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

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Final Report
July 2009

IOWA STATE UNIVERSITY
Institute for Transportation

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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 been proven effective in mitigating these crashes, but these strips are commonly installed in paved shoulders adjacent to higher-volume roads 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.

Candidate locations were selected from a list of paved local rural roads that were most recently listed in the top 5% of roads for run-off-road crashes in Iowa. Horizontal curves were the most favored locations for rumble stripe installation because they commonly experience roadway departure crashes.

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

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

Final Report
July 2009

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- Brian Keierleber, PE — Buchanan County Engineer
- Jim George, PE — Dallas County Engineer
- Todd Hagan, PE — Madison County Engineer
- Kurt Bailey, PE — Polk County Engineer
- Lyle Brehm, PE — Poweshiek County Engineer
- Doug Julius, PE — Sioux County Engineer
- Steve Gannon, PE — Linn County Engineer

The research team also thanks Scott Hanson of the Iowa DOT Office of Contracts for his valuable advice, assistance, and patience during the development of the plans and contract documents describing the installation of the rumble stripes.

The authors would like to thank Iowa State University students Eric Fitzsimmons, Nicole Oneyear, and Bradley Grefe for their assistance in gathering data.

Unless otherwise noted, all photos were provided by Bob Sperry.

EXECUTIVE SUMMARY

Single-vehicle run-off-road crashes are the most common crash type on rural two-lane Iowa roads. Rumble strips have been proven effective in mitigating these crashes, but these strips are commonly installed on paved shoulders adjacent to higher-volume roads 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.

Candidate locations were selected from a list of paved local rural roads that were most recently listed in the top 5% 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.

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 ROR crashes and in improving the 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 this report. The purpose of the second phase is to provide a more long-term assessment of the performance of the pavement markings, conduct preliminary crash assessments, and evaluate lane keeping. This will result in a forthcoming second report.

Five sites were selected for installing the edge line rumble stripes. One additional site where the county had independently installed edge line rumble strips was included, resulting in a total of six sites.

This Phase I report details the site selection process and provides a description of sites selected. The installation process is provided.

Since the treatments have only been in place for one year, three interim measures, including pavement marking wear, changes in vehicle lane keeping, and feedback from user groups, were used to evaluate the effectiveness of the treatments. Lessons learned and recommendations are also provided.

1. BACKGROUND

1.1 Introduction

Run-off-road (ROR) crashes are a serious traffic safety concern. ROR crashes annually account for 38% of U.S. highway fatalities and 1 million injuries. It is also estimated that 24% of highway fatalities occur on two-lane undivided rural roads (Taylor and Meczkowski 2003). Neuman et al. (2003) also estimated that 39% of national fatal crashes are single-vehicle ROR crashes.

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

Addressing roadway departure is also one of the key emphasis areas for the American Association of State Highway and Transportation Officials (2005). A number of strategies have been employed to address roadway departure, including installation of rumble strips on paved shoulders, which has been 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. 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. 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, since raised pavement markers cannot be used due to probable snowplow damage.

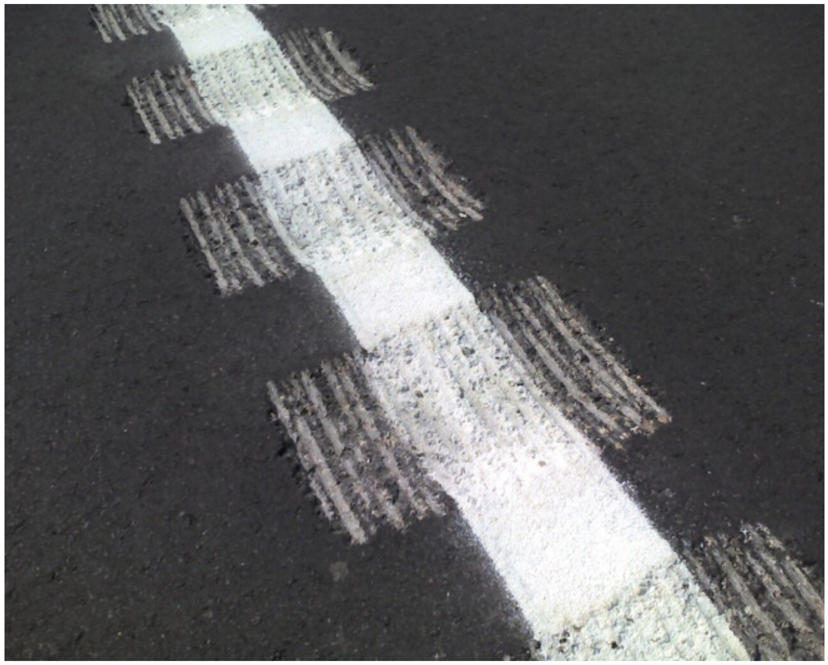


Figure 1-1. Four-inch edge line rumble stripe placement on a rural highway in Iowa

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 Department of Transportation (as reported by ATSSA in 2006) installed edge line rumble stripes on a two-lane roadway and conducted a before and after crash study. It found that right-side ROR crashes were reduced by 25% after installing the rumble stripes. The Texas Transportation Institute (TTI) evaluated the impact of edge line rumble stripes on traffic operations. It found that found that shoulder encroachment decreased by 46.7% after installing edge line rumble stripes (Miles et al. 2005).

A recent study of Missouri's Smooth Roads Initiative (SRI) included 61 sites and over 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 8% decrease in fatal and disabling injury crashes and a 6% decrease in fatal and all injury crashes. However, the analysis only included one year of after data (Potts et al. 2008).

1.2 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. Installing edge line rumble stripes on section**s** with narrow or no paved shoulders, while 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, 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 this report. The purpose of the second phase is to provide a more long-term assessment of the performance of the pavement markings, conduct preliminary crash assessments, and evaluate lane keeping. This will result in a forthcoming second 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. SITE SELECTION

This research project was undertaken to demonstrate the effectiveness of edge line rumble stripes on lower-volume rural paved roads with unpaved shoulders. The project was funded by the FHWA, the IHRB, and the Iowa DOT. Six sites in Iowa were selected for the research. The following describes how sites were selected.

The Iowa DOT crash database was used to identify sections of two-lane paved roadway with unpaved shoulders in 10 counties that had a large number of ROR crashes. The top 5% 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 3 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. The desire was to have a site for each pavement type to assess equipment performance and results. 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. This resulted in a list of seven feasible sites in six counties whose county engineers had all agreed to participate in the research project.

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. A specific amount of funding had been allocated for installing the rumble stripes. 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 and are described in the following section.

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.

The final sites included

- County Road W-13 (Fairbank-Amish Blvd.)—Buchanan County (PCC pavement)
- County Road P-53 (Pitzer Road)—Dallas and Madison Counties (PCC pavement)
- County Road F-70 (SE Vandalia Road/SE 56th Street)—Polk County (HMA pavement)
- County Road F-29 (Old US 6)—Poweshiek County (HMA pavement)
- County Road B-30 (360th Street)—Sioux County (HMA pavement)
- County Road E-16 (Sawyer Road)—Linn County (PCC pavement)

3. INSTALLATION OF RUMBLE STRIPES

3.1 Installation Process

Once a final set of sites was selected based on the list of feasible locations and available funding, the Center for Transportation Research and Education (CTRE) team worked with the Iowa DOT Office of Contracts to develop and let a contract with an independent contractor to complete installation of the rumble stripes. Strips were installed in selected locations, mostly horizontal curve areas, as described in the previous section. Most were installed along the outside edge of the pavement, although two locations in Polk County were placed on narrow paved shoulders where these were present.

The project involved milling narrow width (4–6 inch) rumble strips that were a maximum of approximately 5/8 inch deep along the pavement edge of 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 3-1 to 3-3.

As noted in the previous section, rumble stripe placement varied among road sections, with some continuous and others only in specific areas such as curves or other high-crash locations.

