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16. Abstract

The objective of this study was to investigate the ability of various traffic control measures to delineate horizontal curves so drivers would perceive the curve and slow to an appropriate speed and then be provided guidance through the curve. Pavement delineation (raised pavement markers, transverse stripes, or rumble strips) and shoulder delineation (post delineators and chevron signs) were used.

A laboratory test found that a post delineator configuration in which the distance from the post to the pavement edge and the post spacing remained constant while the height of the delineator on the post increased made a curve appear sharper than other delineator configurations. The delineation treatments did not dramatically decrease speeds at the point of curve, but encroachments decreased substantially and the severity of the encroachments was reduced at locations that originally had a high proportion of moderate or severe encroachments.

Pavement delineation had more of an affect than shoulder delineation. Also, chevron signs were more effective than post delineators.

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Research Report
UKTRP-86-4

DELINEATION OF HORIZONTAL CURVES

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and

Federal Highway Administration
U.S. Department of Transportation

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DELINEATION OF HORIZONTAL CURVES

Executive Summary

The characteristics of accidents that occur at curves show these accidents could be reduced if the curve could be marked so drivers would perceive the curve and slow to an appropriate speed and then be provided additional guidance through the curve. The objective of this study was to investigate the ability of various traffic control measures to delineate horizontal curves so speeds of vehicles entering the curve would be decreased and the drivers would have improved guidance through the curve.

The data collection process consisted of two main tasks: 1) speed and encroachment data were taken at all curve sites before and after installation of the delineation treatments and 2) before-and-after accident analyses were conducted at some of the curve sites.

Pavement delineation (raised pavement markers, transverse stripes, and rumble strips) and shoulder delineation (post delineators and chevron signs) were used. A laboratory test using various configurations of post delineator placement revealed that a configuration in which the distance from the post to the pavement edge and the post spacing remained constant while the height of the delineator on the post increased made a curve appear sharper than other delineator configurations.

While observation showed that the pavement and shoulder treatments increased the curve delineation, the speeds at the point of curve were not decreased dramatically. This may be related to the increased guidance to the driver, which may allow him to maintain a certain speed through the curve. However, encroachments across the centerline or edge line decreased substantially after installation of delineation treatments. Also, the severity of the encroachments were reduced at locations where there was a large proportion of moderate and severe encroachments. The number of accidents also was reduced at locations where pavement delineation was added.

Considering all data, it appears that the pavement delineation had more influence on drivers than did shoulder delineation, Also, of the two methods of shoulder delineation, chevron signs were more effective than post delineators.

The results support the installation of additional delineation at hazardous curve locations and the current program of installing snowplowable markers on two-lane highways. Chevron signs should be used, rather than post delineators, at sharp curves. At high-accident locations, the "ascending even" (AE) pattern could be used for shoulder delineation or rumble strips or transverse stripes could be used. The noise associated with rumble strips must be considered before their use.

TABLE OF CONTENTS

INTRODUCTION

Accident statistics show that 17 percent of accidents in Kentucky in 1984 occurred at a horizontal curve. Accidents at curves tend to be severe, as evidenced by statistics that show 39 percent of fatalities and 26 percent of injuries occurred in accidents on curves.

A comparison of characteristics of accidents occurring at curves with all accidents is given in Table 1. Several significant differences may be noted. Accidents at curves are more severe. There are also more single-vehicle accidents at curves with the accidents occurring more often in rural areas and during the nighttime in unlighted areas. The percentage of accidents on curves having wet or snow pavement conditions was higher than for all accidents. The contributing factors involved more often in accidents at curves, compared to all accidents, included unsafe speed, alcohol, defective tires, defective shoulders, and slippery surface. Unsafe speed was listed as the most frequently occurring contributing factor. The percentage of young and male drivers involved in accidents on curves was also slightly higher than for all accidents. A comparison by directional analysis revealed that, compared to all accidents, there were fewer intersection-related accidents at curves and a higher percentage of fixed object, ran off the road, head on, and opposite direction sideswipe accidents.

Characteristics of accidents at curves show these accidents could be reduced if the curve could be marked so drivers would perceive the curve and slow to an appropriate speed and be provided additional guidance through the curve. The objective of this study was to investigate the ability of various traffic control measures to delineate horizontal curves so speeds of vehicles entering the curve would be decreased and the drivers would have improved guidance through the curve.

REVIEW OF LITERATURE

The Manual on Uniform Traffic Control Devices (MUTCD) lists the traffic control devices commonly used to delineate horizontal curves (1). Methods of delineation include painted centerlines and edge lines, curve warning signs with or without advisory speed signs, post delineators, and chevron alignment signs. Guidelines for the placement of the devices are presented.

A review of literature conducted by the Australian Road Research Board concerning methods of modifying driver behavior on rural road curves indicated that the effects of curve warning and advisory speed signs have been observed to be mostly negligible (2). Roadside delineation, including post delineators and chevron signs, was found to reduce approach and in-curve speeds. This report listed studies in which innovative arrangements of roadside delineation, as well as innovative edge lining and transverse markings, were used to reduce motorists speeds in curves.

A study in Ohio investigated the effects of placement of post delineators on the driver's perceived sharpness of a curve (3). It was found that a combination of ascending delineator height and in-out lateral spacing produced the desired perceptual effects on drivers. Field tests of several delineation treatments revealed that post delineators, placed in the manner described, and raised pavement markers had the most effect on high-speed drivers.

Another Ohio study indicted that modifications yielding an increase in perceived angle of the curve, narrowing of the road, and increased speed perception had significant effects on drivers' approach speeds to curves (4). One modification dealt with the perspective visual angle and involved repainting the inside edge line, making it increasingly wider up to a maximum width of 24 inches at the apex of the curve. Another treatment involved use of the Wundt Illusion to give the illusion of a narrowing of the road at curve entry. Another treatment involved painting a series of straight lines across the road approaching the curve with the distance between the lines decreasing as the distance to the curve decreased. The theory was that the increasing rate of movement of the stripes in the drivers' visual field would affect speed perception and result in decreased speed. This use of transverse stripes has been tested in England (5). Also, two previous studies in Kentucky involved the use of transverse markings (6, 7). In both Kentucky studies, the transverse markings resulted in a reduction of speed.

Raised pavement markers were also tested as delineation at curves in a previous Kentucky study (8). While the markers did not reduce speeds significantly, the numbers of encroachments over the centerline were reduced significantly.

A Montana study investigated use of four different post-mounted delineators at curve locations (9). All the delineators had a positive effect in reducing accidents. The best performance was obtained when typical Type 3 object markers, as shown in the MUTCD, were used (1).

A Virginia study investigated the use of three post-mounted delineator systems (10). The study indicated that drivers react most favorably to chevron signs on sharp curves greater than or equal to seven degrees and to standard delineation on curves less than seven degrees.

Another study dealt with a national survey of the current practices of state highway departments with respect to roadside delineation concepts (11). Emphasis was placed on the raised pavement marker and post-mounted delineator. Post-mounted delineators were used most often (by over 90 percent of the respondents). The placement of posts, along with the height of the delineator, was discussed.

PROCEDURE

DATA COLLECTION

The data collection process consisted of two main tasks: 1) speed and encroachment data were taken at all curve sites before and after installation of the delineation treatment and 2) a before-and-after accident analysis was conducted at some of the curve sites.

Speed data at the study sites were collected for nighttime, and, if applicable, daytime conditions using a radar gun. The observer was stationed as inconspicuously as possible at a point outside the curve to provide an unobstructed view of the curve approach or approaches being monitored. Speeds were recorded at 1) a point on the approaching tangent at least 400 feet from the beginning of the curve and 2) the beginning of the curve. These points were referred to as the "tangent speed" and the "PC speed", respectively.

