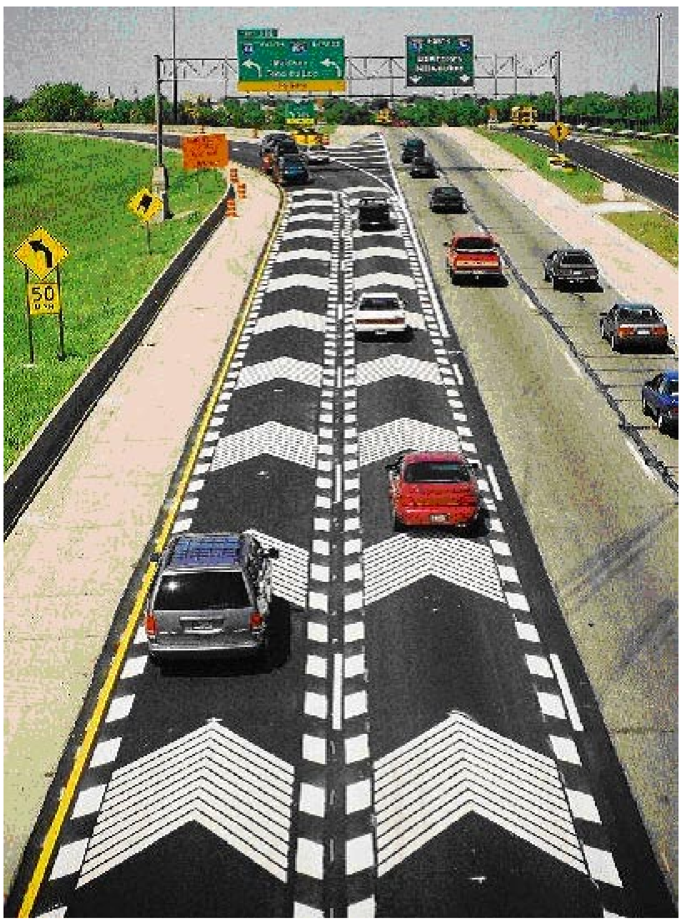
EVALUATION OF THE CONVERGING CHEVRON PAVEMENT MARKING PATTERN

at one Wisconsin Location



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LIST OF ABBREVIATIONS

ADT	Average Daily Traffic
FHWA	Federal Highway Administration
MPH	Miles per Hour
PC	Point of Curvature
PI	Principal Investigator
VPD	Vehicles per Day
VPH	Vehicles per Hour
VPHPL	Vehicles per Hour per Lane
WisDOT	Wisconsin Department of Transportation

ACKNOWLEDGMENTS

The authors of this report would like to acknowledge the following organizations and individuals, without the help of which the report would not have been possible: The AAA Foundation for Traffic Safety for funding this effort, Thomas Loeffler, Regional Program Manager Bureau of Transportation Safety Division of Transportation Investment Management, Ryan Luck, Mike Bub, John Corbin, and John Mishefske of the Wisconsin Department of Transportation, Captain Randy Tylke and Deputy Sheriff Curtis Elliott of the Milwaukee County Sheriff's Department, Frank Both of Century Fence, Waukesha, Wisconsin.

INTRODUCTION

This report describes an evaluation of converging chevron pavement markings in Milwaukee County, Wisconsin. The purpose of the chevron markings is to reduce exit ramp speeds by creating the illusion that the vehicle is speeding and the road is narrowing. Some evidence from Japan indicates that chevron markings do have the intended effect of reducing speeds (Griffin and Reinhardt 1996).

This report should be of interest to experts in the Federal Highway Administration (FHWA), State Departments of Transportation, and others who want to know whether chevron pavement markings can reduce speeds and/or crashes. Although research has been conducted on other illusory pavement marking patterns, to date there have been no other evaluations of the converging chevrons pattern on highway ramps in the United States.

METHODS

On February 2, 1999, the Wisconsin Department of Transportation (WisDOT) requested authorization from the Federal Highway Administration (FHWA) to install "an Experimental Converging Chevron Pavement Marking Pattern" (See Appendix) on one ramp off Interstate 94 at the Mitchell interchange in Milwaukee County, Wisconsin. The request cited the use of this pattern to reduce speeds in a number of locations in Japan.

Authorization to experiment with the converging chevron markings was granted to WisDOT in conjunction with an evaluation sponsored by the AAA Foundation for Traffic Safety and initiated by Dr. Robert Reinhardt of the Texas Transportation Institute (TTI). The chevrons were installed on May 11 and 12, 1999, during the final stages of a freeway resurfacing project. Due to staff changes, TTI subsequently decided not to pursue the project and Dr. Alexander Drakopoulos of Marquette University adopted the project in March 2001, nearly two years after the chevron patterns were installed.

