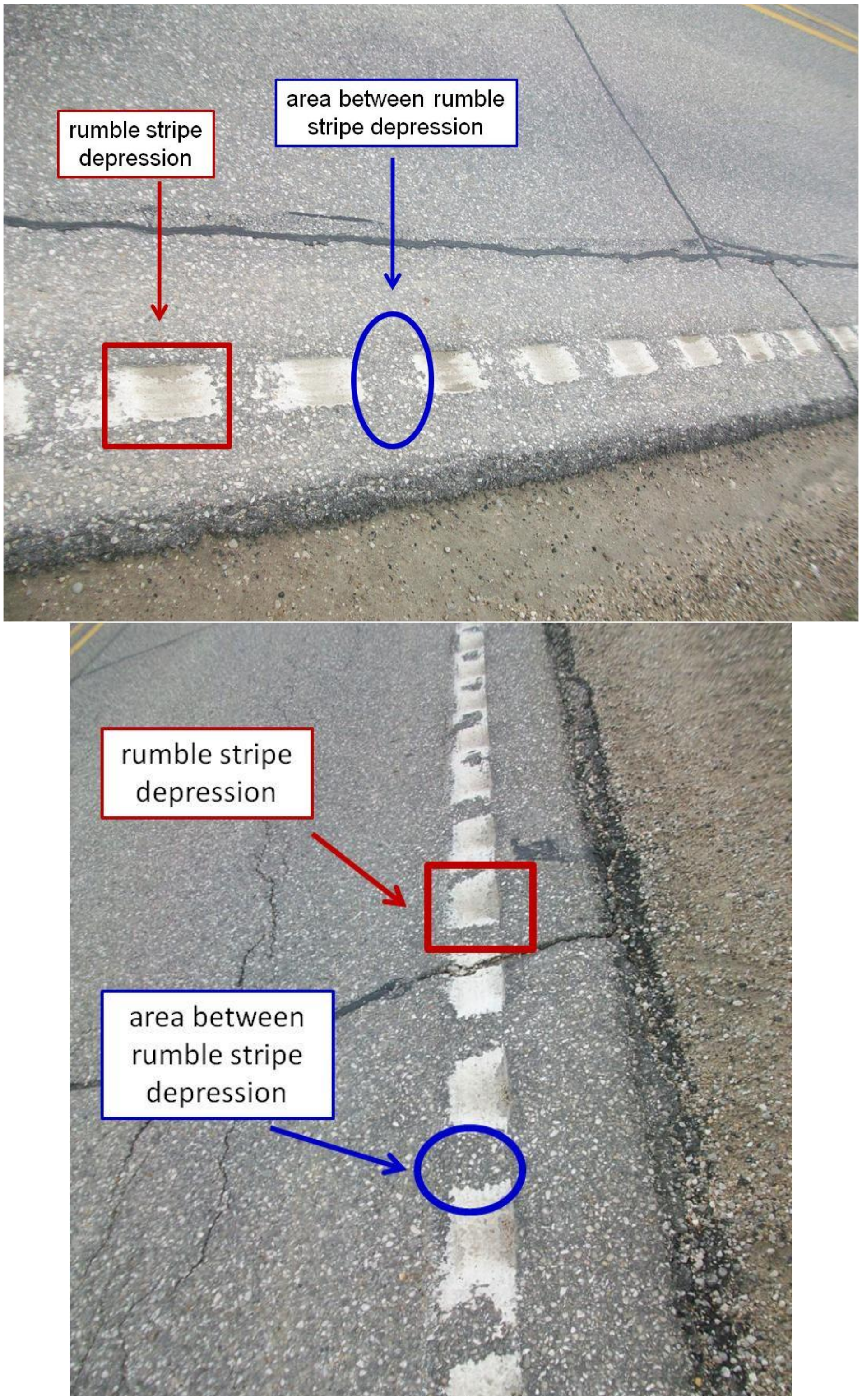

Figure 3.2. Wear at Vandalia/CR F-70 after two years (HMA)