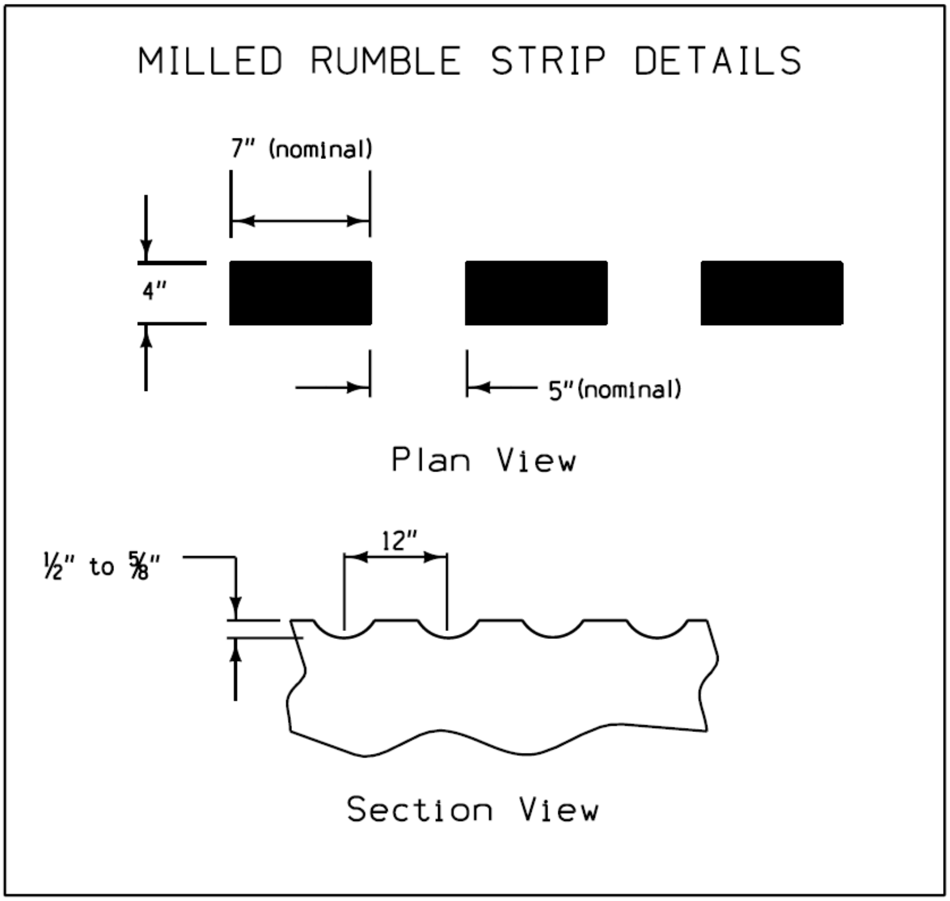


Figure 3-1. Rumble strip detail

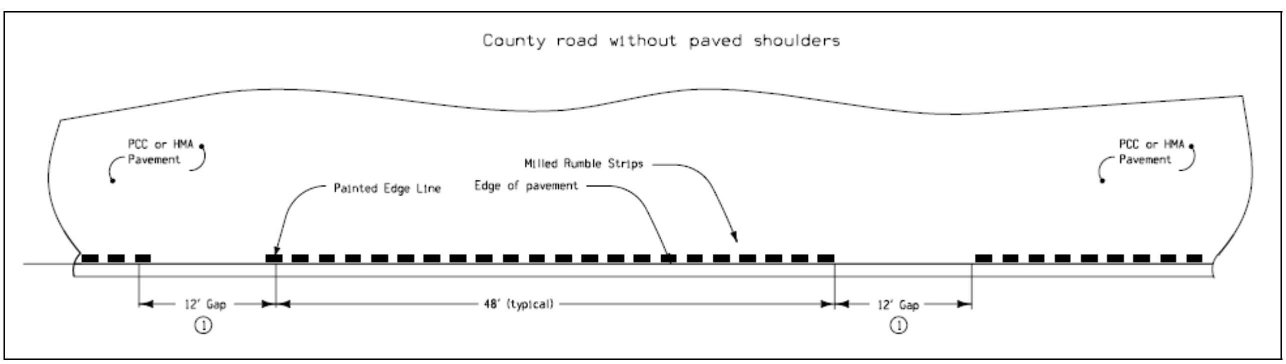


Figure 3-2. Rumble stripe layout for sections with no paved shoulders

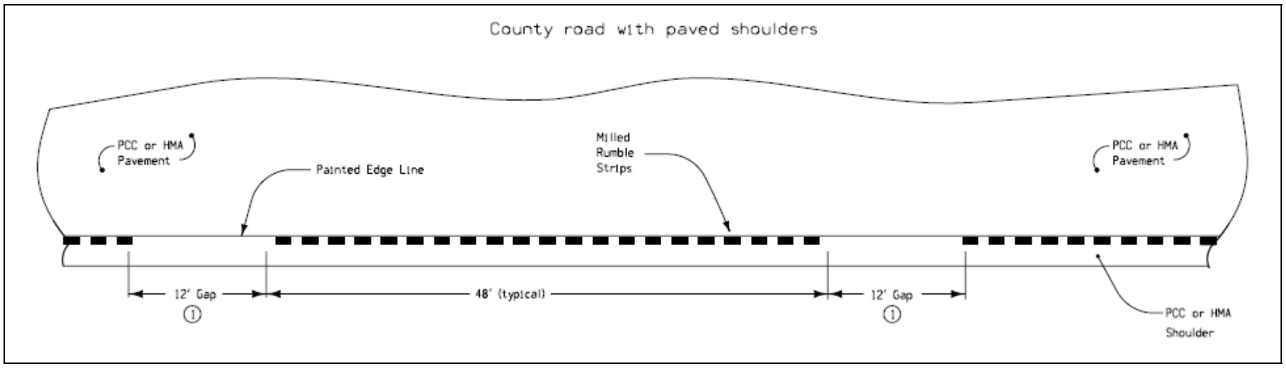


Figure 3-3. Rumble stripe layout for section with paved shoulders

A statewide project, DE-RS07(1)--3C-00, was let on January 16, 2008, by the Iowa DOT. The successful bidder was Iowa Plains Signing, Inc., of Slater, Iowa. A contract was awarded at a cost of $38,766.32. The specified number of working days was 35, with a late start date of April 7, 2008. Contract items included the installation of milled rumble strips and painted pavement markings on both HMA and PCC pavements at six locations on the following five sites:

- County Road W-13 (Fairbank-Amish Blvd.)—Buchanan County (PCC pavement)
- County Road P-53 (Pitzer Road)—Dallas and Madison Counties (PCC pavement)
- County Road F-70 (SE Vandalia Road/SE 56th Street)—Polk County (HMA pavement)**
- County Road F-29 (Old US 6)—Poweshiek County (HMA pavement)
- County Road B-30 (360th Street)—Sioux County (HMA pavement)

Note: The Polk County sections had paved shoulders, allowing rumble stripes to be installed outside of the travel lanes

Initial milling of the rumble strips was subcontracted to Diamond Surfaces, Inc., of Maple Grove, Minnesota; all other contract work, including pavement marking, was handled by the primary contractor, Iowa Plains Signing, Inc. Figure 3-4 shows the milling machine and how the equipment was shifted to the left or right to cut the rumble stripes. Due to operational difficulties, final milling work in some horizontal curve areas was completed by Iowa Plains Signing with a different milling machine. Field work began on June 5, 2008, on Sioux County B-30 following a delay due to adverse weather conditions and equipment problems. Work progressed through Dallas/Madison Counties P-53, Polk County F-70/Vandalia Road, Poweshiek County F-29, and Buchanan County W-13. All locations were milled and edge lines repainted by June 2008.

(a) Milling machine owned by Diamond Surfaces, Inc., used for most of work

(b) Side-shift left—provided most weight over mill head

(c) Side-shift right position

Figure 3-4. Milling machine

The process had three steps: (1) mill in rumble strips, (2) sweep the pavement debris from the rumble strips, and (3) repaint the edge line through the rumble strip. The three steps are shown in Figures 3-5 to 3-7.

Figure 3-5. Close-up of the milling process

Figure 3-6. Machine sweeping completed rumble strips after milling

Figure 3-7. Regular paint truck painting edge line

Work was suspended in early June to allow the contractor time to work on modifications to another piece of equipment that could complete the work that had been omitted on the inside of curves due to operational problems that will be described in the next section. The equipment shown in Figure 3-8 was adapted to allow milling along the low side of horizontal curves and to be performed more adequately, although the milling depth was still minimal and the alignment was less than ideal.

(a) Milling attachment **(b) Milling head**

Figure 3-8. Milling equipment (photos courtesy Iowa Plains Signing, Inc.)

The contractor resumed milling work on October 16, 2008, and completed all contract work on November 3, 2008. Examples of that work are shown in Figure 3-9.

Figure 3-9. Examples of milling work

The contract was recommended for acceptance on November 10, 2008, with 23 working days charged.

All locations were milled and had edge lines repainted by June 2008 except for the short areas on the inside of horizontal curves, which were delayed until more versatile equipment was available. Work on those portions was not finalized until November 3, 2008.

3.2 Problems Noted

Installation work was quite satisfactory in the tangent sections of roadway, but problems with machine stability were encountered when milling was attempted along the low side of super-elevated horizontal curves due to the high center of gravity of the milling machine. Milling machine instability, less than desirable milling depth, and difficulty in maintaining a satisfactory alignment through curves required omitting these sections until a modified machine was developed later in the season. In addition, it was necessary to add an air compressor to the process to remove millings from the pavement edge prior to application of pavement markings. Figure 3-10 shows sections on County Roads B-30 and P-53 after rumble stripes were cut into the pavement surface. Figure 3-11 shows the machine tipping.

Milling in the rumble strips also resulted in some breakup of the pavement surface, as shown in Figure 3-12. In one county, milling was suspended around mailboxes to avoid damage, as shown in Figure 3-13.

(a) B-30 in Sioux County

(b) P-53 in Dallas/Madison County

Figure 3-10. Milling in Sioux and Dallas Counties

Figure 3-11. Machine tipping on inside curve

Figure 3-12. Edge spalling along edge of PPC pavement

Figure 3-13. Milling operation omitting short areas around mailboxes in Polk County

Figure 3-14 shows the difficulty in aligning the painted edge line with the milled rumble strip.

Figure 3-14. Photos showing difficulty in maintaining painted edge line alignment within rumble stripe installation

4. DESCRIPTION OF SITES

The following section describes each site where installation occurred. It also shows images of installation and other information.

4.1 County Road W-13 (Fairbank-Amish Blvd.)

County Road W-13 is in Buchanan County, as shown in Figures 4-1 to 4-3. The section has PCC pavement and starts near the intersection of W-13 and Otterville Boulevard and crosses the intersection with River Road Boulevard. The test section is 7,400 linear feet. Crash data from 2001 to 2006 indicated that the section had a total of 47 crashes, with 16 ROR crashes.