Encroachment data were collected by observation and were subjective in nature. The degree of encroachment referred to the amount the left-side tires of the vehicle crossed the centerline or the right-side tires crossed the edge line. The categories were none, slight (one set of tires touched the centerline or edge line), moderate (tires crossed over centerline or edgeline up to a 1/4 car width), severe (1/4 car width up to 1/2 car width crossed the marked line), and very severe (more than 1/2 car width crossed the marked line). In most instances, a second observer was stationed adjacent to the roadway at the curve and the encroachment information was relayed via walkie-talkie to the first observer who was collecting speed information.

TEST LOCATIONS

In cooperation with the Jefferson County Public Works Department, three sites were selected in Jefferson County for application of transverse stripes, rumble strips, and raised pavement markers. The three sites were on Cooper Chapel Road, Lower Hunters Trace, and Blanton Lane.

The site on Cooper Chapel Road, a single 90-degree curve, was modified with rumble strips on both approaches and raised pavement marker pairs at 10-foot spacings through the curve. A diagram showing details of this installation is shown in Figure 1.

The Lower Hunters Trace location consisted of two 90-degree curves in an "S" configuration connected by a short tangent. Rumble strips were placed on the eastbound approach to the south curve and transverse stripes were placed on the westbound approach to the north curve. Pairs of raised pavement markers were placed at 10-foot intervals along the centerlines of the two curves and at 20-foot intervals between the curves. Figure 2 is a diagram showing details of this installation.

The Blanton Lane location also consisted of two 90-degree curves in an "S" configuration connected by a short tangent. Pairs of raised pavement markers at 10-foot intervals were placed along the centerlines of the two curves. Markers also were placed at 20-foot intervals in the tangent section between the two curves. A diagram giving the details of this installation is contained in Figure 3.

Pairs of raised pavement markers were placed on 20-foot intervals on a curve on Fegenbush Lane (KY 864) in Louisville by the Kentucky Department of Highways.

Several rural curve locations in central Kentucky were considered to be candidates for experimental delineation techniques. Sites in several counties were inspected. Two sites were selected for the evaluation of the post delineators and chevron signs. One site was on US 421 in Franklin County (a 35-degree curve) near Cliffy Drive (ADT = 1,300), and the other was on US 62 in Scott County (a 20-degree curve) near Interstate 64 (ADT = 1,500).

DELINEATION TECHNIQUES

Techniques evaluated in this study included transverse striping, rumble strips, delineator post configurations, chevrons, and raised pavement markers. The rumble strips did not actually provide visual delineation of the roadway; but since they were being used in an attempt to reduce vehicle speeds at the beginning of the curve, they were included in this study.

Transverse stripes and rumble strips were placed individually at variable spacings on the roadway in such a manner that a driver should perceive that he/she was approaching a curve at an increased speed if he/she did not decrease speed. The stripes of preformed tape or the rumble strips were laid on the approaching tangent section at decreasing distances toward the beginning of the curve. Thus, a vehicle crossing over the stripes or rumble strips at a constant speed would experience a progressively shorter time interval between passing over the stripes or rumble strips. The objective was to create a perception of an increased speed to drivers who did not slow appropriately as they approached the curve. The rumble strips provided only an auditory effect; the transverse stripes primarily provided a visual effect in addition to a slight auditory effect since the stripe consisted of a tape having a thickness of 90 mils.

Speed data collected before installation of the transverse stripes or rumble strips were used to determine the average speed at the beginning of the curve (the PC speed) and the speed along the tangent section of the approach at a point before deceleration of the vehicle began. This second speed (the tangent speed) was assumed to be relatively constant over the tangent section before the vehicle begins to decelerate. For light braking ($f = 0.1$), a constant rate of deceleration of 3.22 ft/sec^2 was used. Allowing for crossing one stripe or rumble strip per second, the spacings between transverse stripes or rumble strips were calculated. For example, a vehicle initially traveling at 51 feet per second (35 mph), after passing over the first stripe or rumble strip in the pattern, would travel 47.78 feet in one second at a constant rate of deceleration of 3.22 ft/sec^2. Thus, the spacing between the first and second stripes or rumble strips would be 47.78 (rounded to 48) feet. In addition, two preliminary stripes or rumble strips were placed at the beginning of the pattern at spacings equivalent to the distance that would be traveled in one second at the average tangent speed. If the average tangent speed was 51 ft/sec, two preliminary stripes or rumble strips were placed 51 feet apart, since a vehicle traveling at a constant speed (just before decelerating) would travel 51 feet in one second (totaling 102 feet in two seconds). Therefore, knowing the average tangent speed and the desirable curve entrance speed, the total distance for the pattern of transverse stripes or rumble strips (including the two preliminary ones) was computed. This distance was calculated to be around 450 feet for the Jefferson County locations.

Raised pavement markers were used to provide additional centerline delineation in an attempt to decrease centerline encroachments. The markers were expected to provide a warning for encroaching vehicles by providing a rumble effect, which is not restricted to nighttime conditions.

The post delineators and chevron signs differ from the transverse stripes, rumble strips, and raised pavement markers in that they are placed adjacent to the roadway (on the outside shoulder of the curve) rather than on the pavement. The post delineators and chevron signs were placed in the configuration designed to affect the driver's perception of the sharpness of the curve. This configuration was developed in a laboratory study that will be described in detail.

MATERIALS

Standard three-inch circular delineators were used for the post delineators. The standard chevron alignment sign (18 inches by 24 inches) given in the MUTCD was used. Preformed tape (90 mils thick) was used for the transverse stripes. Bidirectional, yellow raised pavement markers were used. The dimensions of the markers were 4 inches by 4 inches at the base with a height of 0.65 inch or no higher than 0.75 inch including the epoxy adhesive. The rumble strips consisted of two-foot preformed sections placed with epoxy. Each section had a width of 3 1/2 inches, with the first 1 7/8 inch ramped to a height of 1/2 inch.

RESULTS

POST DELINEATOR PLACEMENT LABORATORY TESTS

Several different configurations of post delineator placement were identified. It would have been impractical to test each alternative at a field location and collecting speed and encroachment data. As a method of identifying the configurations that showed that greatest potential, laboratory tests were utilized.

A total of 11 configurations were used. The different configurations were obtained by varying 1) the height the delineator was placed on the post (h), 2) the distance the post was placed from the roadway shoulder (d), and 3) the spacing between posts (s). A listing of the configurations used, how these three factors were or were not varied, and the abbreviation used for each configuration is given in Table 2. A more detailed description of the configurations is given in Table 3. In the standard configuration, the delineator was placed at a constant height of 4 feet, the post was placed at a constant distance of

5 feet from the shoulder, and the spacing between posts remained at 20 feet. The height that the delineator was placed on the post varied from a minimum of 1.5 feet to a maximum of 5 feet. The distance the post was placed from the roadway shoulder varied from a minimum of 2 feet to a maximum of 7 feet, 10 inches. The spacing between posts varied from a minimum of 5 feet to a maximum of 35 feet.

Delineators were placed at the different configurations, using portable stands, at a roadway curve, and nighttime photographs were taken. The photographs were taken at distances of 100, 300, and 500 feet from the beginning of the curve, which was where the first delineator was placed. The photographs of all configurations were then placed on a display and labeled as Configurations 1 through 11. The questionnaire shown in Figure 4 was then given to a sample of licensed drivers to determine if they perceived any difference in the configurations. Photographs of each configuration, taken at the 300-foot distance from the start of the curve, are shown in Figures 5 through 15.

A total of 40 questionnaires were completed. The questions that asked the respondents for the configurations that made the curve appear sharpest or flattest were used to rank the various configurations. Specifically, using responses to Question 2, three points were given to the configuration judged to be the sharpest, two points for the next sharpest, and one point for the third sharpest. Similarly, using responses to Question 4, three points were given to the configuration judged to be the flattest, two points for the next flattest, and one point for the third flattest. The total number of points using Question 4 were subtracted from the total points from Question 2 to obtain a ranking. This analysis is given in Table 4.