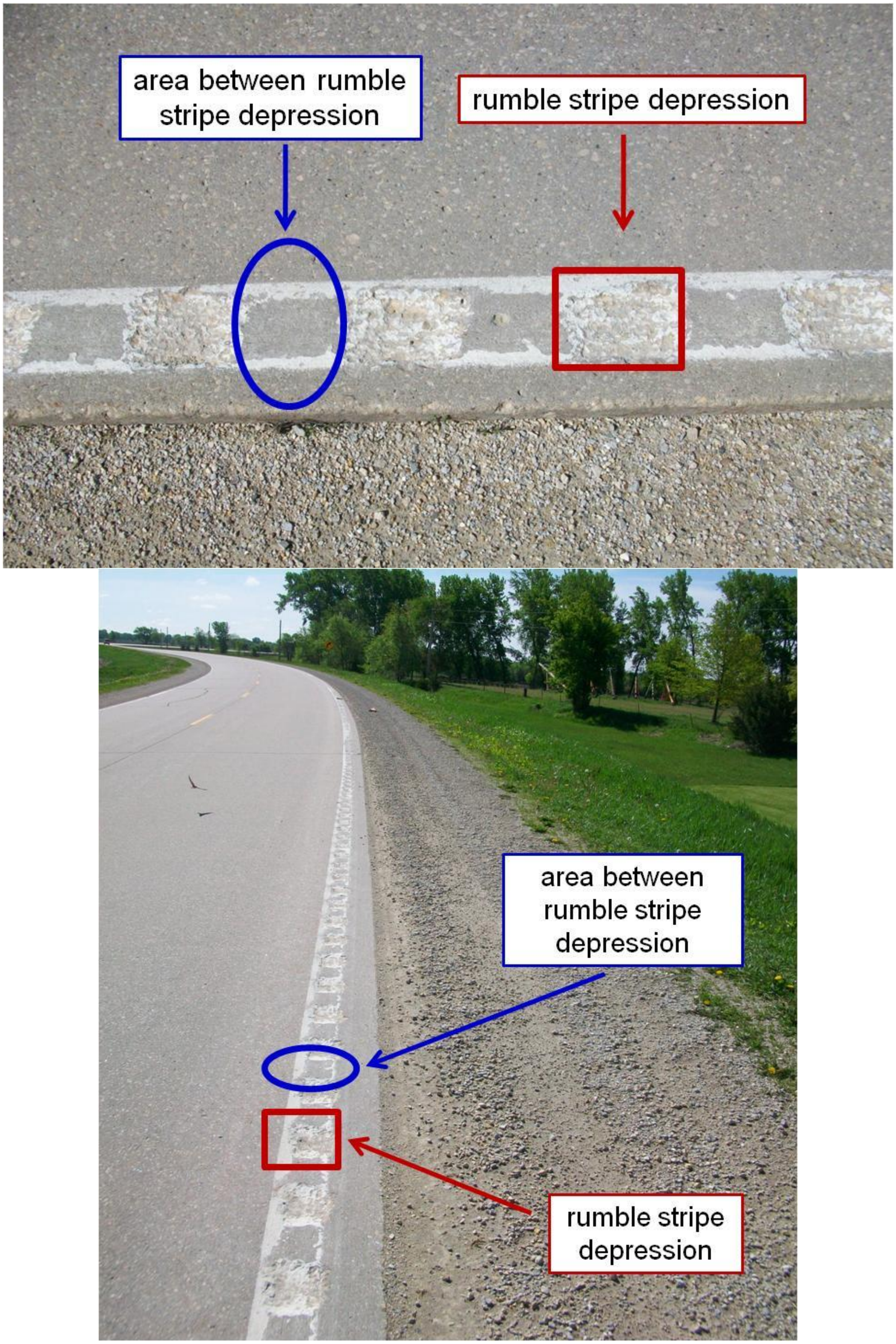

Figure 3.3. Wear at CR P-53 after two years (PCC)

One problem that was noted with the rumble stripes was accumulation of material (sand, gravel, dirt) within the stripe as shown in Figure 3.4. The most likely cause is winter maintenance. As shoulder material is pulled up it is likely that the pavement edge is covered and the depression tends to trap the material. When this occurs, the pavement marking within the rumble stripe is not visible and the effectiveness of the treatment is compromised.