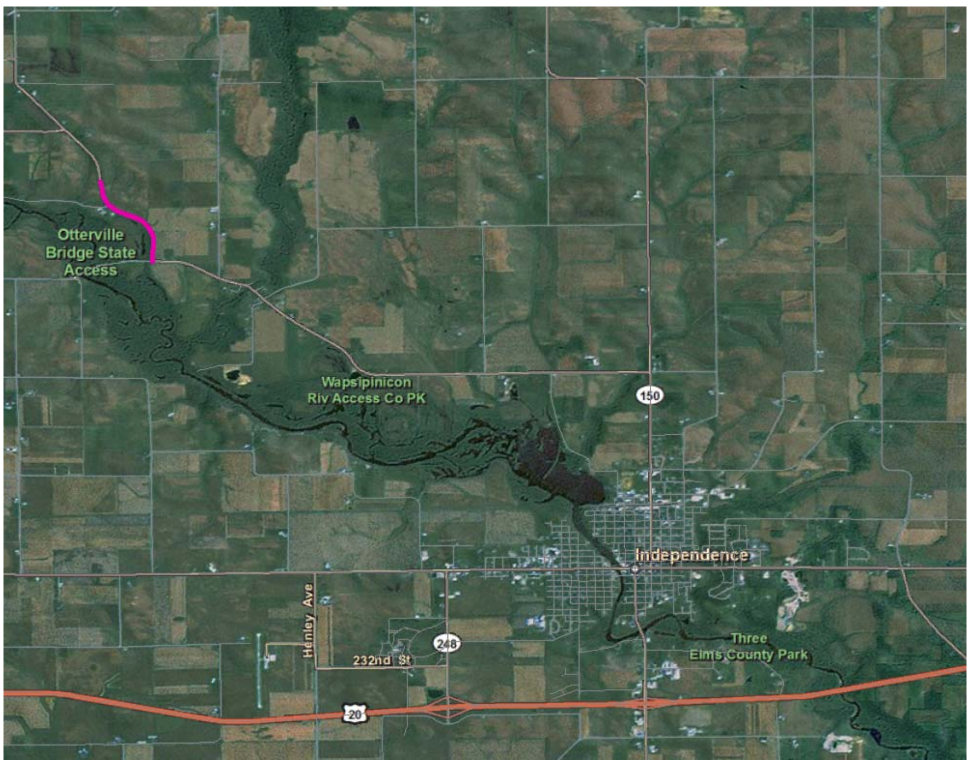


Figure 4-1. Location of test section on W-13

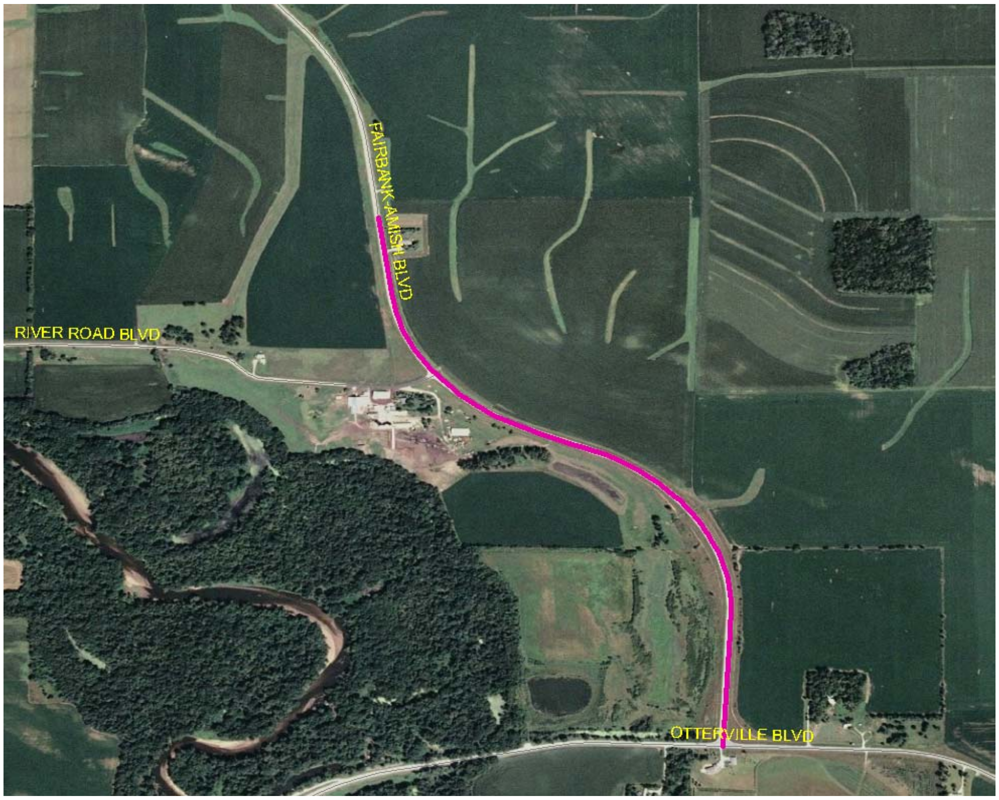


Figure 4-2. Test section on W-13

Figure 4-3. Rumble stripe installation on W-13 (photo courtesy of Neal Hawkins, CTRE)

4.2 County Road P-53 (Pitzer Road)

County Road P-52 (Pitzer Road) is located in Dallas and Madison Counties, as shown in Figures 4-4 to 4-6. The pavement is PCC. The test section starts approximately 0.25 miles north of the intersection with County Road G-14 in Madison County and runs to the Iowa Interstate Railroad crossing in Dallas County. The section is approximately 8,600 linear feet. Crash data from 2001 to 2006 indicated that the section had a total of 19 crashes, with 12 ROR crashes.

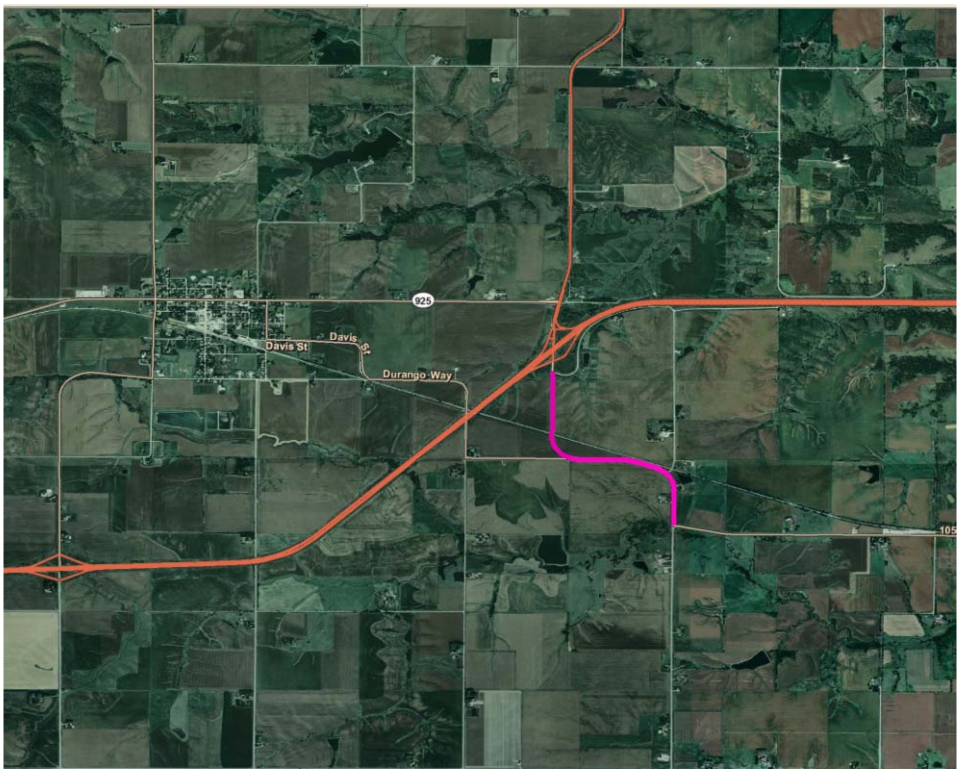


Figure 4-4. Location of test section on P-53

Figure 4-5. Test section on P-53

Figure 4-6. Rumble stripe installation on P-53

4.3 County Road F-70 (Vandalia Road)

Vandalia Road (SE 56th Street) is located in Polk County, as shown in Figures 4-7 to 4-9. The pavement is HMA. The test section is composed of two segments. One starts approximately 20 feet west of the intersection with 60th Street and ends near the intersection with SE 72nd Street. The second segment begins approximately 0.5 miles west of the intersection with 56th Avenue and ends at the intersection with SE Stewart Drive. The total length of both segments is 32,737 linear feet. Crash data from 2001 to 2006 indicated that the section had a total of 39 crashes, with 23 ROR crashes.

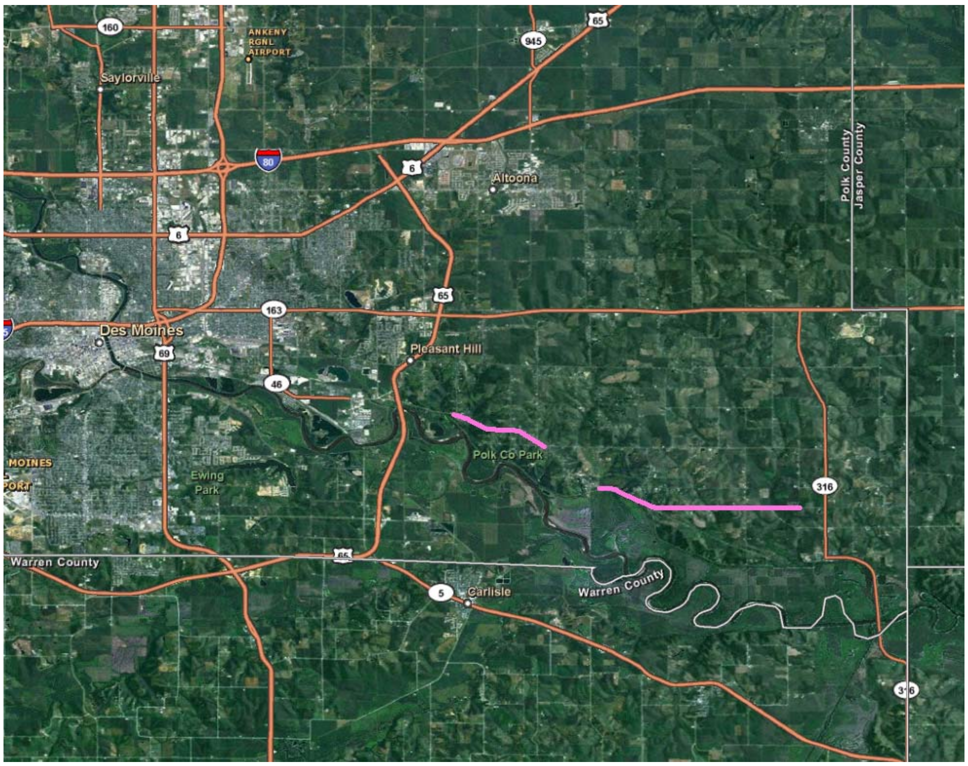


Figure 4-7. Location of test section on Vandalia Road (F-70)