Figure 1 shows a series of white chevrons painted on the road surface. The chevrons are placed increasingly close together as a driver moves into the pattern. As the motorist crosses progressively larger numbers of chevrons per unit of time, the driver receives an impression of traveling faster than the vehicle's actual speed. The length of each individual pattern is based on the initial speed of vehicles entering the pattern, the desired speed when exiting, brake reaction time, and constant deceleration once brakes are applied (see Appendix). To determine chevron placement in this study, the experts used an assumed entering speed of 65 mph and a desired exiting speed of 50 mph (the posted speed limit and the advisory speed for the test ramp).

The pattern was 610 feet long from the tip of the first chevron set to the tip of the last set and consisted of 16 sets of chevrons. The precise chevron location can be seen in Figure 2. A total length of 640 feet is indicated on this figure (beginning of the first set to the end of the 16th set).

Figure 1: **Evaluated device, as installed on the Northbound ramp of the Mitchell Interchange.** Courtesy of Frank Both, Century Fence Company, Pewaukee, WI.

Figure 2: Detector Locations

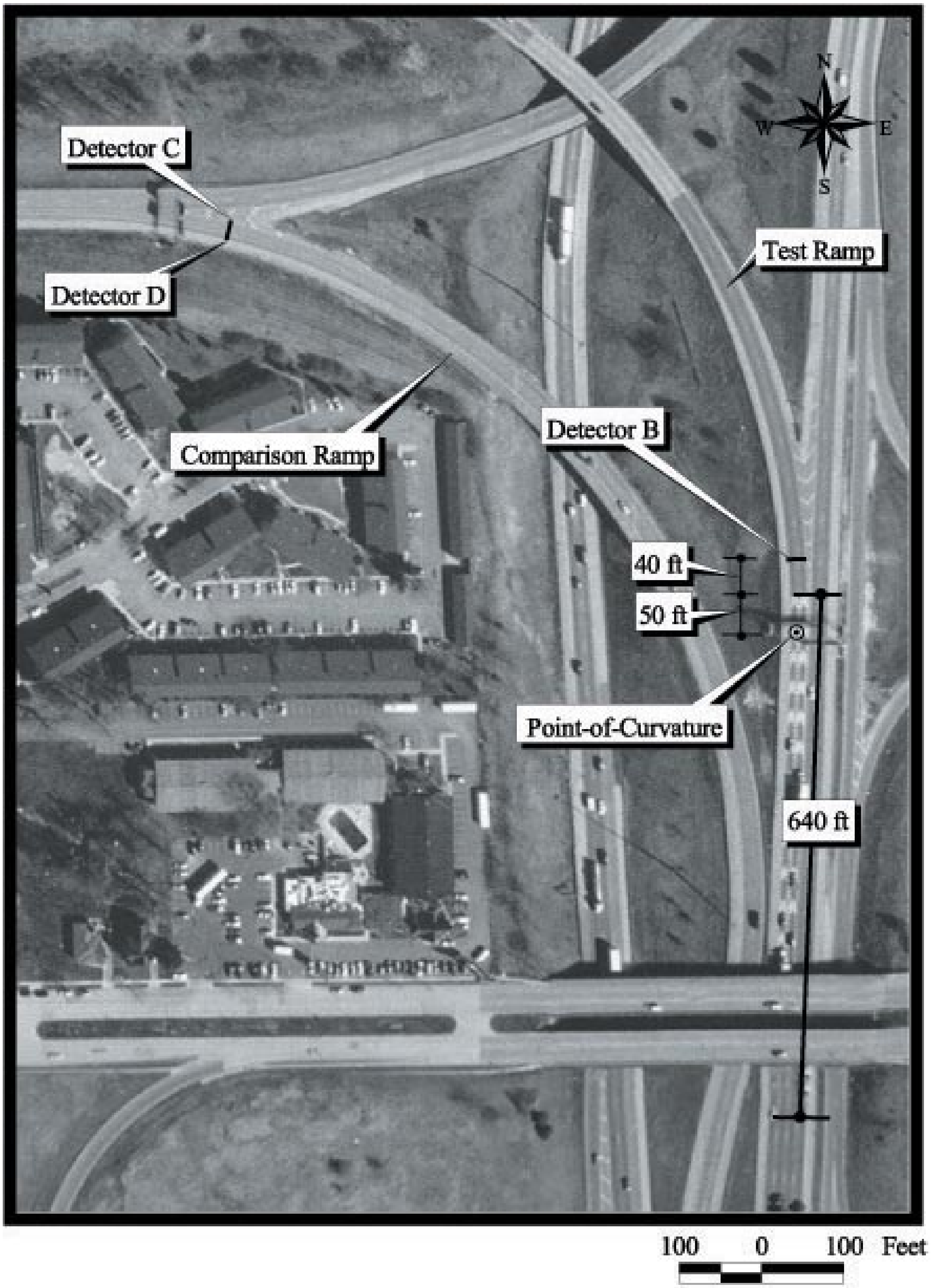


Figure 3: Mitchell Interchange

The original chevron installation was performed as part of a resurfacing project by Century Fence of Waukesha, Wisconsin, for the Wisconsin Department of Transportation. Chevron pattern stationing was completed by WisDOT. Installation began the afternoon of May 11, 1999, and was completed the following evening. No traffic control measures specific to the pavement marking installation were included in the chevron pattern installation expenditures, because such measures were already in place for the construction project. The installation cost was $40,000.

In the spring of 2001, high-pressure hoses and detergents were used to clean traffic grime from the markings. The markings were subsequently repainted on October 30, 2001 at a cost of $38,000, including traffic control costs related to the painting operation. This work took two evenings to complete.

The Mitchell Interchange is a directional Y-type urban interchange that provides for all directional movements through high-speed ramps. Study ramps had two 12-foot asphalt traffic lanes and 12-foot concrete shoulders. The speed limit approaching the study ramps and the advisory speed limit for the ramps were 50 mph throughout the evaluation period.