Figure 3.4. Rumble stripe depression filled with material

3.2 Crash Analysis

3.2.1 Descriptive Statistics

A crash analysis was conducted to determine the impact of rumble stripes on crashes. Crash data were extracted from the Iowa DOT crash databases. The before period was five years (2003 through 2007). Crashes for 2008 were omitted since work on the rumble stripes commenced in June 2008 and was completed in November 2008. The after period was only two years (2009 and 2010).

Crashes were selected by overlaying the project extents for each site with crash data by year. Crashes that were intersection-related were removed from the analysis. Annual average daily traffic (AADT) by year was also extracted for each section. Seven test sites were included in the analysis.

One site had rumble stripes installed at two locations at some distance from each other. As a result, these two sections were treated as separate locations. Seven control sites were also selected. The control sites were proximate in location to the corresponding treatment sites. The control sites also had similar traffic patterns as the treatment sites. Statistics for the control sites and treatment sites are shown in Tables 3.1 and 3.2, respectively.

Table 3.1. Crash statistics for control sites

Control Sites	Before		After		Change in Crashes/yr
	Total	Crashes/yr	Total	Crashes/yr	
380th	5	1.0	3	1.5	0.5
F-60	18	3.6	6	3.0	-0.6
F-29	6	1.2	2	1.0	-0.2
IA 316	3	0.6	0	0	-0.6
Otterville	7	1.4	4	2.0	0.6
Sawyer	10	2.0	1	0.5	-1.5
SE 64th	4	0.8	5	2.5	1.7

Table 3.2. Crash statistics for treatment sites

Treatment Sites	Before		After		Change in Crashes/yr
	Total	Crashes/yr	Total	Crashes/yr	
B-30	7	1.4	3	1.5	0.1
E-16	5	1.0	1	0.5	-0.5
F-29	6	1.2	3	1.5	0.3
P-53	3	0.6	2	1.0	0.4
Vandalia 1	9	1.8	3	1.5	-0.3
Vandalia 6	6	1.2	4	2.0	0.8
W-13	2	0.4	0	0.0	-0.4

3.2.2 Crash Analysis

To model the number of crashes per year, a Poisson regression model was created. The model assessed these variables:

- Period (before for years 2003 through 2007 or after for years 2009 and 2010)
- Treatment (yes for intersections with rumble strips added or no for intersections without rumble strips)
- Location ID to account for the multiple observations for each location

Because only two years of crashes were available after the rumble strips were added, the researchers didn't have enough observations to consider all three variables in the model. Therefore, only the effect of treatment and location were assessed. The results for both variables were found to not have statistical significance at the 95 percent confidence level.

The lack of statistical significance may be due to several factors. Only seven treatment sites were tested resulting in a low sample size. In addition, even though the locations were considered to be "high-crash," given the majority of the sections were less than two miles long and volumes were less than 1,500 vpd, the actual number of crashes was low. Consequently, due to the low sample size and number of crashes, it was difficult to conduct a statistically-valid crash analysis. If sufficient samples were available, it would be useful to assess whether crash severity was reduced, given this may be a more useful measure of safety.

3.3 Lateral Position

The ideal method to evaluate the effectiveness of a countermeasure is to conduct a crash analysis, given reduction in crashes and crash severity is the objective of a safety treatment. As described in the last subsection, the researchers didn't obtain any conclusive results from the crash analysis. Reasons for this, as discussed, include low sample size and a short after analysis period.

As a result, the researchers used lane position as a crash surrogate. Lane position or deviation from the lane center has been used to assess the effectiveness of different lane departure countermeasures such as wider edge lines (Donnell et al. 2006), post-mounted delineators (Zador et al. 1987, Chrysler et al. 2009), advance warning (Charlton and DePont 2007), and rumble strips or rumble stripes (Finley et al. 2009, Rasanen 2005).

Stimpson et al. (1977) identified lateral placement and speed as the best indicators for assessing driver behavior on horizontal curves. Use of lateral position, assumes a correlation between lane position and likelihood of running off the roadway. The assumption is that with edge-line rumble stripes, drivers will be more likely to lane keep. Several studies have used lane-keeping as a measure of effectiveness, including Pratt et al. (2006) and Taylor et al. (2005).