The AE configuration, in which the distance from the post to the pavement edge and the post spacing remained constant while the height of the delineator on the post increased, was ranked number one by a large margin. Both the second and third ranked configurations involved increasing the height of the delineator on the post while also increasing or decreasing the distance the post was placed from the roadway shoulder.

The AE configuration was listed most often (seven times) in Question 1 as appearing significantly sharper than all other configurations. Almost all respondents (85 percent) indicated that they noted a configuration that made the curve appear sharper. Even though the AE configuraton was ranked much higher than any other, using the method shown in Table 4, it was only listed by 18 respondents (which was more than any other) in Question 2 as being one of the three configurations that made the curve appear sharpest. It may be noted there was a wide variation in opinions.

In response to Question 3 concerning a configuration that made the curve appear flatter, Configurations STD, IS, and DOI were listed most often. Configuration STD was listed most often as one of the three configurations that made the curve appear flattest (from Question 4).

Two questions were aimed at determing the driving habits of the respondents. Most respondents (59 percent) indicated they drive through curves faster than the advisory speed shown on curve warning signs. Thirty-eight percent indicated they drive at the advisory speed while only three percent (one driver) indicated that she drove slower than the advisory speed. There was a wide variation in the response to whether they would drive on or over the centerline on a curve having adequate sight distance and no cars approaching in order to keep from having to slow as much. Twelve respondents indicated they did this some of the time while eleven indicated they either did this almost always or only once in a while. Only six stated they did this practically never.

The respondents also were asked whether the centerline, edge line, or post delineators shown in the display assisted them most in judging the apparent sharpness of the curve. Fifty-two percent indicated the post delineators assisted most. The centerline was indicated by 28 percent while the edge line was indicated by 20 percent. These results are logical since post delineators may be seen for a longer distance around the curve than either the centerline or edge line.

The respondents consisted of 33 males and 7 females. The age distribution was three from 16 to 19 years old, twenty from 20 to 25 years of age, thirteen from 26 to 40 years old, and four over 40 years old.

FIELD INSTALLATIONS

The curve locations may be classified into four locations where pavement delineation (raised pavement markers, transverse stripes, or rumble strips) was added and two locations where post delineators and chevron signs were added. At the four pavement delineation locations, the experimental devices were left in place for over one year and before-and-after accident data were summarized in addition to speed and encroachment data. Several configurations of post delineators and chevron signs were placed at the other two locations, and data collection was limited to speeds and encroachments.

A summary of speed and encroachment data at locations with pavement delineation added is given in Table 5. The average speed reduction from a position at the beginning of the advance delineation to the point of curve increased in all but two instances, where it remained the same. As shown in Table 5, there was a statistically significant decrease in speeds at the point of the curve in 11 of 14 comparisons (12). Considering all locations, the average speed at the point of curve dropped from about 25 mph before to 22 mph after, or a reduction of 3 mph. Both Lower Hunters Trace and Cooper Chapel Road had curve warning signs with 15-mph advisory speed plates, while the advisory speed at the Blanton Lane location was 20 mph and the advisory speed at the Fegenbush Lane location was 20 mph. The speed limit at all four locations was 35 mph.

Daytime and nighttime photographs showing the eastbound approach of the Lower Hunters Trace location before and after the addition of transverse stripes and raised pavement markers are shown in Figures 16 and 17, respectively. Daytime and nighttime photographs showing the westbound approach of the Lower Hunter's Trace location before and after the addition of rumble strips and raised pavement markers are shown in Figures 18 and 19, respectively. Nighttime photographs of the Cooper Chapel Road location before and after the addition of raised pavement markers and rumble strips are shown in Figure 20. Nighttime photographs of installation of raised pavement markers at the Blanton Lane and Fegenbush Lane locations are shown in Figures 21 and 22, respectively.

The photographs document the increased nighttime delineation provided at these locations that contributed to the small reduction in speeds at the point of curvature. It is feasible that the added delineation through the curves would not reduce speeds dramatically because of the increased guidance to the driver. This added guidance provided by the pavement delineation should result in a reduction in centerline and edge line encroachments. The large reduction in encroachments that resulted is shown in Table 5. The percentage of encroachments decreased in all but one instance. Considering all data, the percentage of encroachments decreased from 34 to 21 (a 38-percent decrease) during the daytime and from 42 to 24 (a 43-percent reduction) during the nighttime. The severity of encroachments was lessened both during the day and night. Using all daytime data, moderate encroachments decreased from 24 to 10 percent and very severe encroachments decreased from 2 percent to none. The percentage of slight encroachments increased from 70 to 86 and the severe encroachments remained at 4 percent. Considering all nighttime data, moderate encroachments decreased from 18 to 13 percent, severe encroachments decreased from 24 to 2 percent, and very severe encroachments decreased from 13 percent to none. The severity of the encroachments was worse during the nighttime and the improvement was more. The large majority of encroachments (91 percent) were across the centerline rather than the edge line. Combining all data, the distribution of encroachments by severity was 69 percent with slight encroachment, 17 percent moderate, 10 percent severe, and 4 percent with very severe encroachments. The smallest percentage of encroachments occurred on the southbound approach at Blanton Curve, which was a right-hand curve. Encroachments were generally higher for left-hand curves, where drivers tend to "cut the corner", than for right-hand curves.

A summary of accidents the year before and after installation of the additional pavement delineation is given in Table 6. There was a substantial overall reduction in accidents at three of the four sites. The number of before and after accidents remained the same at the Lower Hunters Trace location. The accident summary shows that there was a problem with wet weather accidents at three of these locations. Most accidents at these three locations were two-vehicle accidents in which the vehicle on the inside of the curve slid on the wet pavement across the centerline into an opposing vehicle. There was a reduction in nighttime accidents at each location. Considering all locations, there was a reduction of from 15 nighttime accidents before to 7 after.

A summary of speed and encroachment data at the two locations where various configurations of post delineators and chevron signs were added is given in Table 7. Both curves had curve warning signs. The US-421 location had an advisory speed of 25 mph while the US-62 location did not have an advisory speed plate in conjunction with the curve warning sign. The speeds decreased, in most instances, at the point of curve after the addition of post delineators or chevron signs, but the change was very small. At the US-421 location, daytime speeds at the start of the curve were reduced from 32 mph to 28 mph (chevrons only) while nighttime speeds were reduced from 28 mph before to 27 mph after (for both chevron signs and post delineators). At the US-62 location, speeds changed from 41 mph before to 39 mph during the day (chevrons only) and was 40 mph both before and after during the nighttime (for both the post delineators and chevrons). As with pavement delineation, post delineators and chevron signs had a larger effect on encroachments than speeds. At the US-421 location, encroachments were reduced from 24 percent to 15 percent during the day (chevrons only) and from 28 percent to 19 percent during the night (24 percent for post delineators and 14 percent for chevron signs). At the US-62 location, percentage encroachments were basically unchanged during the day but were reduced from 51 percent to 29 percent during darkness (29 percent for post delineators and 26 percent for chevron signs). Encroachments at these two locations were not severe with, overall, 90 percent slight encroachment, 9 percent moderate, and 1 percent severe. The severity of the encroachments was not severe either before or after installations of the trial devices. At both locations, chevron signs were slightly more effective than post delineators.

Daytime and nighttime photographs of the US-421 location with no added delineation are given in Figure 23. The nighttime delineation provided by post delineators placed in a standard configuration (at a 30-foot spacing) and in an ascending even (AE) configuration (nine delineators placed from 1.5 feet to 5.5 feet above the roadway surface at 0.5-foot increments) is shown in Figures 24 and 25, respectively. Daytime and nighttime photographs of the chevron signs placed in a standard configuration (at a 60-foot spacing) and in an ascending even (AE) configuration (four signs placed at 2.0, 2.5, 3.0, 3.5 feet above roadway surface) are shown in Figures 26 and 27, respectively. Daytime and nighttime photographs of the US-62 location with no added delineation are given in Figure 28. Nighttime delineation provided by post delineators placed in a standard configuration (at a 50-foot spacing) and in an ascending even pattern (eight delineators placed from 1.5 to 5.0 feet above the roadway surface at 0.5-foot increments) is shown in Figures 29 and 30, respectively. Daytime and nighttime photographs of the chevron signs placed in a standard configuration (at a 100-foot spacing and in an ascending even configuration) are shown in Figures 31 and 32, respectively.