The ramp selected for the treatment on I-94 has four northbound lanes approaching the study location. The two lanes closest to the median branch out from the two northbound lanes at the Mitchell Interchange and follow a curve to the left to continue west to I-894 (test ramp lanes). The chevrons were installed on each of the two northbound lanes just before the ramp that heads west (**Figure 3**).

The test ramp with the converging chevron pattern installation was selected based on traffic volumes and roadway geometry and because the ramp had a history of large-truck rollovers that caused long road closures. The ramp was sufficiently isolated from merging/diverging effects of adjacent ramps and traffic volumes were low enough so that congestion alone would be unlikely to cause lower speeds during most hours of the day. Detailed ramp geometry information is provided in **Figure 4**. Test ramp Average Daily Traffic (ADT) for 1999 was 39,010 vehicles per day (VPD) and 42,800 VPD for the year 2000, an increase of 9.7%.

Approaching the Mitchell interchange, I-894 has three lanes in the eastbound direction. The three lanes branch out into four lanes through a fork that splits the middle lane in two, with one lane continuing north and the other continuing south. Following the fork, a two-lane ramp curves to the left to continue northbound and another two-lane ramp (comparison ramp) curves to the right to continue southbound (see **Figure 3**). The comparison location was chosen because it was unaffected by the presence of the experimental pattern, was in close proximity to the test ramp, had similar geometry (both ramps had two lanes and radii and super-elevations were similar), and had similar average daily traffic (ADT) volumes. Detailed comparison ramp geometry information is presented in **Figure 5**. Comparison ramp Average Daily Traffic (ADT) for 1999 was 39,230 vehicles per day (VPD) and 42,200 VPD for the year 2000, an increase of 7 percent.

Speed information was provided by four permanent loop detectors. Two were embedded in the pavement near the chevrons (the test ramp) and two were embedded in a nearby comparison ramp. These loop detectors were part of the freeway monitoring system and had been in place for many years. The detectors reported five-minute traffic volume and average speed; they did not provide individual