3.3.1 Methodology

To collect lateral position, the team followed a methodology used by TTI (Finley et al. 2009) that uses pneumatic road tubes set up in a Z configuration, as shown in Figure 3.5.

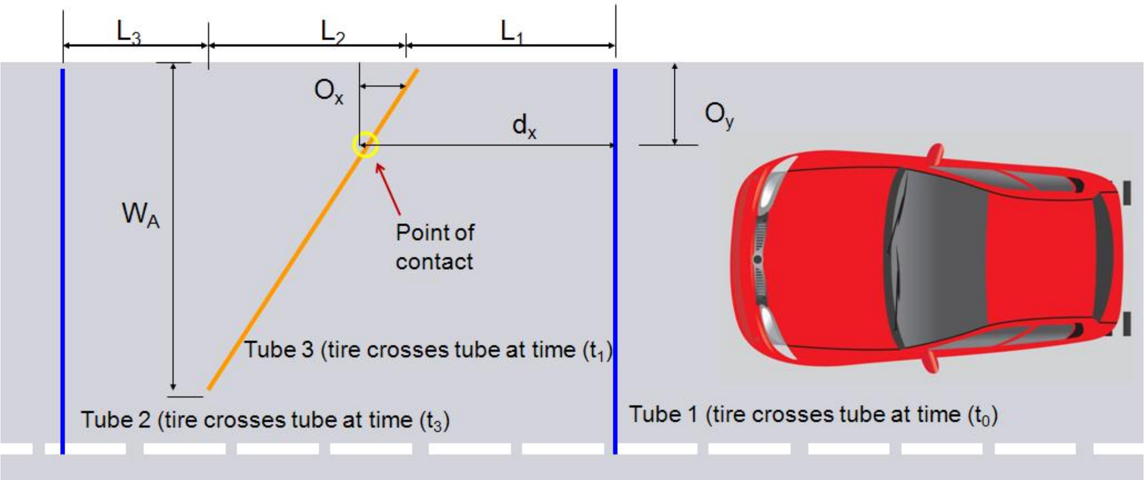

Figure 3.5. Layout configuration of road tubes to measure lateral displacement

Using the time stamp of when each tire strikes a particular road tube and geometric relationships, the distance that the vehicle is from the edge of the roadway (O_x) can be determined. The tube configuration is set up so the right edge of the right lane line for tube 1 is the reference point (0,0). The road tube configuration in the field is shown in Figure 3.6.

Figure 3.6. Road tube layout to measure lateral displacement in the field

The researchers collected data over several days before and approximately one month after installation of the edge-line rumble stripes. Data were collected at one or two locations at four sites (six locations).

Data from the counters provided output as raw data into a spreadsheet with date, time (to the millisecond), and sensor (tube) number. Each row represented one tire strike on a particular sensor and data were ordered sequentially.

Ideally, tubes 1 and 2 receive one strike for each vehicle axle while tube 3 could receive one or two strikes depending on whether the outside tire crosses tube 3. As a result, a particular tube order indicates number of axles and direction.

Other scenarios such as a vehicle crossing the center lane from the other direction, a vehicle crossing the tubes at an unusual angle, and air backwash result in tube configurations that are illogical and could be identified and tagged as erroneous and then removed from the final datasets.

The researchers calculated vehicle speed using the elapsed time from when the first axle of tires struck tube 1 and tubes 2 using Equation 1.

$$v = \frac{(L_1 + L_2 + L_3)}{(t_2 - t_1)} \tag{1}$$

With speed known and the time the first tire strikes tube 3, the distance from tube 1 to tube 3 was calculated using Equation 2.

$$d_x = \mathrm{v}\,(t_3 - t_1) \tag{2}$$

The variable d_x is different for each vehicle given each vehicle strikes tube 3 at a different location depending on its distance from the edge line. Using properties of similar triangles, the lateral distance the wheel is from edge of the right lane (O_y) was calculated. A 6 ft track width and known lane width were used to convert lateral position to reflect distance of vehicle center in relationship to lane center.