SUMMARY

A laboratory test using various configurations of post delineator placement indicated that a configuration in which the distance from the post to the pavement edge and the post spacing remained constant, while the height of the delineator on the post increased, made a curve appear sharper than other delineator configurations. This configuration, along with a standard configuration and chevron signs, were placed at two

curve locations to determine their effect on speeds and encroachments. At four other curve locations, pavement delineation (raised pavement markers, transverse stripes, or rumble strips) was added and speed, encroachment, and accident data were used to analyze the effects.

Observation showed and photographs documented that both the pavement and shoulder treatments increased the curve delineation. The speeds at the point of curve were not decreased dramatically. This finding may be related to the increased guidance to the driver. However, encroachments (primarily across the centerline) decreased substantially after installation of the delineation treatments. Also, at locations where there were a large amount of moderate and severe encroachments, the severity of encroachments was reduced after installation of the delineation treatment. The number of accidents also decreased dramatically at three of the four locations where pavement delineation was added.

Considering all data, it appears that pavement delineation had a greater effect on drivers than shoulder delineation. Also, chevron signs had slightly more influence on speeds and encroachments than post delineators.

IMPLEMENTATION

The results support the installation of additional delineation at hazardous curve locations. The current program involving installation of snowplowable markers on two-lane highways is supported. Use of chevron signs on sharp curves, such as those included in this study, should be considered rather than typical post delineators. Use of an "ascending even" (AE) pattern for the chevron signs or post delineators should be considered at problem locations. Rumble strips or transverse stripes should be limited to high-accident locations. The noise associated with rumble strips must be considered before their use.

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TABLE 1. COMPARISON OF CHARACTERISTICS OCCURRING AT CURVES WITH ALL ACCIDENTS (1984 DATA)

		PERCENTAGE OF ACCIDENTS IN CATEGORY	
VARIABLE	CATEGORY	ALL ACCIDENTS	ACCIDENTS AT CURVES
Severity	Fatal	0.5	1.1
	Injury	21.6	33.0
	Property-Damage-Only	77.9	65.9
Number of Units	One	22.6	46.1
	Two or More	77.4	53.9
Land Use	Rural	30.6	61.9
	Other	69.4	38.1
Light Condition	Day	70.3	63.5
	Dawn-Dusk	3.7	4.4
	Dark-Lighted	13.2	8.4
	Dark-Unlighted	12.7	23.7
Surface Condition	Dry	70.7	60.2
	Wet	20.9	25.3
	Snow-Ice	8.1	13.8
	Other	0.4	0.7
Contributing Factors	Unsafe Speed	8.6	23.5
	Failed to Yield Right-of-Way	16.9	13.2
	Alcohol	6.5	10.9
	Inattention	29.0	18.8
	Defective Brakes	2.0	2.0
	Defective Tires	1.0	2.4
	Defective Steering	0.4	0.8
	Defective Shoulders	0.3	1.0
	Slippery Surface	11.5	23.3
Type of Vehicle	Passenger Car	91.7	89.7
	Truck	6.4	7.7
Driver Age (Years)	16-24	33.3	38.3
	25-44	42.4	43.0
	45 or above	24.3	18.6
Driver Sex	Male	64.7	69.6
	Female	35.3	30.4
Directional Analysis	Intersection	27.5	14.6
	Non Intersection		
	Fixed Object	10.1	23.3
	Ran-off-Road	5.2	14.6
	Head-on	1.5	4.8
	Opposite-Direction Sideswipe	4.8	14.5

TABLE 2. LIST OF POST DELINEATOR CONFIGURATIONS TESTED

HEIGHT	DISTANCE FROM POST TO SHOULDER	POST SPACING	ABBREVIATION
Constant	Constant	Constant	STD
Constant	Increasing	Constant	EIO
Constant	Decreasing	Constant	EOI
Constant	Constant	Increasing	IS
Constant	Constant	Decreasing	DS
Increasing	Constant	Constant	AE
Increasing	Increasing	Constant	AIO
Increasing	Decreasing	Constant	AOI
Decreasing	Decreasing	Constant	DOI
Decreasing	Increasing	Constant	DIO
Decreasing	Constant	Constant	DE

TABLE 3. DESCRIPTION OF POST DELINEATOR CONFIGURATIONS USED

POST NUMBER	STD			EIO			EOI			IS			DS			AE		
	H*	D**	S***	H	D	S	H	D	S	H	D	S	H	D	S	H	D	S
1	4	5	-	4	2.0	-	4	7.8	-	4	5	-	4	5	-	1.5	5	-
2	4	5	20	4	2.8	20	4	7.0	20	4	5	5	4	5	35	2.0	5	20
3	4	5	20	4	3.7	20	4	6.2	20	4	5	10	4	5	30	2.5	5	20
4	4	5	20	4	4.5	20	4	5.3	20	4	5	15	4	5	25	3.0	5	20
5	4	5	20	4	5.3	20	4	4.5	20	4	5	20	4	5	20	3.5	5	20
6	4	5	20	4	6.2	20	4	3.7	20	4	5	25	4	5	15	4.0	5	20
7	4	5	20	4	7.0	20	4	2.8	20	4	5	30	4	5	10	4.5	5	20
8	4	5	20	4	7.8	20	4	2.0	20	4	5	35	4	5	5	5.0	5	20

POST NUMBER	AIO			AOI			DOI			DIO			DE		
	H	D	S	H	D	S	H	D	S	H	D	S	H	D	S
1	1.5	2.0	-	1.5	7.8	--	5.0	7.8	--	5.0	2.0	-	5.0	5	-
2	2.0	2.8	20	2.0	7.0	20	4.5	7.0	20	4.5	2.8	-	4.5	5	-
3	2.5	3.7	20	2.5	6.2	20	4.0	6.2	20	4.0	3.7	20	4.0	5	20
4	3.0	4.5	20	3.0	5.3	20	3.5	5.3	20	3.5	4.5	20	3.5	5	20
5	3.5	5.3	20	3.5	4.5	20	3.0	4.5	20	3.0	5.3	20	3.0	5	20
6	4.0	6.2	20	4.0	3.7	20	2.5	3.7	20	2.5	6.2	20	2.5	5	20
7	4.5	7.0	20	4.5	2.8	20	2.0	2.8	20	2.0	7.0	20	2.0	5	20
8	5.0	7.8	20	5.0	2.0	20	1.5	2.0	20	1.5	7.8	20	1.5	5	20

* H is the height of the delineator on the post (feet).
** D is the distance of the post from the roadway shoulder (feet).
*** S is the spacing between posts (feet).

TABLE 4. RANKING OF POST DELINEATOR CONFIGURATIONS

CONFIGURATION	WEIGHTED NUMBER OF POINTS			
	SHARPEST	FLATTEST	DIFFERENCE*	RANKING
STD	13	27	-14	9
EIO	19	11	8	5
EOI	25	16	9	4
IS	10	25	-15	11
DS	11	22	-11	8
AE	44	11	33	1
AIO	36	21	15	2
AOI	28	14	14	3
DOI	21	26	-5	7
DIO	12	16	-14	9
DE	13	15	-2	6

* Weighted number of points for curve appearing sharpest minus weighted number of points for curve appearing flattest.