Figure 4: Test Ramp Geometry

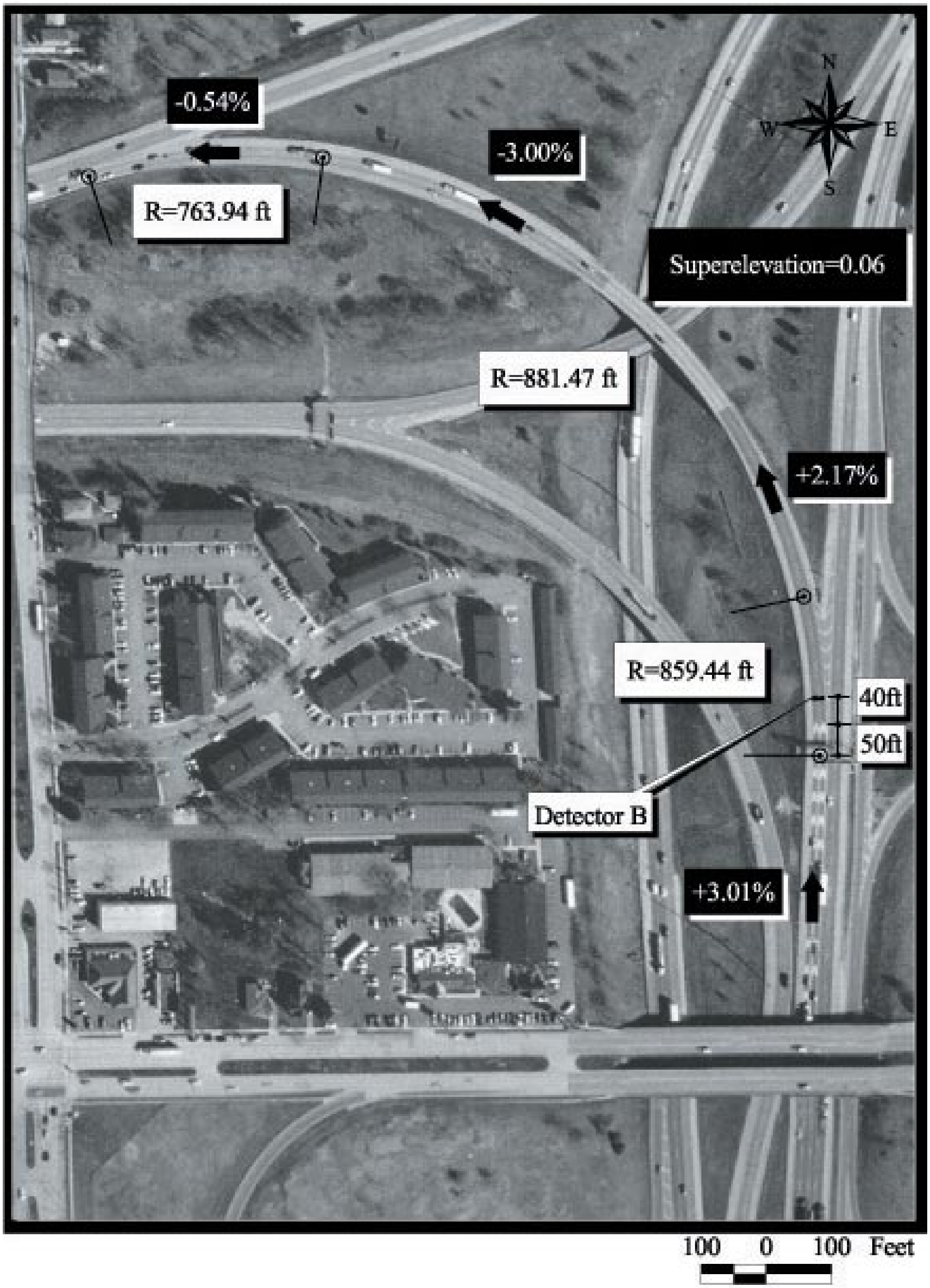
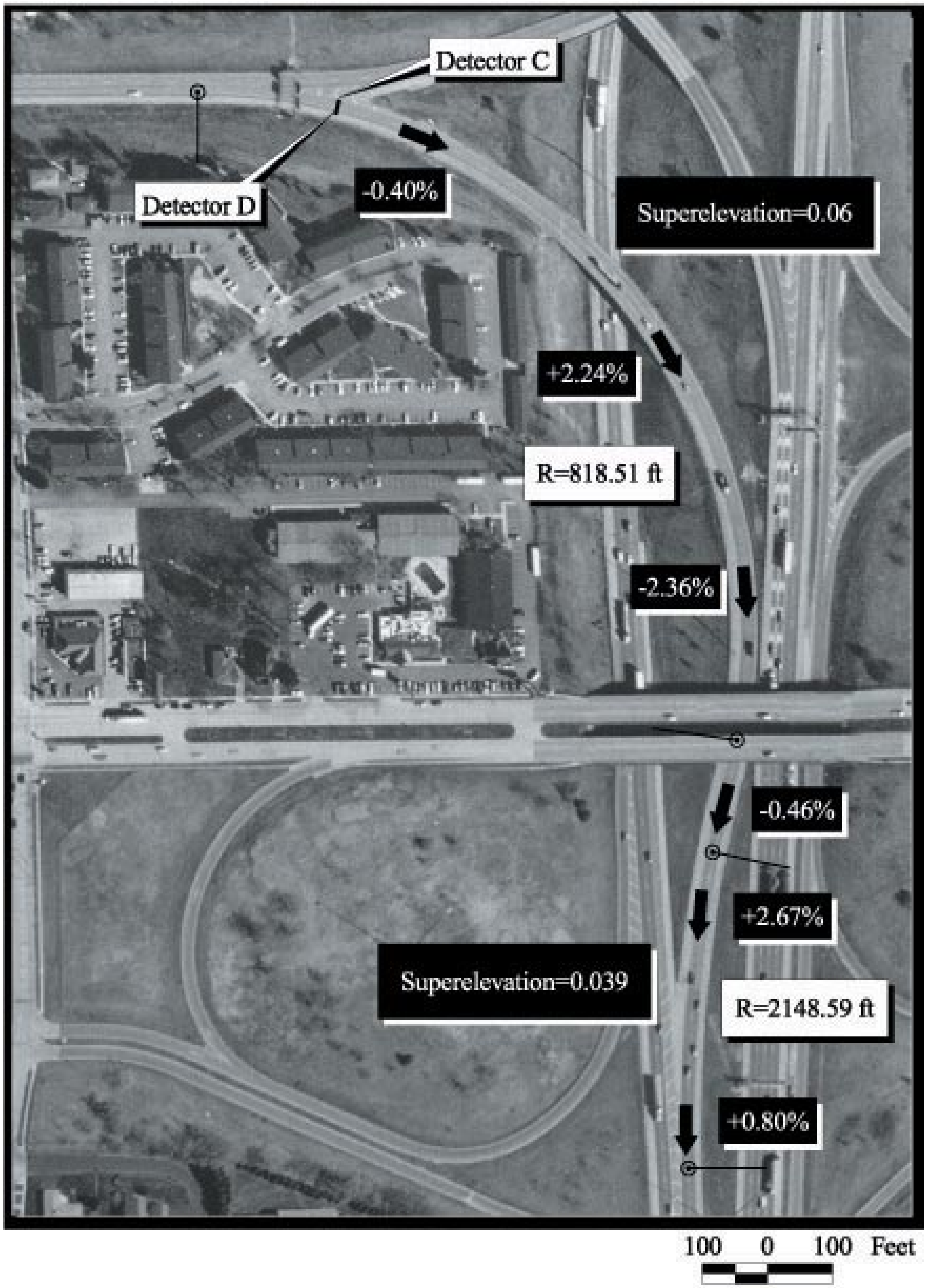