Given data reduction was mostly a manual process and large trucks made up only a small percentage of the traffic stream, only passenger cars were included in the analysis.

3.3.2 Results

Changes in mean speed, 85th percentile speed, and lateral lane position were calculated and compared for the before and after period. It was not known if the treatment was likely to affect vehicle speeds. During daytime conditions, drivers may not notice the rumble strips unless they stray near the lane edge. During nighttime and lower visibility conditions, the rumble strip is expected to provide improved delineation.

On one hand, this may cause drivers to slow given they are better able to judge the sharpness of the curve and respond appropriately. On the other hand, better visibility may encourage drivers to drive faster. As a result, mean and 85th percentile speeds were evaluated for evidence to determine if either might be true. Results for nighttime versus daytime conditions are presented in Tables 3.3 and 3.4.

Table 3.3. Speed and position from lane center for daytime conditions

Location	Average Position from Lane Center (ft)			Mean Speed (mph)			85th Percentile Speed (mph)		
	Before	After	Absolute Difference	Before	After	Difference	Before	After	Difference
Vandalia 2	-1.40	1.10	0.30	50.6	50.7	**0.1***	57.7	57.1	-0.6
Vandalia 1	-1.70	0.60	1.10	41.7	44.9	3.2	49.4	51.2	1.8
F-29	-2.92	-1.37	1.55	52.8	57.3	4.5	59.3	64.6	5.3
W-13 South	-1.70	-1.90	0.20	48.6	51.1	2.5	41.3	45.3	4.0
W-13 North	-2.30	-1.70	0.60	51.1	51.8	**0.7***	56.8	58.7	1.9
P-53	-0.70	-1.10	-0.40	42.9	49.4	6.5	34.6	41.5	6.9

***** Not statistically significant at the ninety-five percent level of confidence

Table 3.4. Speed and position from lane center for nighttime conditions

Location	Average Position from Lane Center (ft)			Mean Speed (mph)			85th Percentile Speed (mph)		
	Before	After	Absolute Difference	Before	After	Difference	Before	After	Difference
Vandalia 2	-2.2	0.7	1.5	50.4	50.6	**0.2***	56.5	54.0	-2.5
Vandalia 1	-2.0	0.4	1.6	42.0	43.4	**1.4***	49.6	49.4	-0.2
F-29	-3.2	-1.8	1.4	54.4	56.4	2.0	59.6	63.4	3.8
W-13 South	-2.1	-2.2	**0.1**	50.5	51.7	**1.2***	50.5	51.7	1.2
W-13 North	-2.8	-2.0	0.8	52.4	54.1	1.7	58.3	59.6	1.3
P-53	-1.3	-1.2	**0.1**	44.1	49.7	5.6	37.8	41.5	3.7

***** Not statistically significant at the ninety-five percent level of confidence

Statistical significance of changes from the before to after period were tested using a standard t-test. As indicated, daytime mean speed increased slightly in most cases from the before to after period but the changes were either small or not statistically significant. A similar situation was observed for mean nighttime speeds. Differences were smaller and, in half of the cases, the differences were not statistically significant.

Eighty-fifth percentile speeds were also typically higher for the after period for both daytime and nighttime with smaller differences occurring for the nighttime conditions. Consequently, given speed changes were nominal and similar for the daytime and nighttime periods, it is not likely that the treatment influenced speeds from the before to after period.

Changes in the average position of vehicles in relationship to the center of the lane for daytime conditions are shown numerically in Tables 3.3 and 3.4. Given lateral vehicle position can be to the right or left of the lane center, the absolute difference in change from the lane center was calculated. Average offset from the lane center decreased by more than 1 ft for both of the Vandalia/CR F-70 sites studied. Average offset improved by 0.2 to 0.6 ft for the remaining sites except for CR P-53 where deviation from the lane center increased by 0.4 ft.

Differences were evaluated using a t-test and were all statistically significant at the 95 percent level of confidence. The information is shown graphically in Figure 3.7. As noted, wheel path is centered closer to the lane center in the after period for all but one site.