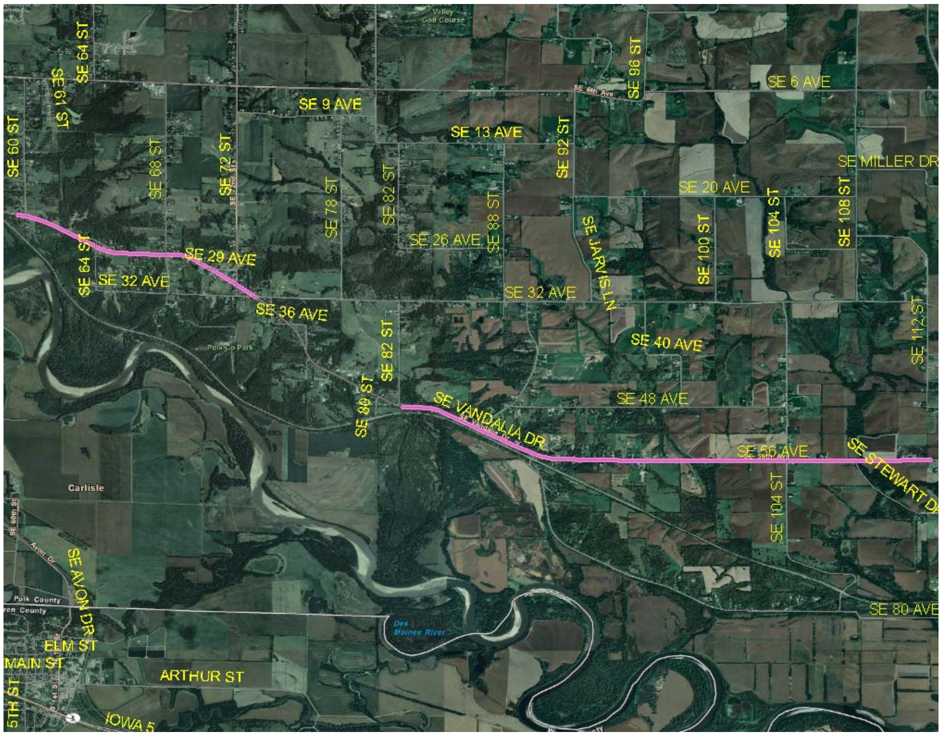


Figure 4-8. Test section on Vandalia Road (F-70)

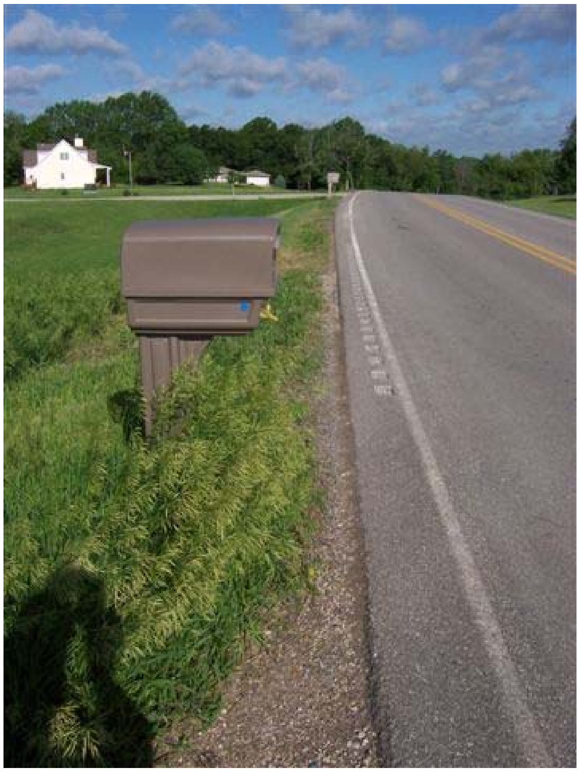


Figure 4-9. Rumble stripe installation on Vandalia Road (F-70)

4.4 County Road F-29 (Old US 6)

County Road F-29 (Old US 6) is located in Poweshiek County, as shown in Figures 4-10 to 4-12. The pavement is HMA. The section includes two segments. One is located 100 feet west of 400th Avenue to approximately 0.3 miles east of 230th Street, and the other simply encompasses a curve west of Victor. Both segments in the section total 9,560 linear feet. Crash data from 2001 to 2006 indicated that the section had a total of 11 crashes, with 8 ROR crashes.

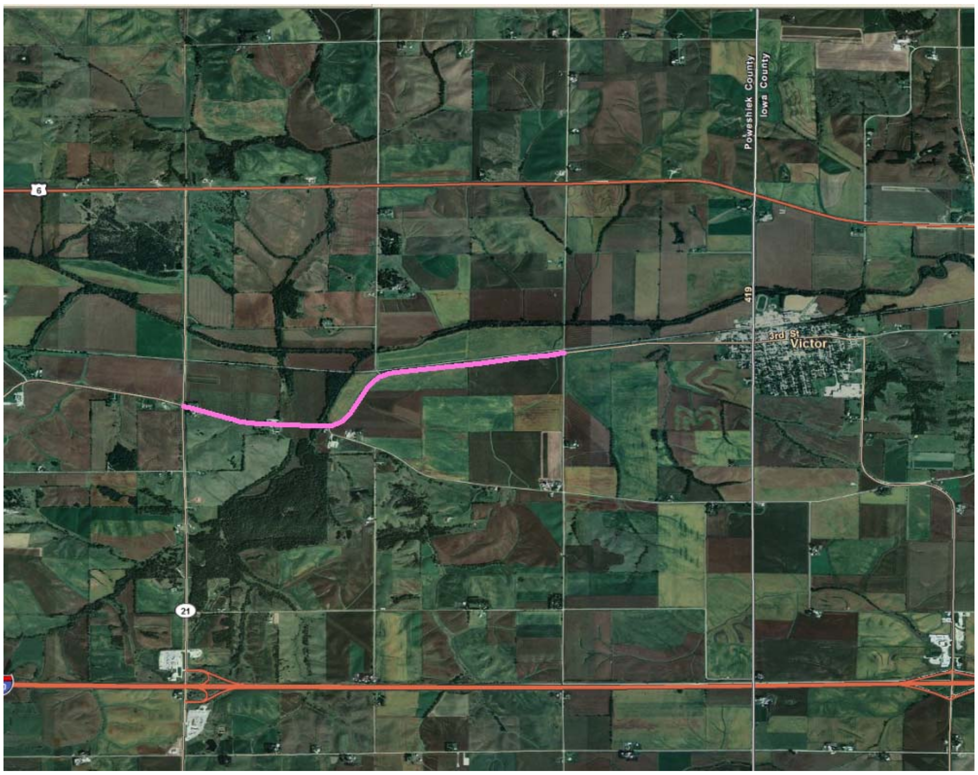


Figure 4-10. Location of test section on F-29

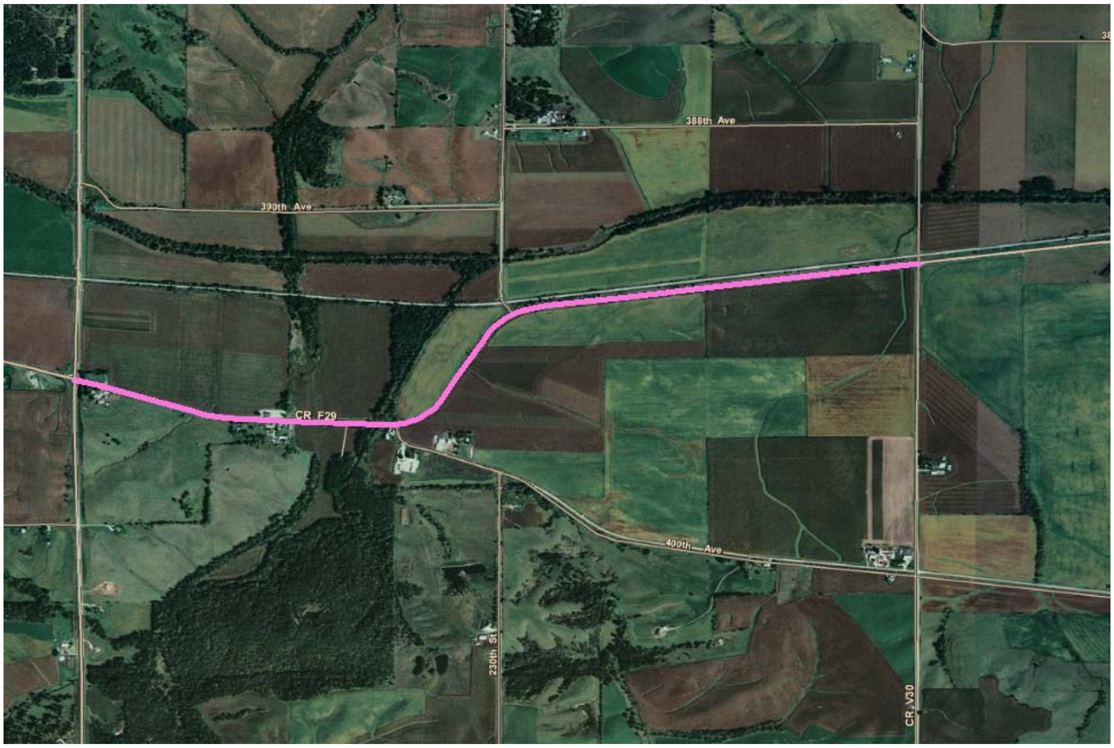


Figure 4-11. Test section on F-29

Figure 4-12. Rumble stripe installation on F-29

4.5 County Road B-30 (360th Street)

County Road B-30 (360th Street) is in Sioux County, as shown in Figures 4-13 to 4-15. The pavement is HMA. The section starts approximately 0.2 miles east of County Road K-18 (Chestnut Avenue) and runs approximately 0.8 miles to the east. The section is 8,500 linear feet. Crash data from 2001 to 2006 indicated that the section had a total of 17 crashes, with 9 ROR crashes.