TABLE 5. BEFORE AND AFTER SPEED AND ENCROACHMENT DATA AT LOCATIONS WITH PAVEMENT DELINEATION ADDED

LOCATION	APPROACH	TRAFFIC CONTROL ADDED	LIGHT CONDITION	AVERAGE SPEED AT PC (MPH)		AVERAGE SPEED REDUCTION (MPH)		PERCENT ENCROACHMENTS	
				BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER
Lower Hunters Trace	Westbound	Rumble Strips	Day	29	26*	11	13	43	27
		Raised Pavement Markers	Night	28	25*	10	13	50	14
	Eastbound	Transverse Stripes	Day	24	25	14	14	41	36
		Raised Pavement Markers	Night	23	22	14	15	76	16
Cooper Chapel Road	Southbound	Rumble Strips	Day	22	22	16	16	17	10
		Raised Pavement Markers	Night	22	18*	13	17	46	36
	Eastbound	Rumble Strips	Day	23	20*	16	19	48	21
		Raised Pavement Markers	Night	21	18*	16	20	47	44
Blanton Lane	Eastbound	Raised Pavement Markers	Day	23	20*	14	17	44	22
			Night	23	20*	14	17	52	18
	Southbound	Raised Pavement Markers	Day	25	23*	5	7	13	7
			Night	24	22*	5	7	8	7
Fegenbush Lane	Southbound	Raised Pavement Markers	Night	30	27*	6	10	22	26
	Northbound	Raised Pavement Markers	Night	30	24*	11	14	32	29

* The average speed at the point of curve after adding pavement delineation showed a statistically significant decrease (at 0.01 level of significance).

TABLE 6. BEFORE AND AFTER ACCIDENT DATA AT LOCATIONS WITH PAVEMENT DELINEATION ADDED

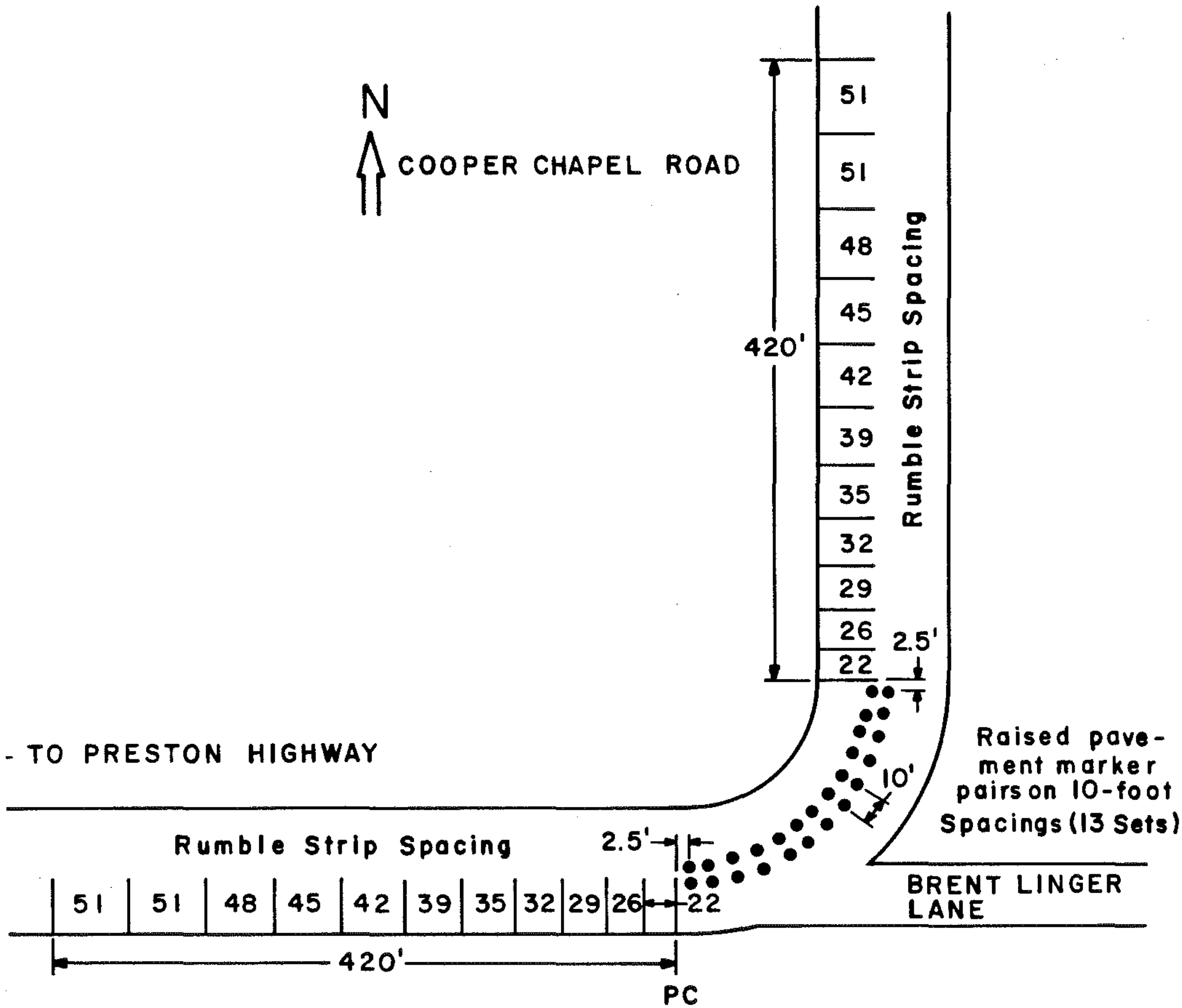
LOCATION	TOTAL ACCIDENTS		WET SURFACE ACCIDENTS		NIGHTTIME ACCIDENTS	
	ONE YEAR BEFORE	ONE YEAR AFTER	ONE YEAR BEFORE	ONE YEAR AFTER	ONE YEAR BEFORE	ONE YEAR AFTER
Lower Hunters Trace	13	13	12	10	4	3
Cooper Chapel Road	30	13	26	12	3	1
Blanton Lane	18	3	17	2	4	2
Fegenbush Lane	6	3	0	1	4	1