Figure 5: Comparison Ramp Geometry



vehicle speeds or vehicle classification information. The locations of the four detectors (**A, B, C** and **D**) are shown in **Figure 3**.

Detector **A** was located in the median lane, 1960 feet upstream of the beginning of the chevrons. Detector **B** was also located in the median lane, 40 feet downstream from the end of the chevrons and 90 feet downstream from the test ramp point of curvature (PC). Detectors **C** and **D** were placed side-by-side on the comparison ramp median and shoulder lanes, respectively, 200 feet downstream from the ramp PC.

If the chevrons were effective, speeds measured by detector **B** would be lower in the period following chevron pattern installation. Information from detectors **C** and **D** was needed to verify that speeds did not change on the comparison ramp in the after period and to ensure that any speed changes at detector **B** were due to chevron pattern installation rather than broader changes in traffic and environmental conditions at the Mitchell interchange. Detectors **B**, **C**, and **D** were all installed on curved directional ramps with very similar geometry and were located short distances downstream from their respective ramp's PC.

Detector **A** information was also intended to verify that speeds in the median lane did not change because of broader traffic or environmental conditions unrelated to the chevron installation. Because drivers could not see the chevron pattern from this location, presumably their speeds would not be affected by its presence on the other ramp.

The original plan was to base the evaluation on a before-and-after comparison of mean and 85th percentile speed averages and crash data. The "before" period for the crash analysis was from May 15, 1997 to May 14, 1999, and the "after" period was from May 15, 1999 to May 14, 2001. Unfortunately, detectors **A** and **B** were inoperative from approximately the time the chevrons were installed through the following year. After checking data for consistency and reliability and consequently eliminating some periods, the "before" period for the speed data analysis was set to December 1998-March 1999 and the "after" period was set to December 2000-March 2001.

FINDINGS

Impact on Crashes

Given the relatively short time frame and the small number of crashes, it was decided that statistically robust crash analyses were not possible. Therefore, only the raw crash data without statistics are presented in this report (**Table 1**).

Table 1. Number of Crashes Before and After Chevron Installation

	Analysis Period		Total
	Before	After	
Test ramp	14	8	22
Comparison ramp	73	59	132
Total	87	67	154

Impact on Speeds

Analysis of more than 25,000 observations for each detector in each analysis period resulted in very narrow 95 percent confidence intervals for mean speeds. **Table 2** presents mean speed changes at each of the four analyzed detectors **A**, **B**, **C** and **D** before and after the chevron installation. The largest change was measured at detector **B**, where mean speeds dropped by 15 mph following installation of the chevrons.