Table 3.4 provides average position from the lane center for nighttime conditions. As indicated, the vehicle wheel path moved closer to the lane center for all sites studied but was not statistically significant at the 95 percent level of confidence for the CR W-13 south and P-53 locations. The change was around 1.5 ft for three of the sites.

Vehicle wheel path in relationship to the lane center from the before to after period is shown graphically in Figure 3.8. On average, improvement in lane position was higher for the nighttime period than for the daytime period.

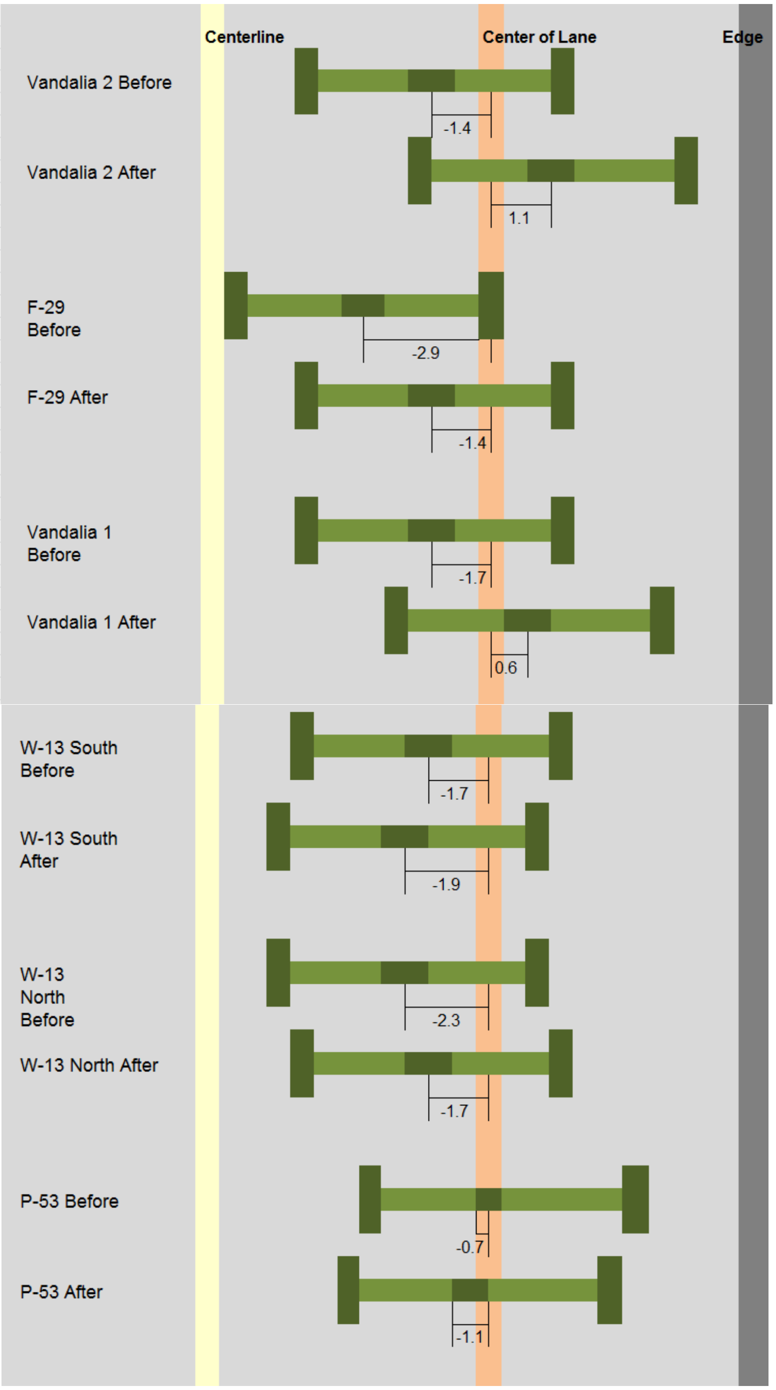