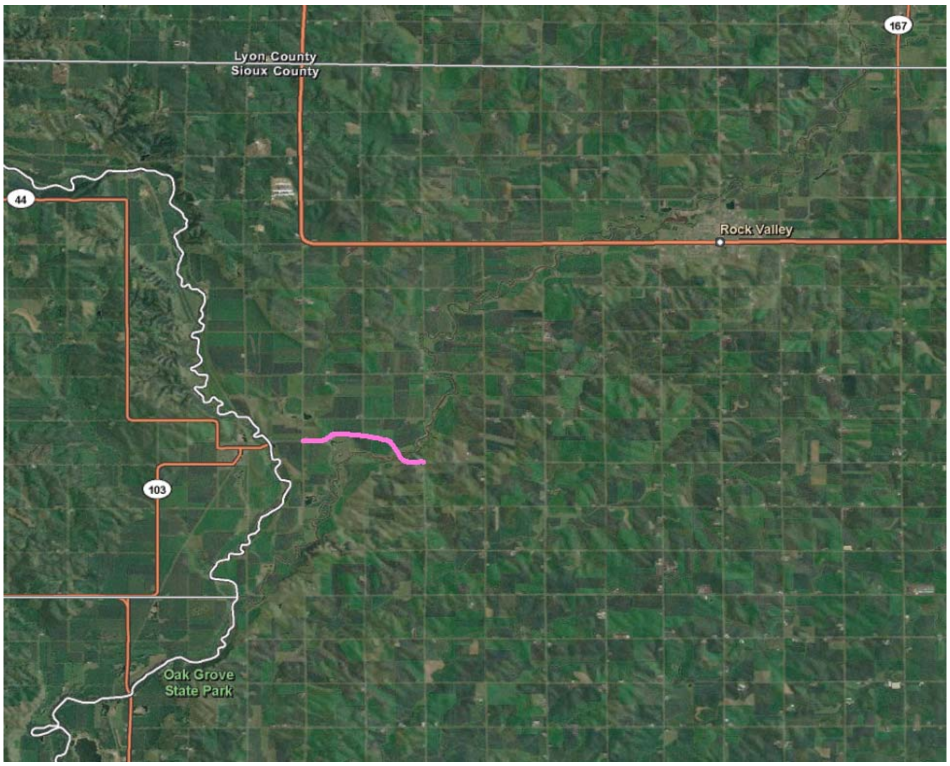


Figure 4-13. Location of test section on B-30

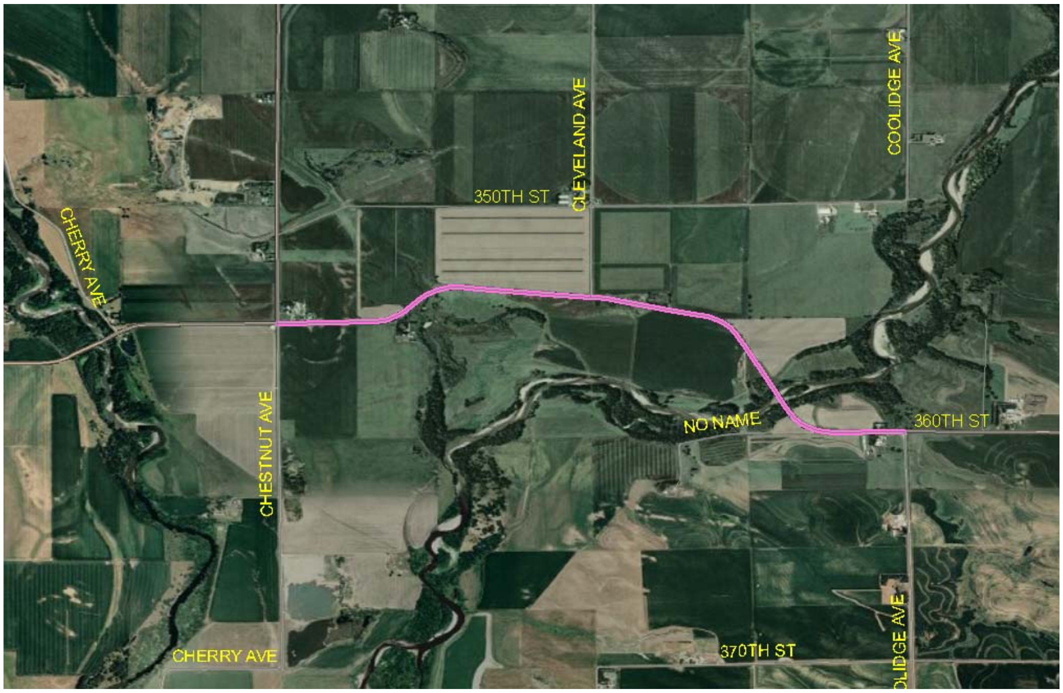


Figure 4-14. Test section on B-30

Figure 4-15. Rumble stripes on B-30

4.6 County Road E-16 (Sawyer Road)

County Road E-16 (Sawyer Road) is in Linn County, as shown in Figures 4-16 to 4-18. The pavement is newly constructed PCC. The section starts approximately at the intersection of Drexler Road and ends at the intersection with Duck Pond Road. The section is approximately 5,500 linear feet. For the period of 2001 through 2006, there were a total of 13 crashes, of which 6 were ROR incidents.

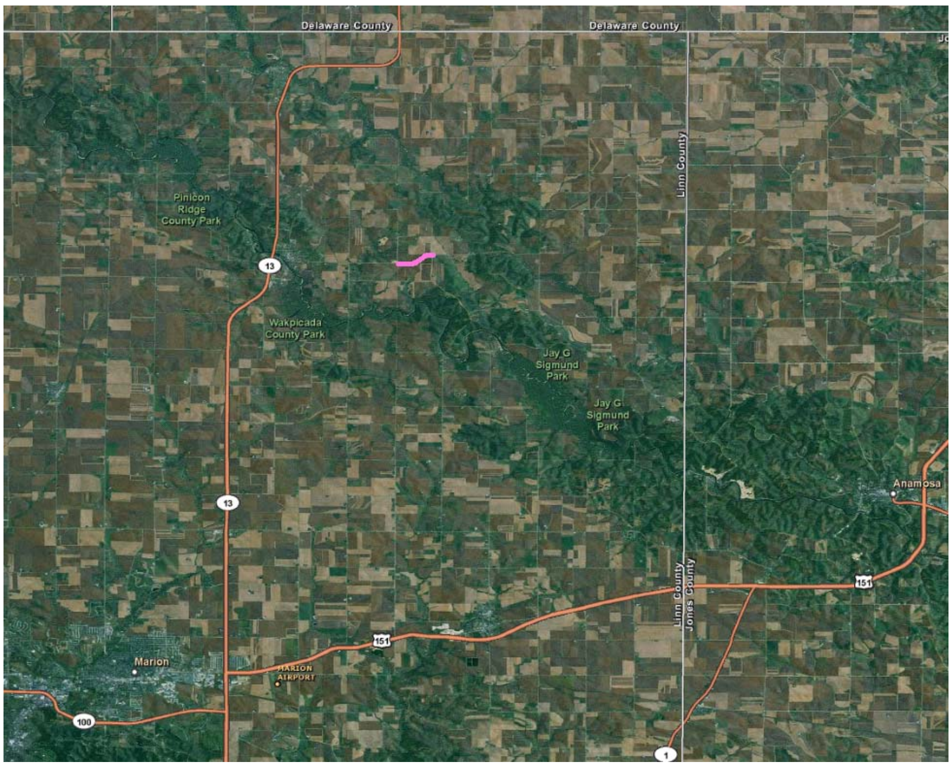


Figure 4-16. Location of test section on E-16

Figure 4-17. Test section on E-16

Figure 4-18. Rumble stripe installation on E-16

5. EVALUATION METHODOLOGY AND RESULTS

The best measure of effectiveness for the edge line rumble stripes is reduction in ROR crashes. However, in order to be statistically valid, a crash analysis requires several years of before and after data, which cannot be completed for at least 3–5 years. In order to have some evaluation of the first phase, three interim measures were used. The first evaluation was the pavement markings wear. It is expected that less wear on the pavement marking will occur in the edge line rumble stripe since the marking is slightly below the normal surface of the roadway. The second evaluation was to determine whether vehicle lane keeping improved with the rumble stripes present. Both evaluation methods are described in the following sections. The third evaluation was an initial assessment of the impact of the rumble strip/stripe system on user groups. This is important since some groups can be adversely affected by placement of rumble strips or rumble stripes.