Table 2. Mean Speeds at Study Detectors (mph)

Detector	Before	After	Difference Before - After
A	60	57	-3
B	64	49	-15
C	50	49	-1
D	46	48	+2

Weighted by 5-minute Volume

The 85th percentile speeds are similar to the mean speeds, but the changes are even more pronounced (Table 3). The speed change for detector **B** was minus 17 mph, for detector **D** it was plus 3 mph, and for A it was minus 3 mph. It is estimated that 3 mph of this 17 mph speed reduction was caused by increased traffic volume and thus the chevron installation accounted for the remaining 14 mph reduction.

Table 3. 85^{th} Percentile Speeds at Study Detectors (mph)

Detector	Before	After	Difference Before - After
A	63	60	-3
B	70	53	-17
C	53	51	-2
D	48	51	+3

Weighted by 5-minute Volume

Hourly volume patterns were very similar between detector **A** and detector **B** when comparing the before and the after data. In the post-installment period, both detectors registered higher hourly volumes between 9:00 am and 3:00 pm and lower hourly volumes from 4:00 pm to 6:00 pm. Detector **A** recorded a speed change of minus 3 mph between the before and the after periods. Given the similarity of hourly volume pattern changes between detectors **A** and **B** in the before and the after periods, it would be reasonable to expect that speeds at detector **B** would have shown a similar reduction of 3 mph, regardless of whether the chevrons were present. Consequently, of the mean speed reduction of 15 mph at detector **B**, 12 mph could be attributed to the chevron pattern installation and 3 mph to traffic volume effects. Standard errors of the means for observed speeds were very small.

Reduced speeds at detector **B** in the "after" period were very pronounced, especially considering that the "after" period started 18 months after the installation and thus gave local drivers a chance to get used to the chevrons. Speed changes between the before and after period at all hours of the day shifted in the same direction and by the same amount (parallel translation), upward for detector **D** and downward for detectors **A**, **B**, and **C**).

DISCUSSION

The installation of chevron patterns on the test ramp appeared to result in large speed reductions, but it is not possible to generalize from this single example. The chevron pattern was expected to affect speeds during the least congested parts of the day, when speeds were not affected by higher levels of congestion. However, speeds were found to be lower in the “after” period during all hours on both weekdays and weekends. The large speed reductions were observed despite the fact that data for the after period were collected 20 months after the converging chevron pavement markings were installed.

There is one very strange finding. There was a mean speed increase of 4 mph (from 60 to 64 mph) between detectors **A** and **B** in the “before” period. Given that traffic was heading into a horizontal curve (test ramp) right after traveling on a 3% grade, it was expected that drivers would slow down, not speed up. In the “after” period, speeds were in the expected direction. Detector data for the after period showed a speed decrease from **A** to **B** of 8 mph (from 57 to 49 mph).

Limitations

In part because the study was conducted after the fact, the evaluation has many weaknesses. To add to the difficulty, the evaluation was assigned to the investigator fully 18 months after the chevrons had been installed. Consequently, only historical data could be used for the evaluation and the format of the data was already fixed, with five-minute traffic information summaries and crash records.

Because of a hardware failure that immediately followed the chevron installation, a full year of speed data was unavailable for detectors **A** and **B**. Consequently, the “after” period was shifted to a year later than would have been the case if the detector had been operational.

It is important to keep in mind that this evaluation is based on a single installation. It would have been preferable to have data on many chevron pattern installations, but the Milwaukee County installation was the only one in the United States at the time. Given the small number of crashes in the “before” and “after” period for the test ramp, only the raw crash data are reported and no statistics are presented.

From a research perspective, the comparison site may not have been a good choice since during the “before” period it had a crash rate more than five times as high as the test site. Although vehicle volume data were very similar for the test and comparison sites, the test site had 14 crashes in the before period compared to 73 for the comparison site. It is not known why the comparison site had five times the number of crashes, but it is possible that other factors that could affect speeds were systematically different between the two sites.

RECOMMENDATIONS

More research evaluating the effect of chevron markings on speed and crashes is needed before any definitive statement can be made about their efficacy. Because of the methodological hurdles in this study, it is recommended that future studies be done prospectively. Ideally, test and comparison sites should be chosen and data collection should begin well before the pavement markings are installed. This would allow the researchers to monitor the speed detectors to make sure they are working and to identify any construction or other events that might affect speeds and/or crashes.

No detrimental effects from the installation of the converging chevron pattern were identified. There did not appear to be any adverse impact on traffic flow and there did not seem to be any unintended increase in crashes. Converging chevron pavement markings appear to reduce speeds but more research is needed. It is hoped that FHWA and state DOTs will install and evaluate more of these converging chevron pavement markings.