Figure 3.7. Distance from lane center for daytime conditions

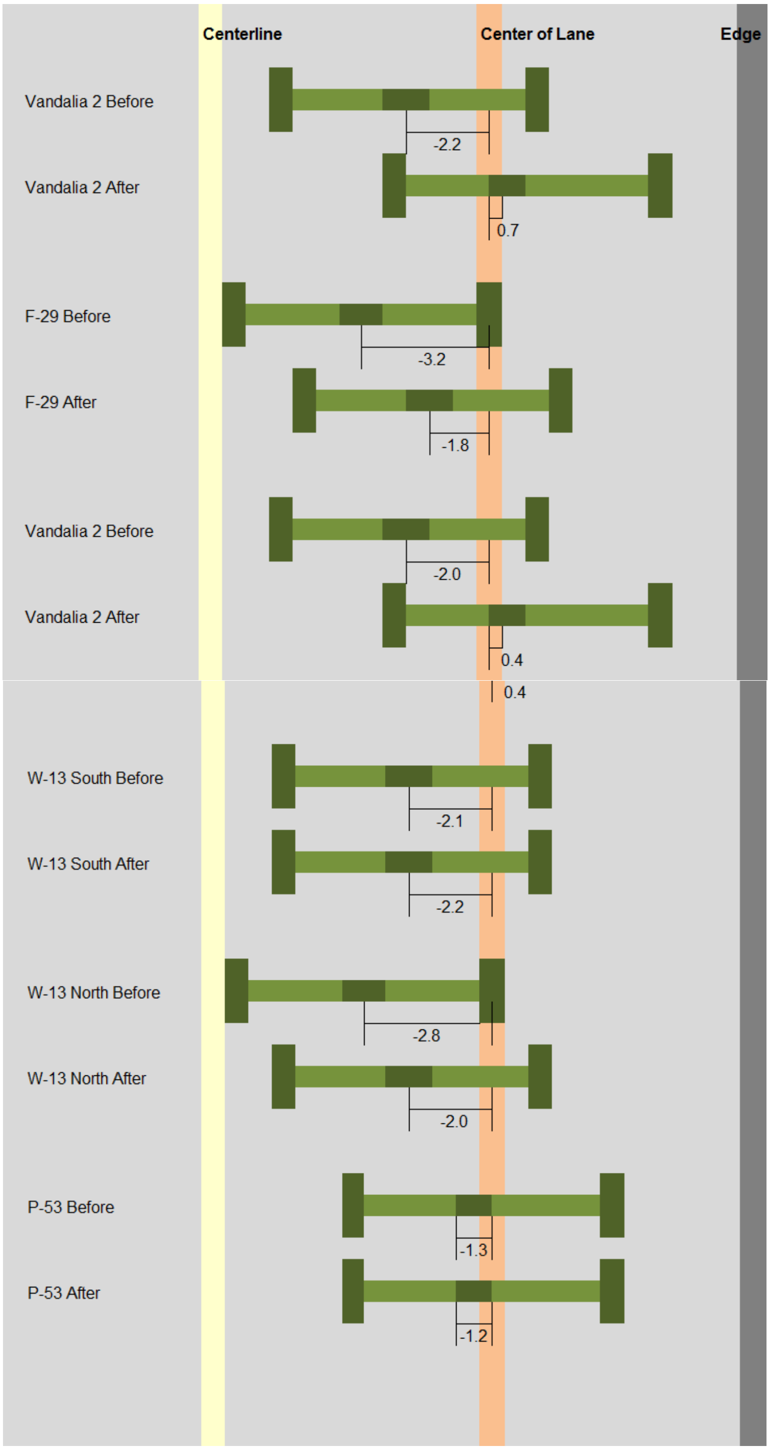

Figure 3.8. Distance from lane center for nighttime conditions

4. CONCLUSIONS AND RECOMMENDATIONS

4.1 Summary

SVROR crashes are the most common crash type on rural two-lane Iowa roads. Rumble strips have proven effective in mitigating these crashes, but these strips are commonly installed in paved shoulders on higher-volume roads in Iowa. Lower-volume paved rural roads owned by local agencies do not commonly feature paved shoulders, but frequently experience ROR crashes.