TABLE 7. BEFORE AND AFTER SPEED AND ENCROACHMENT DATA AT LOCATIONS WITH POST DELINEATORS AND CHEVRON SIGNS ADDED

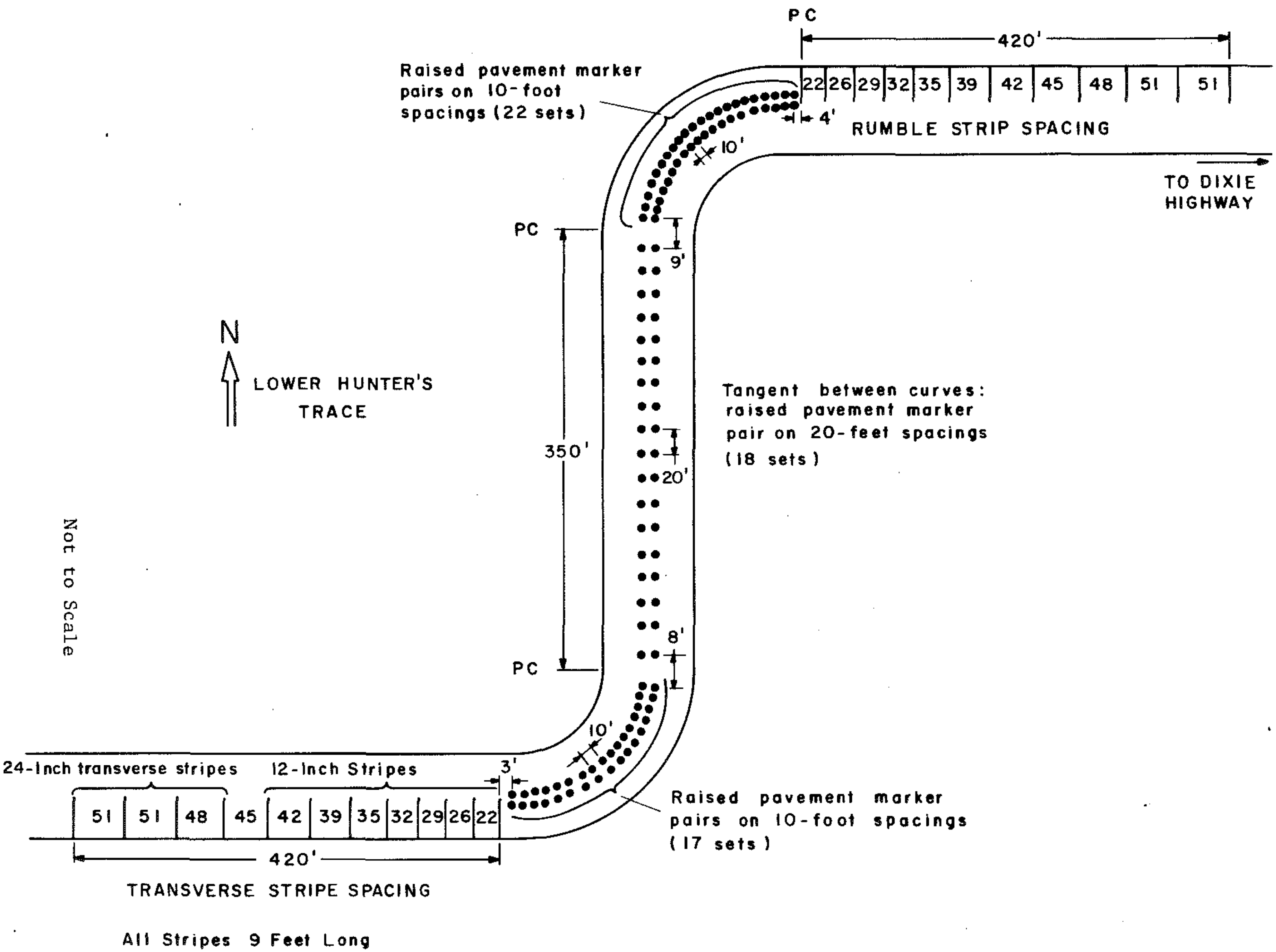
LOCATION	TRAFFIC CONTROL	LIGHT CONDITION	AVERAGE SPEED AT PC (MPH)	AVERAGE SPEED REDUCTION (MPH)	PERCENT ENCROACHMENTS
US 421 Franklin County	None Added	Day	32	7	24
		Night	28	10	28
	Post Delineators - STD	Night	27	11	23
	Post Delineators - AE	Night	27	11	25
	Chevron Signs - STD	Day	29*	13	13
		Night	27*	12	10
	Chevron Signs - AE	Day	27*	11	17
		Night	27	11	17
US 62 Scott County	None Added	Day	41	9	17
		Night	40	10	51
	Post Delineators - STD	Night	39	12	31
	Post Delineators - AE	Night	41	8	30
	Chevron Signs - STD	Day	39	12	19
		Night	39	11	24
	Chevron Signs - AE	Day	37*	12	16
		Night	40	10	29

* The average speed at the point of curve after adding chevron signs showed a statistically significant decrease (at 0.01 level of significance).

Figure 1. Delineation Treatment at Cooper Chapel Road



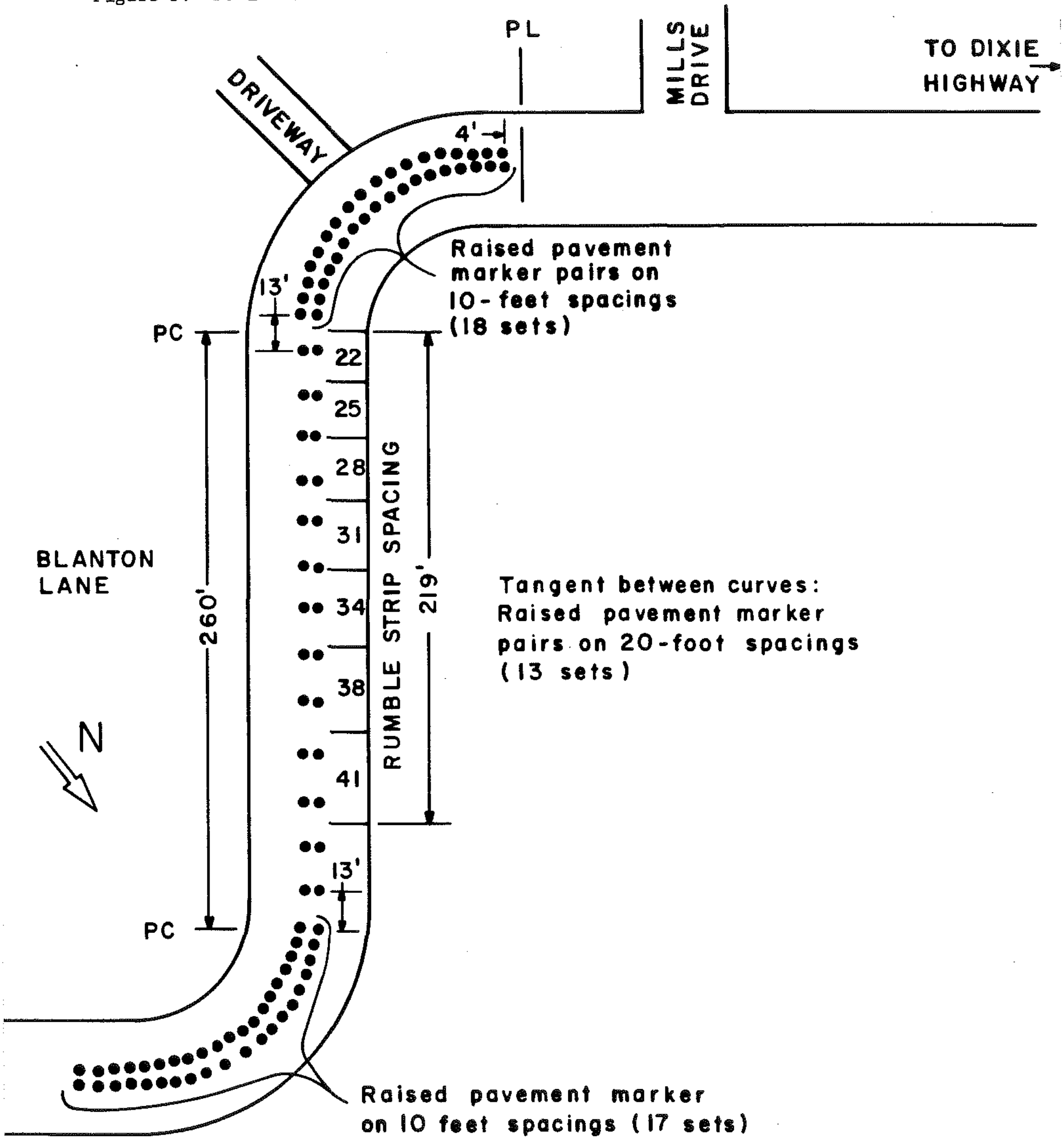
Not to Scale



Not to Scale

Figure 2. Delineation Treatment at Lower Hunters Trace

Figure 3. Delineation Treatment at Blanton Lane



Not to Scale

Figure 4. Curve Delineation Questionnaire.

During nighttime driving, driver negotiation of rural horizontal curves depends upon, among other things, how sharp the curve appears to be to the driver. Upon approaching the curve, the driver takes cues from the centerline, edge line, delineators, etc., in order to select a speed that will allow him (or her) to safely negotiate the curve. It is when these cues are misread or ignored that an unsafe speed upon approach to the curve may lead to accidents.

Shown on the display are eleven different techniques for delineating the same curve. For Configurations 1 through 11, three photographs for each configuration were taken at distances of 500, 300, and 100 feet from the curve. A typical driver would most likely begin to slow down somewhere around 300 feet from the curve. Imagine yourself as a driver approaching this curve at night and please answer the following questions.