Note: Detector details and an extensive presentation on detector selection and data reliability are available from the author. For additional details on the methodology or results, please contact Dr. Alex Drakopoulos at:

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APPENDIX

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February 2, 1999

Mr. Rudy Umbs
Federal Highway Administration
Safety Design and Operations Division (HHS-10)
400 7th Street SW
Washington, D.C. 20590

Subject: Request for authorization to Experiment with Chevron Pavement Markings

Dear Mr. Umbs:

The Wisconsin Department of Transportation requests approval to install an experimental Converging Chevron Pavement Marking Pattern to reduce speeds at a specific location in Milwaukee, the I-94 Westbound approach to the two-lane exit to the I-894 Westbound bypass.

The proposed pattern has been used in a number of locations in Japan. It consists of a series of white chevrons on the road surface with the spacing between chevrons decreasing as the driver travels over the pattern. Each chevron extends across only one lane of traffic. Therefore, in the proposed location, two side-by-side patterns would be installed. Traffic flow is in the direction indicated by the chevrons.

The illusion created by this pattern is intended to convince drivers that they are traveling faster than they really are and to create the impression that the road is narrowing. It is anticipated that these factors will contribute to reduced travel speeds. Although research has been conducted on other patterns of illusory pavement markings, we are unaware of any previous applications of the converging chevrons in the United States.

The relatively low cost and potential benefits of this application suggest that it could be an excellent traffic control device for speed reduction and safety. With your approval, we look forward to conducting this experiment in cooperation with the AAA Foundation for Traffic Safety and Dr. Robert Reinhardt of the Texas Transportation Institute.

If you need additional information, please call me at (414) 521-5348 or e-mail gary.knerr@dot.state.wi.us

Sincerely,

Gary P. Knerr, P.E.
Systems Operations Group Manager

Cc: Peter Rusch, State Traffic Engineer
Thomas Loeffler, Bureau of Transportation Safety
William Bremer, FHWA Safety & Traffic Operations

Attachment A

Instructions for setting out the converging chevron markings.

Figure I shows an installation of the chevrons in Japan. The proposed layout will be derived from this example. The right two lanes in the photo will be what the northbound traffic on the IH-94 approach to the westbound ramp would see. The one point about the photo to be stressed is that while the on coming traffic to the left has 4 chevrons per set and the out bound traffic on the right appears to have 6 or 8 chevrons per set, EACH SET IN THE PROPOSED APLICATION WILL HAVE 10 CHEVRONS.

This determination was made based on the anti-skid characteristics of this pattern and the relatively high rate of speed at the site. The number of chevrons per set has to do with the speed within the pattern and the current application calls for 10 chevrons per set.