5.1 Retroreflectivity

Evaluation of the wear and visibility of pavement markings was conducted for all test sections. After initial installation, pavement markings were repainted through the rumble stripe section. The wear on pavement markings was evaluated using a retroreflectometer, as shown in Figure 5-1.

The LTL-X Retrometer measures the R1 parameter for pavement markings. The R1 parameter—the coefficient of retroreflected luminance—represents the brightness of road markings illuminated by headlights as seen by motor vehicle drivers. R1 is measured in millicandelas per square meter per lux ($mcd*m^{-2}*lx^{-1}$). LTL-X simulates a driver's viewing distance of 30 meters at an observation angle of 2.29° using an illumination angle of 1.24°.

The top of the machine contains the illuminating and observation system and control electronics. At the bottom, an optical system with a mirror directs a beam of light toward the road surface through a dust-protection window. A xenon lamp in the tower shoots a light, which is used for the measurements. The light is deflected by a mirror through a lens toward the road. The light reflected from the road goes back up through the lens and mirror and is calculated by the machine (Technical Specs for the LTL-X Retrometer).

The retroreflectometer measures light reflected from the pavement markings in millicandelas per square meter per lux (mcd). Retroreflectivity is used as a measure of pavement marking quality degradation. However, it should be noted that there is a certain amount of variability in retroreflectivity (Kopf 2004).

There are currently no federal standards for what is considered an acceptable reading, but the Iowa DOT requires a reading of 300 mcd for new white paint lines and 200 mcd for yellow markings. The Iowa DOT considers replacing pavement markings when they are half of the above values.

Readings with the retroreflectometer were first taken at most of the sites in the summer (July 2008). At that point, the markings should have been intact. Readings were taken at each site again in the fall (October 2008). Depending on date of installation, the markings had been installed for approximately six months. At that point, some wear due to maintenance, tires, and weather would have occurred. Readings were taken again the following spring (April 2009). At this point, the markings would have been exposed to several months of ice and snow, and snowplows would have gone over the markings numerous times, resulting in significant wear. This was the case for all sites except for E-16 in Linn County. The rumble stripes were placed by the county, so installation was after the other sites. The fall readings for that section represent new application.

Retroreflectometer readings were taken at two positions within each test section. Readings were taken directly over the rumble stripes at approximately 500- to 1,000-foot intervals at locations where the rumble stripes were actually present (within the grooved portion). Four readings were taken in each location and then averaged. When the rumble stripes were installed, an extra 500 feet of edge line was painted beyond the rumble strip so data could be compared for sections without rumble strips. However, some of these areas were repainted by the counties during the period, and while the county repainted areas outside the rumble stripes, they did not repaint the rumble stripes themselves. As a result, those sections could no longer be used as controls. Therefore, data were collected intermittently on the solid painted areas between rumble stripes to further define the comparison. This was used as a control section. Initial data were collected mainly within those 500-foot sections but was expanded (and later eliminated) at each project for subsequent collections. This is shown in Figure 5-1.

(a) Fall readings **(b) More readings in spring after winter snowplow work**

Figure 5-1. Retroreflectivity data being taken

Although the appearance of the stripes seemed the same for the initial and most of the fall collections, county maintenance crews had pulled up the gravel shoulders on the Poweshiek project, filling the stripes with loose granular material. This rendered them ineffective until the paint contractor blew out the material with compressed air. Also, the spring collection period revealed that the many of the stripes had been filled or partially filled with loose gravel material, even on the Polk County roads with paved shoulders. See Figure 5-2. This may be attributed to winter maintenance using sand (sometimes mixed with salt) on slick roads. The amount of filling seemed to be much heavier on the asphalt pavements than on the PCC pavements.

Figure 5-2. Rumble stripes filled with sand

Some of the stripes, especially at the tops of hills, on straight road segments seemed to accumulate only a small amount of caked fines in the bottom of the stripe. See Figure 5-3.

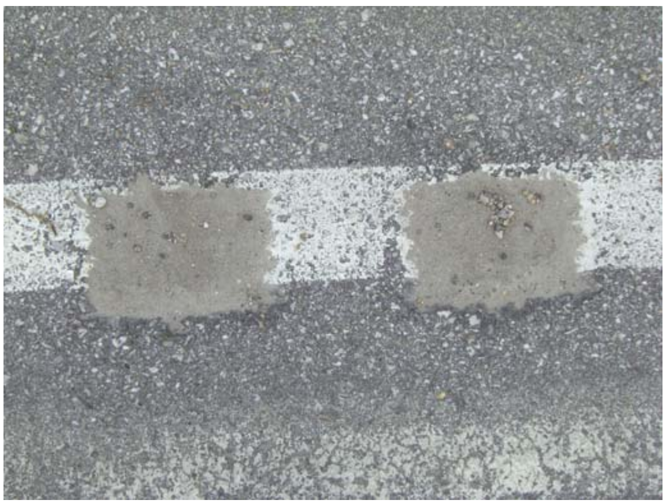


Figure 5-3. Rumble stripe with caked fines in bottom

Stripes that were caked and only partially filled showed better retroreflectivity readings than those that were completely filled. Although the authors did not wish to introduce a possible maintenance activity for using these stripes, they did consider that the performance might be better if the loose (or caked) material was broomed from the stripe. See Figure 5-4. Therefore, they did broom (by hand) several stripes of each type and shot them for performance. In all cases, the retroreflectivity of the swept stripes measured lower than the untouched ones. The authors believe that this may have occurred due to dust created by the brooming covering most of the reflective beads and/or due to the brooming action itself removing much of the beading from the paint surface. Using a stiff or soft bristle hand broom seemed to make no difference.

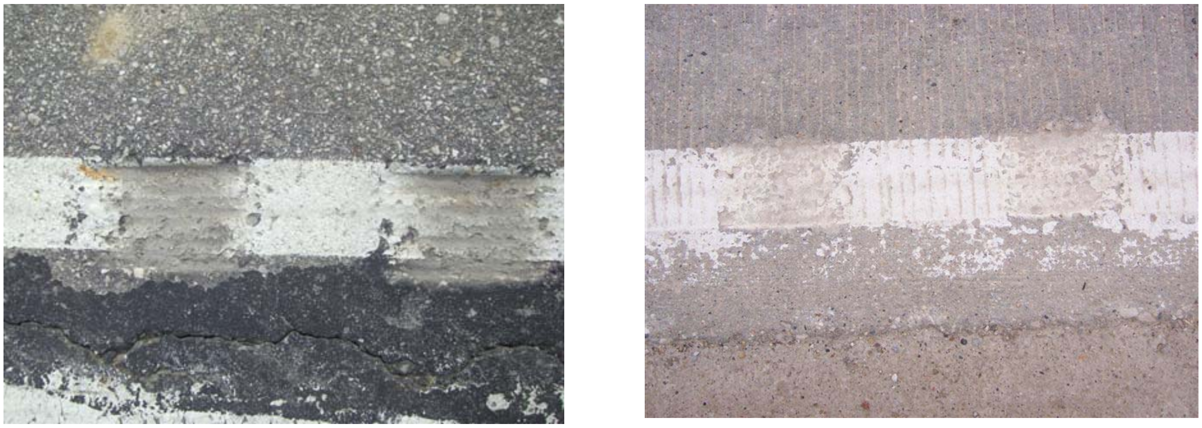


Figure 5-4. Swept stripe areas on asphalt and PCC pavements

Two readings for each location (within a rumble stripe versus along a “normal” section) were compared for each time period (summer 2008, fall 2008, and spring 2009). Since readings were not taken at exactly the same location each time data were collected, values were averaged and a t-test was used to compare whether readings from one time period were different and statistically significant from a subsequent time period. Results are provided in Table 5-1. The change in average readings from summer to fall is also provided in Figure 5-5, and the change in average readings from summer to spring is shown in Figure 5-6.

As indicated in both the table and figures, there does not appear to be any clear trend indicating that paint markings in the grooved portion of the rumble stripe fare any better or worse than paint markings on regular surfaces. Overall, the average readings are lower for those taken within the rumble stripe than for those taken on normal surfaces. It is believed that this occurs because of the way the retroreflectometer takes readings. The retroreflectometer is designed to record readings from a flat surface, and it is believed that the concave surface of the rumble stripes affected readings. For this reason, the change in readings between different times of the year was compared rather than actual readings.

Charts were also made that show individual readings at each site. Figures 5-7 to 5-9 show readings for the control “flat” areas on test section W-13 for summer 2008, fall 2008, and spring 2009, respectively. Figures 5-10 to 5-12 show readings for rumble stripe areas on test section W-13 for summer 2008, fall 2008, and spring 2009, respectively.