1. Does any single configuraton (Number 1, 2, 3, etc.) made the curve appear signficantly sharper than all of the others? ____Yes ____No. If so, which one? ____

2. Please rank the three configurations that make the curve appear to be sharpest (if you answered "yes" to Question 1, rank that one first). ----(Sharpest) ____ (Next Sharpest) ____(Third Sharpest)

3. Does any single configuration make the curve appear significantly flatter (not as sharp) than all of the others? ____ Yes ____No If so, which one? ____

4. Similar to Question 1, please rank the three configurations that make the curve appear to be flattest. ____(Flattest) ____(Next Flattest) ____(Third Flattest)

5. Suppose you are approaching a curve similar to this one in your vehicle at night. If the curve warning sign lists an advised safe speed for negotiating the curve, would you be most likely to drive faster than the advisory speed, at the advisory speed, or slower than the advisory speed? ____Faster ____At Advisory Speed ____ Slower

6. For this same type of curve at night, if there were adequate sight distance and no cars were approaching in the other direction, would you be likely to "cut the corner" (that is, drive on or over the centerline) in order to keep from having to slow down as much?
   ____ Almost Always ____ Some of the Time ____ Only Once in a While ____ Practically Never

7. Look at any one of the photographs taken at 100 feet from the curve. Which of these elements is most important in assisting you to judge the apparent sharpness of the curve so that you may select a safe speed for negotiating the curve? (Please choose only one.)
   ____ Centerline ____ Edgeline ____ Post Delineators

8. Please mark your appropriate age category and sex. This is optional, but would be very helpful. Thank you.
   AGE ____16-19 ____20-25 ____26-40 ____41-50 ____51 and over
   SEX ____M ____F

Figure 5. STD Configuration, 300 Feet from Start of Curve.

Figure 6. EIO Configuration, 300 Feet from Start of Curve.

Figure 7. EOI Configuration, 300 Feet from Start of Curve.

Figure 8. IS Configuration, 300 Feet from Start of Curve.

Figure 9. DS Configuration, 300 Feet from Start of Curve.

Figure 10. AE Configuration, 300 Feet from Start of Curve.

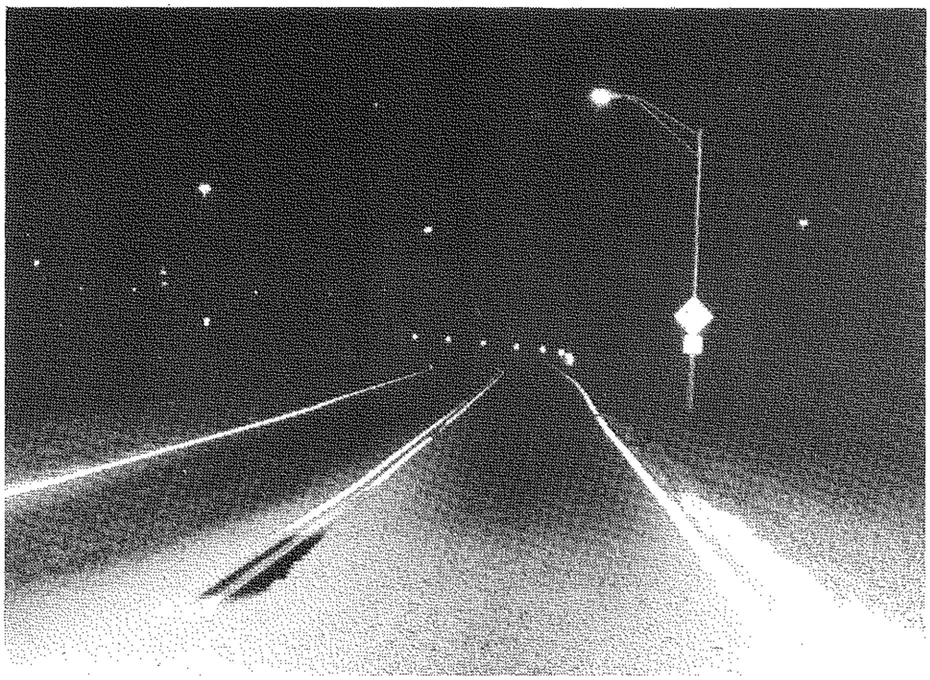


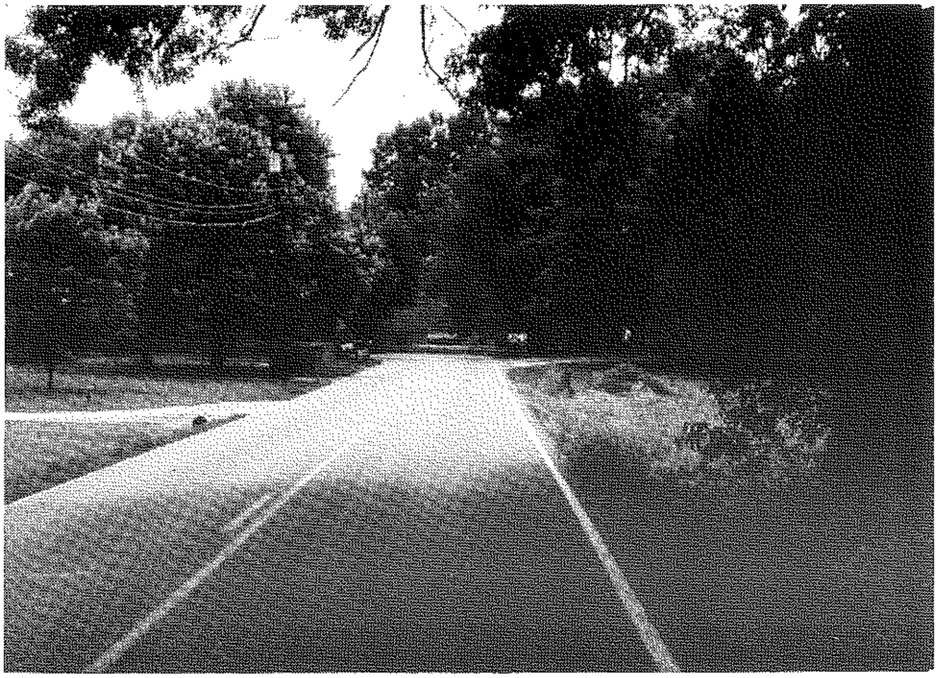
Figure 11. AIO Configuration, 300 feet from Start of Curve

Figure 12. AOI Configuration, 300 Feet from Start of Curve

Figure 13. DOI Configuration, 300 Feet from Start of Curve.

Figure 14. DIO Configuration, 300 Feet from Start of Curve.

Figure 15. DE Configuration, 300 Feet from Start of Curve.