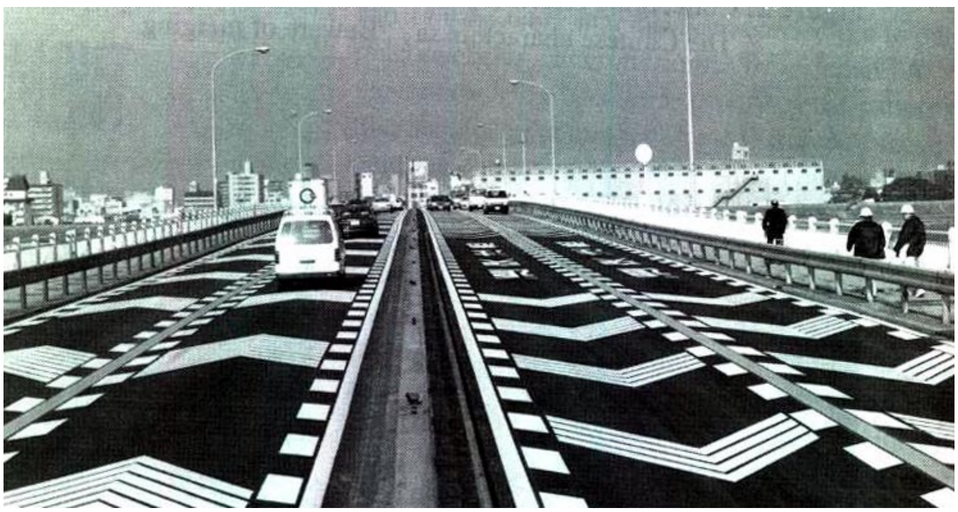

Figure A1. Converging chevrons on the Yodogawa River Bridge

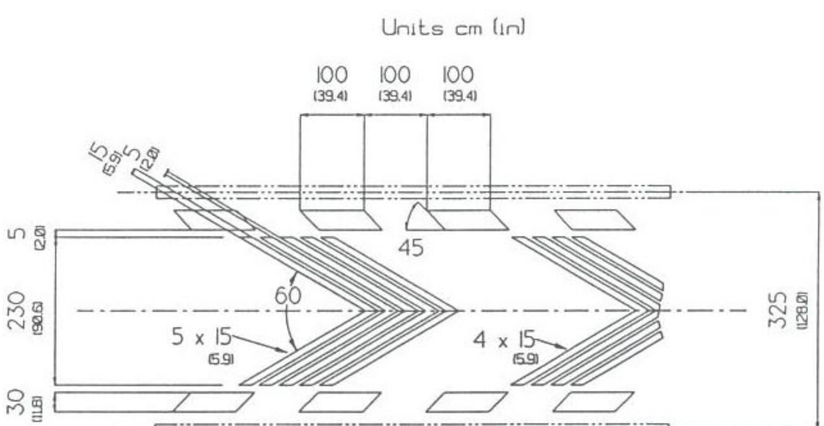

Figure A2. indicates the actual dimensions of the patterns. Although this example shows sets of 5 (left) and 4 (right) chevrons per set, as stated above, all sets will have 10 chevrons of 15 cm each.

The length of an individual chevron pattern is based on certain enabling assumptions. These assumptions include the initial speed of vehicles entering the pattern (v_1), the desired speed upon leaving the pattern (v_2), reaction time (the time that elapses prior to braking), typically 0.5 s (t_b), and constant deceleration once brakes are applied (a). The pattern length for the current application was calculated as follows:

Pattern Length Calculation

$$L = v_1 t_b + \frac{(v_1^2 - v_1^2)}{2a}$$

v_1 = speed entering pattern = 95.33 fps (65 ph)

v_2 = speed exiting pattern = 73.33 fps (50 mph)

t_b = reaction time = .5 sec

a = deceleration braking = 3.3 fps^2

$$L = (95.33) * .5 + \frac{(95.33^2 - 73.33^2)}{6.6} = 610 \text{ ft}$$

Average speed in pattern = 84.33 fps (57.5 mph)

$$\text{Time to traverse pattern} = \frac{610}{84.33} = 7.2 \text{ sec}$$

Number of chevron sets (at 2.2 per sec) = 15.8

@2.2/sec = 1 pattern every .4545 sec

$$\text{Uniform deceleration} = \frac{95.33 - 73.33}{6.7\ *} = 3.28 \text{ fps or the 3.3 fps used initially}$$

Deceleration per chevron = 3.3 * .4545 = 1.49885 fps, call it 1.5

* 7.2 total - .5 reaction time

Pattern Size

The spacing of the patterns is dependent on the pattern size, which is itself a function of the number of individual stripes making up the pattern. Since each set of chevrons will have 10 individual stripes the size of each chevron is the same.

Given: 15cm (5.9 in) wide stripes and 5 cm (2 in) wide spaces
Given: 60 degree (30 degrees either side of center line)

To determine running length along highway:

$$\text{Sine } 30 = \frac{15\text{ cm}}{X} \qquad \text{Sine } .5 = \frac{15\text{ cm}}{X} \qquad x = 30\text{ cm for stripes, } 10\text{ cm for spaces}$$

One stripe and space = 40 cm

From beginning of first stripe to end of last stripe in a 10 set pattern would be:

(9 * 40) + 30 = 390 cm or 12' 9.5"

Pattern Spacing

While it is possible to calculate pattern spacing such that the distance between each set of chevrons is a constantly decreasing length, the practicality of installing this type of pattern and the actual ability of drivers to perceive this precision makes it impractical. Therefore an approximation that keeps drivers within the marked portion of the pattern for an increasingly longer time (from .14 sec to .18 sec) was chosen, which duplicates the Japanese application of these markings.

Given that the last set needs to be completed prior to the detector loop, that loop will act as the reference point. At the anticipated speeds involved, the maximum distance between the end of the pattern and the loop detector should be 40 feet. This would allow approximately _ second to pass between the end of the pattern and the detector. Using this 40 foot mark as the ending point of the pattern, the following table gives the positions of the 16 sets of markings (negative numbers indicating upstream distances in advance of the loop detector).

SET	Distance
1	-618
2	-576
3	-534
4	-492
5	-450
6	-410
7	-370
8	-330
9	-292
10	-254
11	-216
12	-180
13	-144
14	-108
15	-74
16	-40

The actual point within the pattern (front, center, etc.) where the distance measurement is made is arbitrary as long as it is consistent.

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