Table 5-1. Comparison of retroreflectivity readings for test sections

Site	Summer RS	Fall RS	Spring RS	Change Summer to Fall	Change Summer to Spring	Summer "Normal"	Fall "Normal"	Spring "Normal"	Change Summer to Fall	Change Summer to Spring
W-13	259	127	167	132	92	314	206	224	108	90
P-53	205	166	134	39	71	267	270	237	-3	30
F-70 Segment 1	189	151	126	38	62	244	180	181	64	63
F-70 Segment 2	178	169	141	9	37	314	314	205	0	109
F-29	151	107	102	44	49	206	151	156	55	50
B-30	180	141	127	39	53	224	202	194	22	30
E-16*		309	234	Change fall to spring 75			323	244	Change fall to spring 79	

*Rumble stripes for E-16 were placed later, so fall 2008 represents a new installation

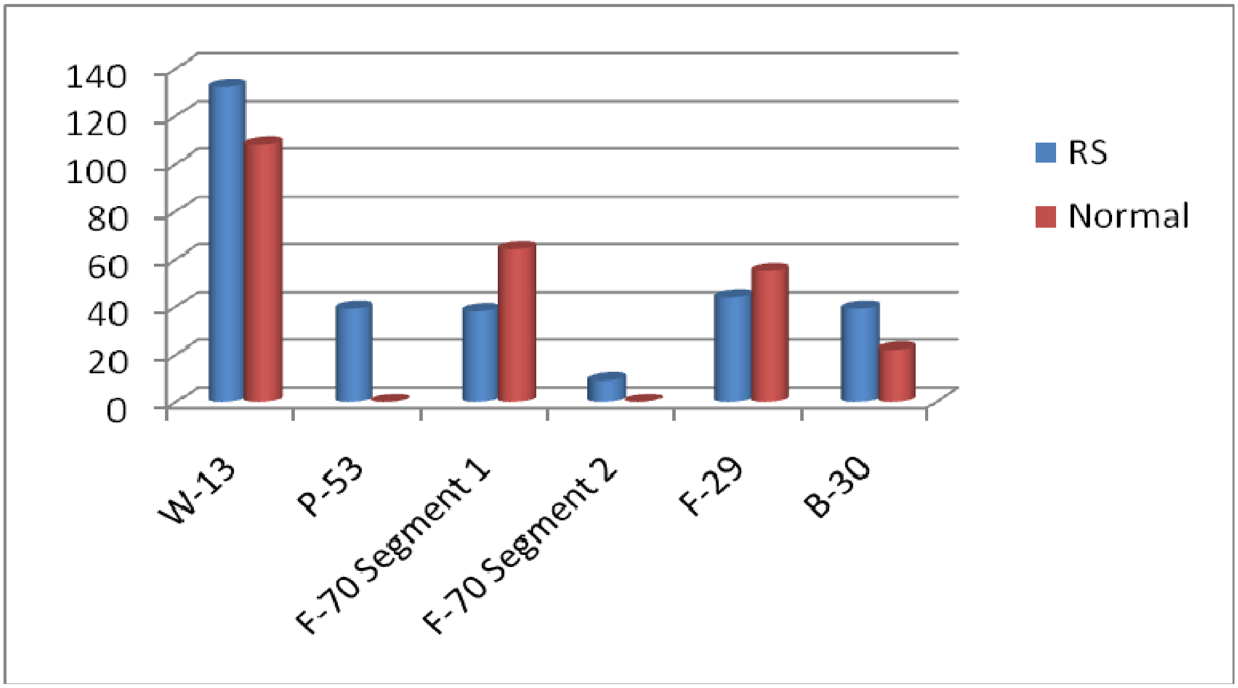


Figure 5-5. Change in average readings from summer to fall

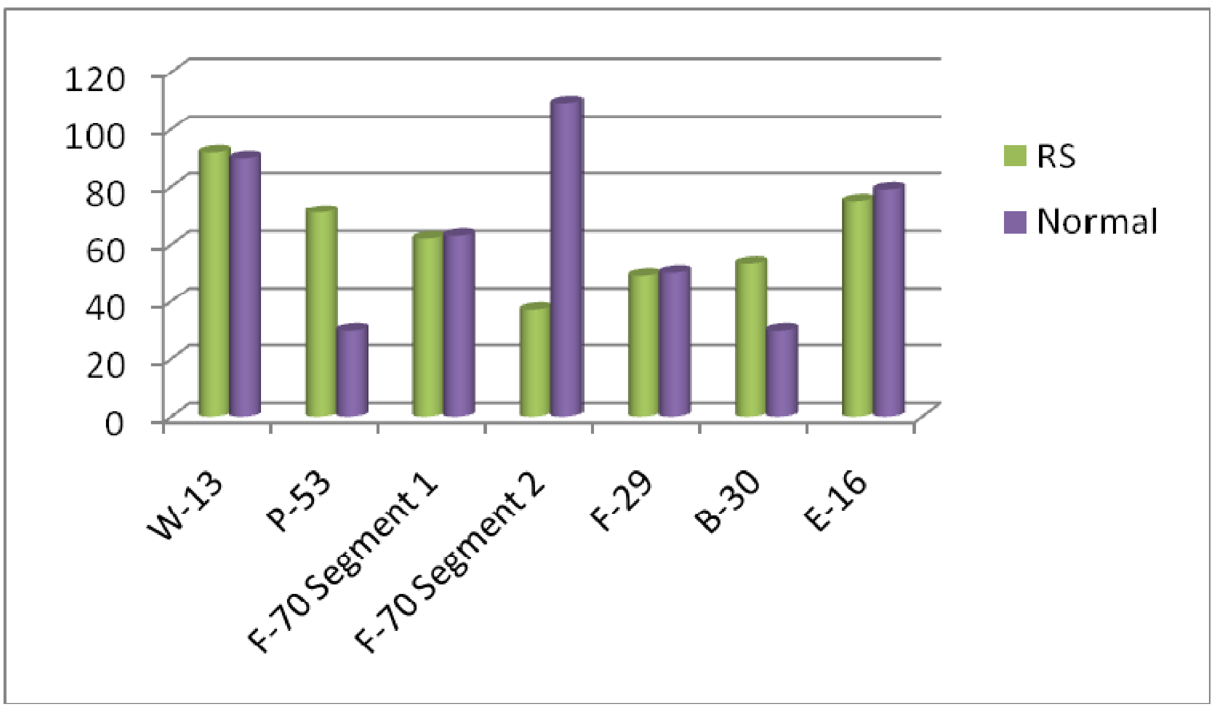


Figure 5-6. Change in average readings from summer to spring

Figure 5-7. Summer readings for control for test section W-13

Figure 5-8. Fall readings for control for test section W-13

Figure 5-9. Spring readings for control for test section W-13

Figure 5-10. Summer readings for rumble stripes for test section W-13

Figure 5-11. Fall readings for rumble stripes for test section W-13

Figure 5-12. Spring readings for rumble stripes for test section W-13

5.2 General Wear

Wear on pavement markings was also compared by visual inspection. Figure 5-13 shows a section of the rumble stripes in Buchanan County taken in May 2009. Notice how, in general, the markings have worn considerably, but the area within the groove appears to have experienced even greater wearing. The pavement in this section is PCC.

Figure 5-13. W-13 pavement markings in spring and after wear over winter, showing more wear in the groove than in the flat section

It was noted that the amount of exposed paint on the stripes and, therefore, their visibility effectiveness was increased in areas that were on hills where rain and melting snow would wash out some of the loose material out. Unfortunately, this does not increase their visibility for traffic going down the hills since the loose material migrates to the lower portion of the stripe with rainfall.

Some of the paint that was applied late in the fall (inside curve segments in Dallas/Madison, Polk, Buchanan, and Poweshiek Counties) did not seem to adhere well in the stripe area, especially on the PCC surfaces. Much of the paint was loose and had chipped away by the spring evaluation. Brooming seemed to remove most of the loosened pieces. See Figure 5-14.

Figure 5-14. Peeling paint chips on flat area

In other areas, the paint seemed to be holding up well in both the rumble stripes and flat sections. Figure 5-15 shows a portion of F-29 taken in spring 2009. Figure 5-16 shows a portion of E-18 taken in spring 2009.

Figure 5-15. Similar wear for rumble stripe and flat section (taken spring 2009). F-29 is on the left and P-53 is on the right.

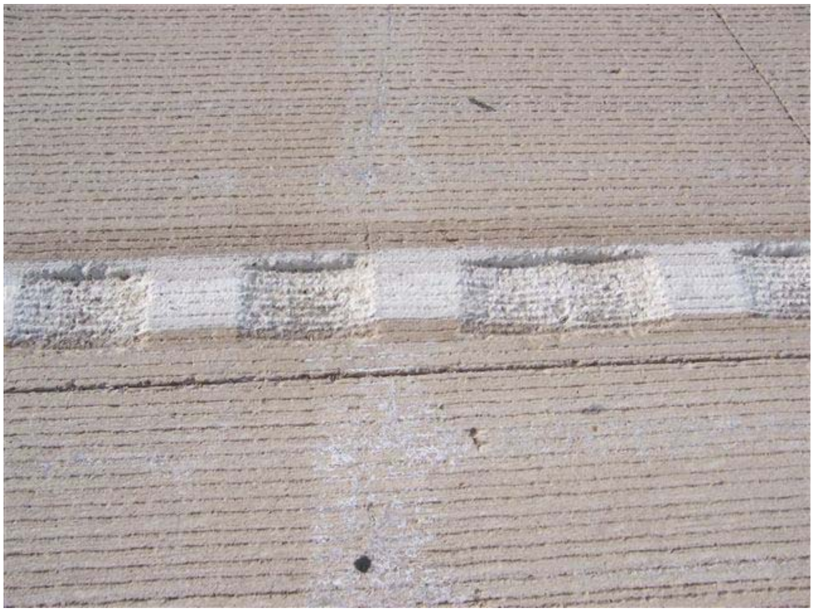


Figure 5-16. Similar wear for rumble stripe and flat section on E-16 (taken spring 2009)

In other areas, the paint in the rumble stripe appeared to weather better and show less wear than the pavement markings on the flat portion of the roadway. Figure 5-17 shows a portion of F-29 that shows less wear in the groove than in the flat areas. Figure 5-18 shows a similar scenario for P-53.