For roads where paved shoulders are not a viable option due to cost, narrow shoulders, and right-of-way restrictions, an alternative process has been devised, which involves milling narrow-width rumble strips directly along the existing pavement edge, followed by placement of standard edge-line pavement markings over the milled areas.

Although it is believed that using rumble stripes can decrease lane departures, limited information was available that demonstrates the effectiveness of the treatment. The research described in this report evaluated the effectiveness of edge-line rumble stripes in Iowa. The project identified and selected candidate locations on rural two-lane rural roads with no paved shoulders. Rumble stripes were installed and evaluated for six locations.

The rumble stripes were installed and some initial evaluations were conducted as part of Phase I of the research (http://www.intrans.iastate.edu/reports/HallmarkTR-577_report.pdf). In this Phase II report, additional evaluations about the effectiveness of rumble stripes were conducted.

The first evaluation was pavement marking wear. One of the advantages that has been attributed to rumble stripes is additional visibility of the pavement marking. It is thought that the shape of the rumble stripe itself provides a raised (vertical) surface so that the markings are more visible at night and particularly when some amount of precipitation is on the pavement surface. In addition, the depression protects part of the pavement marking, which can lead to improved wear.

Consequently, part of the evaluation was to monitor wear over time. Iowa receives a significant amount of snow from December through March. Road maintenance in Iowa is aggressive and includes scraping and the use of salt and sand. As a result, winter maintenance is harsh on pavement markings. Several sites were visited two years after application of the rumble stripes and a qualitative assessment of pavement marking wear was conducted.

At all of the sites, a significant portion of the regular pavement markings that were flush with the pavement surface had been worn away by the snowplows. Much of the marking within the rumble stripe remained. As a result, the rumble stripe was successful in preserving the pavement marking, which will lead to improved visibility. One problem that was noted with the rumble stripes is that material (sand, gravel, and dirt) tends to accumulate within the stripe.

A before and after crash analysis was also conducted. A set of control sites were included. Results of the analysis were inconclusive. However, only seven treatment sites were tested and only a short after period (two years) was available.

In addition, even though the locations were considered to be "high-crash," given the majority of the sections were less than two miles long and volumes were less than 1,500 vpd, the actual number of crashes was low. Consequently, due to the small sample size and low crash totals it was difficult to conduct a statistically-valid crash analysis.

Lane position was evaluated for several sites as a surrogate measure of safety given only a short after period was available for crash analysis. Lateral position was measured using a Z configuration of road tubes positioned from the lane edge.

Lane position was calculated using vehicle and lane width. Lateral position was measured before and after installation at six locations and compared for nighttime and daytime conditions separately. Results indicate that, in most cases, average vehicle position moved closer to the lane center after application of the rumble stripes for both daytime and nighttime.

4.2 Recommendations

Even though the most significant potential benefit (crash reduction) of narrow-width rumble stripes will not be known for several years, the results of this project indicate that narrow-width rumble stripes may have positive applications as mitigation for ROR crashes on lower-volume rural paved roads.

Based on information gained in both Phases I and II, the research team offers the following recommendations for consideration:

- Based on preliminary evaluation results, local agencies could consider installation of narrow-width rumble stripes along paved rural roads (with or without paved shoulders) when they have a high potential for or actual number of ROR crashes.
- More definitive specification requirements for milling equipment should be considered, including alignment controls and minimum downward pressure for the milling head, especially on PCC pavements.
- Close inspection of the installation process should be applied. Of particular importance is the application of painted edge lines to ascertain sufficient paint and glass beads are applied. Specifications should describe minimum rates and initial retroreflectivity requirements for both.
- More investigation of propensity of the milled areas for filling with deleterious material should be undertaken. This project indicated significant variation in this occurrence between roadway sections, and that reason should be identified if possible.
- Continue to monitor the reaction to rumble stripes from special road users, such as bicyclists, horse-drawn vehicle users, and agricultural equipment operators.

- On roadway sections with an unusually high number or rate of left-side lane departure, narrow-width rumble stripes should be considered for centerline installation.
- A cost-effective measure of nighttime, wet-condition visibility should be developed for assessing performance of pavement markings, whether rumble stripes or standard applications.

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