Figure 5-17. Another portion of F-29 showing less wear in the rumble stripe than in the flat area (taken spring 2009)

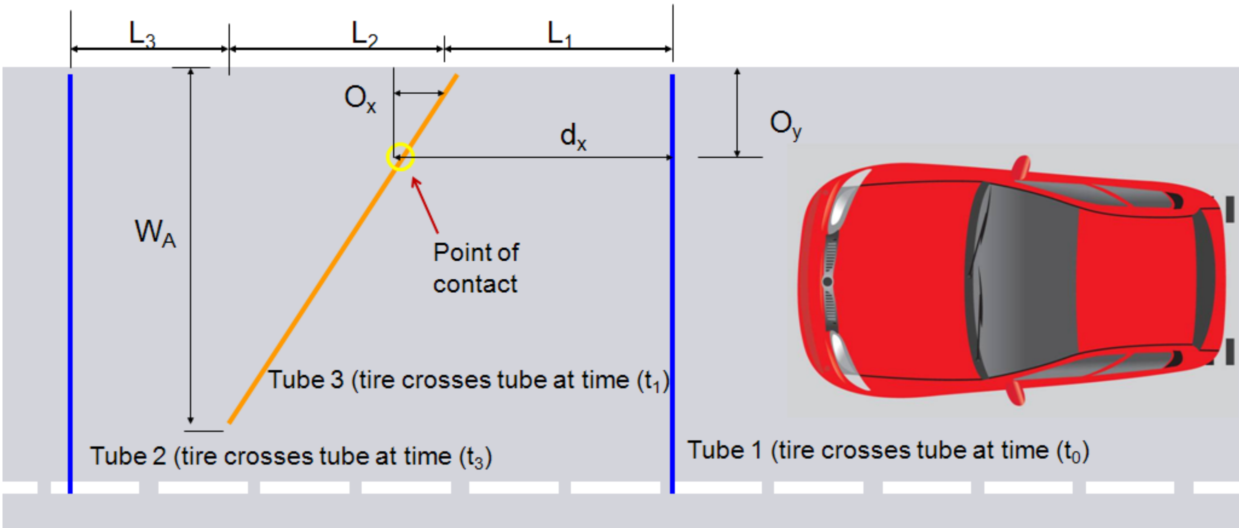
Figure 5-18. Another portion of P-53 showing less wear in the rumble stripe than in the flat area (taken spring 2009)

5.3 Lateral Position

Lateral position of passing vehicles is one method that has been used to evaluate the effectiveness of rumble strips. It is assumed that with edge line rumble stripes, drivers will be less likely to veer near the outside roadway edge. Several studies have used lane keeping as a measure of effectiveness, including Porter et al. (2006), Taylor et al. (2005), and TTI (2007).

In order to collect lateral position, the team followed a methodology used by Porter et al. (2006) and TTI (2007) that uses pneumatic road tubes set up in a "Z" configuration, as shown in Figure 5-19. 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 configuration was set up on one section of P-53, as shown in Figure 5-20.

Data were collected over seven days for the before period and five days for the after. The methodology requires that vehicle tires strike the three tubes in a consistent order. Vehicles that have a tire cross slightly outside the tubes or that have an unusual axle configuration cannot be included, which results in a large number of vehicles not being used. A total of 1,328 vehicles were included for the before period, and 702 vehicles were included in the after period.



$$v = \frac{L_1 + L_2 + L_3}{t_3 - t_0} \qquad o_x = d_x - L_1 \qquad d_x = v\,(t_1 - t_0) \qquad o_y = \frac{o_x\ a}{L_2}$$

Figure 5-19. Layout configuration of road tubes to measure lateral displacement

Figure 5-20. Road tube layout to measure lateral displacement in the field

The road tubes were set up before and then approximately 1 month after installation of the edge line rumble stripes. Lateral displacement is the distance from the outside right wheel to the right roadway edge. As shown in Table 5-2, before installation of the rumble stripes, the average lateral displacement was 3.09 feet with a standard deviation of 1.2 feet. After installation, the average lateral displacement was 3.64 feet. The percentage of vehicles within 1 foot of the pavement edge decreased from 2% before to 0% after installation. The percentage of vehicles within 2 feet of the lane edge decreased from 22% before installation of the edge line rumble stripes to 16% after. As indicated by the results, vehicles were positioning themselves farther from the pavement edge with edge line rumble stripes.

Table 5-2. Lateral position before and after installation of edge line rumble stripes along P-53

	Before	After	Difference
Mean (ft)	3.09	3.64	-0.56 feet
Std (ft)	1.2	1.3	
% within 1 foot of lane edge	2.0	0.4	1.6%
% within 2 feet of lane edge	22.3	15.5	6.8%

Difference in mean lateral displacement was compared using a t-test. Differences were statistically significant at the 95% level of significance. Differences in the percentage within 1 or 2 feet were compared using a test of proportions, and differences were also statistically significant at the 95% level of significance.

5.4 Follow-up with User Groups

Several user groups were consulted after installing the edge line rumble stripes. Amish groups in Buchanan and Davis Counties were surveyed about problems they encounter driving on public roads with horse drawn buggies and wagons, including their experience with rumble stripes when present. The discussions with Amish groups were conducted as part of another related project. County engineers were also questioned about their experience.

The test section W-13 is in Buchanan County and is an area where many Amish reside. None of the Amish present at the meeting in that county indicated a problem with the rumble stripes, nor had the Buchanan County Engineer received any complaints, but the volume of slow moving, horse-drawn vehicles on that section of W-13 is unknown.

There are no test sections in Davis County as part of this research. However, rumble stripes are present along Iowa 2 in that county, as shown in Figure 5-21. As shown, the rumble strip is wider than that used along test sections. The Amish group in Davis County indicated that recently installed rumble strips were a problem for the horse and buggies. They indicated that the horses were reluctant to cross the strips and could easily injure their feet. They also indicated that the vibrations caused by rumble strips were hard on the buggies and that the buggies can fishtail when crossing the strips. The Amish indicated that they would prefer not to have rumble strips on roadway sections that they commonly use. Note the narrow shoulders present on Iowa 2 along with the rumble stripes, as shown in Figure 5-21. In this section, there is very little room for the buggies to maneuver around the rumble strips. It should be noted that the standard width for milled rumble strips on Iowa DOT roadways such as Iowa 2 is 16 inches.

Figure 5-21. Edge line rumble stripes in place along Iowa 2 (image courtesy of Neal Hawkins, CTRE)

Although no formal contact was made with bicycle groups, the Buchanan County Engineer indicated that he had received no comments or concerns from bicycle groups along W-13, which is a high bike traffic area. No other participating county indicated any complaints from bicyclists regarding the presence of the narrow width rumble stripes.

The following comments and concerns from participating counties were solicited after initial construction and again in March 2009. In general, the county engineers had positive reactions to the rumble stripes.

- Stripes do make noise when vehicles cross them, but not as much as 16-inch-wide rumbles used by Iowa DOT
- Problems with alignment close to edge have caused some damage there—will this affect pavement performance?

- No complaints or negative comments received from the public
- Compliments on increased safety and visibility of edge have been received
- Traffic seems to respond to the audible warning
- One crash reported in area with stripes—car swerved for deer. Otherwise, working well.
- Received many positive comments; retroreflectivity seems good to the eye in early spring 2009
- Will pooling water during thawing and refreeze cause deterioration?
- Positive comments from all
- The Buchanan County Engineer indicated no complaints or concerns from the bicycle community, even though W-13 has relatively high bicycle use

6. CONCLUSIONS AND RECOMMENDATIONS

6.1 Summary

Preliminary evaluation results were encouraging. The installation process and visual observations indicated that narrow width rumble stripes along lower-volume rural roads is indeed a feasible and relatively low-cost mitigation for local agencies to consider for sections of roadway with high road departure crash histories or the potential for that type of crash.

Although longevity of the painted edge lines did not seem to improve in the rumble stripe locations, general results and reactions from the installation of these narrow width rumble stripes has been mostly positive. Final evaluation of effectiveness will be concluded in 2011 with an analysis of crash history for ROR crashes before and after the installation of the rumble stripes. The final report will be listed on the InTrans web site at www.intrans.iastate.edu.

6.2 Lessons Learned

Several lessons were learned during the course of installing and monitoring the edge line rumble stripes.

First, as described earlier in this report, some installation problems were encountered during milling operations. If rumble stripe installation is to be adopted as a recommended tool for mitigating roadway departure on lower-volume rural roadways, milling machine design will need to be modified to allow placement of these narrow width rumble strips along the pavement edge, regardless of shoulder quality along that edge. The modified machine developed by Iowa Plains Signing performed much better than the higher center of gravity machine owned by Diamond Surfaces, but the design should still be improved further to provide adequate and predictable alignment and milling depth in a variety of alignment situations and pavement types, especially on PCC pavement, where a heavier machine is necessary to consistently achieve desired milling depth.

Several other observations were made during installation:

- There were problems maintaining horizontal consistency with distance from edge; as a result, the guidance system in the milling machine needs refinement.
- Inadequate removal of millings resulted; a compressor was added to the installation process to remove material.
- The milling machine had problems with stability around the low side of horizontal curves; those areas had to be omitted initially but were later cut with the modified Iowa Plains Signing machine.
- Breakup of edges on PCC pavement occurred when the milling operation was attempted too close to the edge.
- It was difficult to achieve the desired 5/8 inch milling depth in PCC pavement (most measured approximately ½ inch in depth) due to insufficient downward pressure on

the milling head.

- The milling operation had to omit areas in close proximity to mailboxes on the section with paved shoulders (Polk County).
- It was difficult to align the painted edge line with the rumble strips, but it is important that the paint line follow the rumble strips closely for maximum effectiveness.

During the evaluation process, several other lessons were learned.

Some of the rumble stripes collected an unusual amount of debris. See Figure 6-1. It was commonly believed that wind from vehicle tires would force dirt and other material from the rumble strips, leaving the area fairly clean. This was not the case on F-70 and in several other locations. This problem persisted over several seasons and was not an isolated occurrence. It is not known why this problem occurred in a few areas but not others.

Figure 6-1. Rumble stripes on B-30 filled with debris

6.3 Recommendations

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