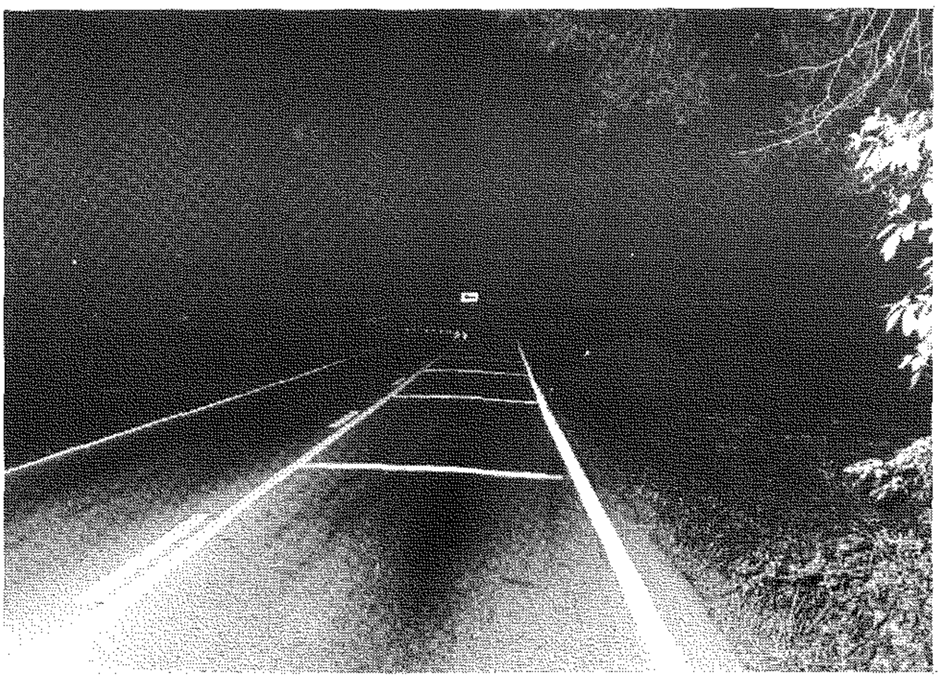


Before

After

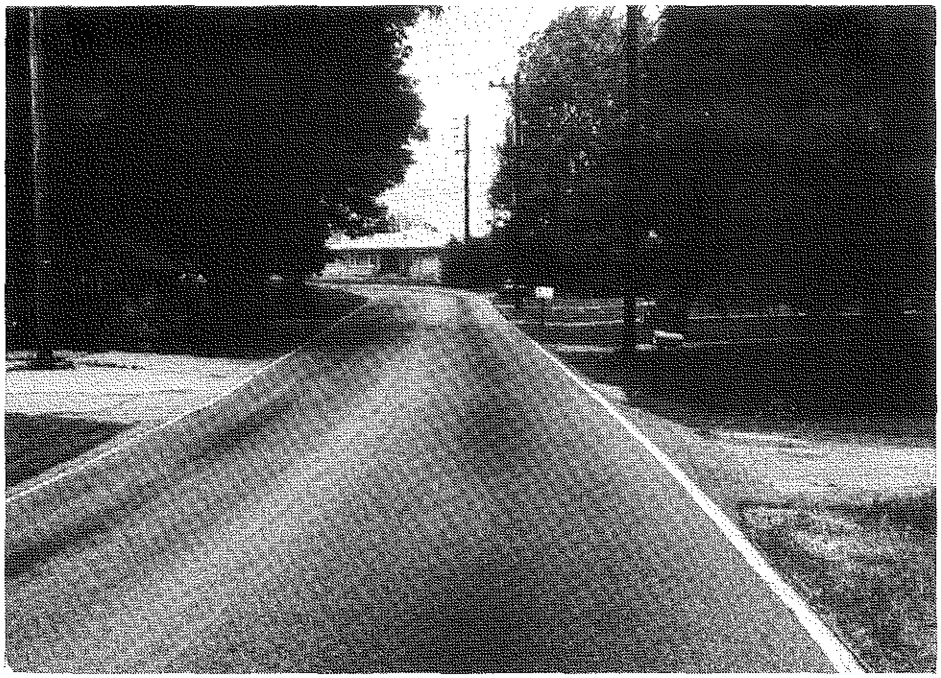
Figure 16. Daytime Photographs of Lower Hunters Trace Eastbound Approach Before and After Addition of Transverse Stripes and Raised Pavement Markers.

Before



After

Figure 17. Nighttime Photographs of Lower Hunters Trace Eastbound Approach Before and After Addition of Transverse Stripes and Raised Pavement Markers.



Before

After

Figure 18. Daytime Photographs of Lower Hunters Trace Westbound Approach Before and After Addition of Rumble Strips and Raised Pavement Markers.

Before

After

Figure 19. Nighttime Photographs of Lower Hunters Trace Westbound Approach Before and After Addition of Rumble Strips and Raised Pavement Markers.

Before

After

Figure 20. Nighttime Photographs of Cooper Chapel Road Southbound Approach Before and After Addition of Raised Pavement Markers and Rumble Strips.

Figure 21. Nighttime Photograph of Blanton Lane After Installation of Raised Pavement Markers.

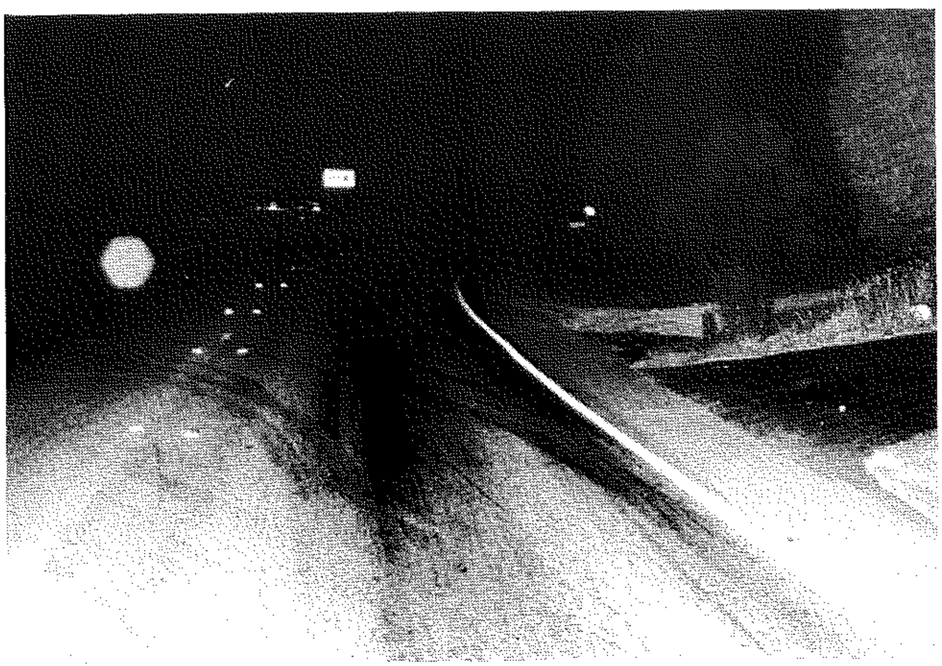
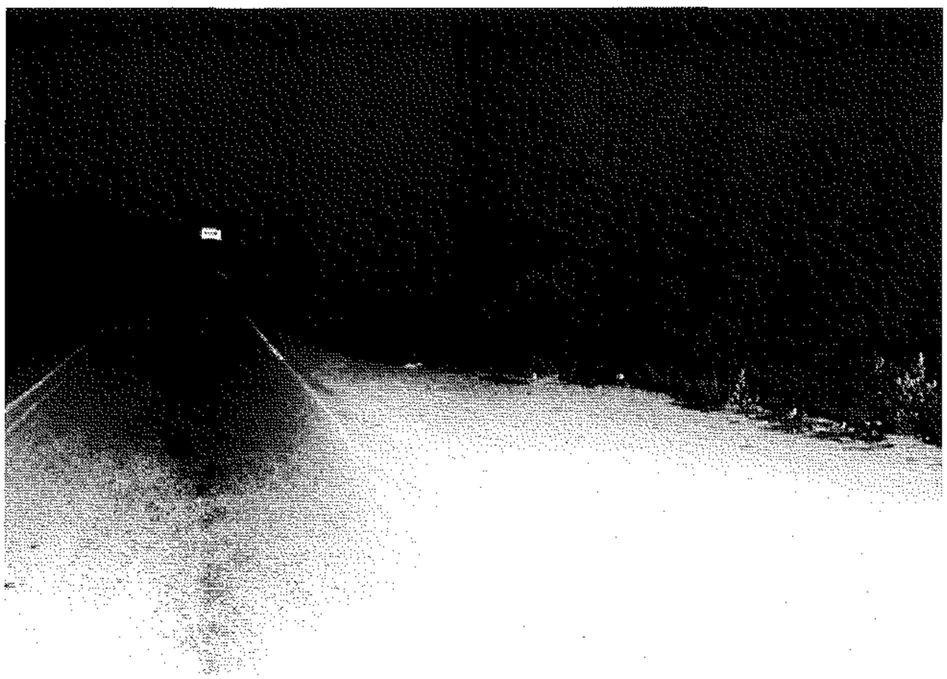


Figure 22. Nighttime Photograph of Fegenbush Lane After Installation of Raised Pavement Markers.

Daytime

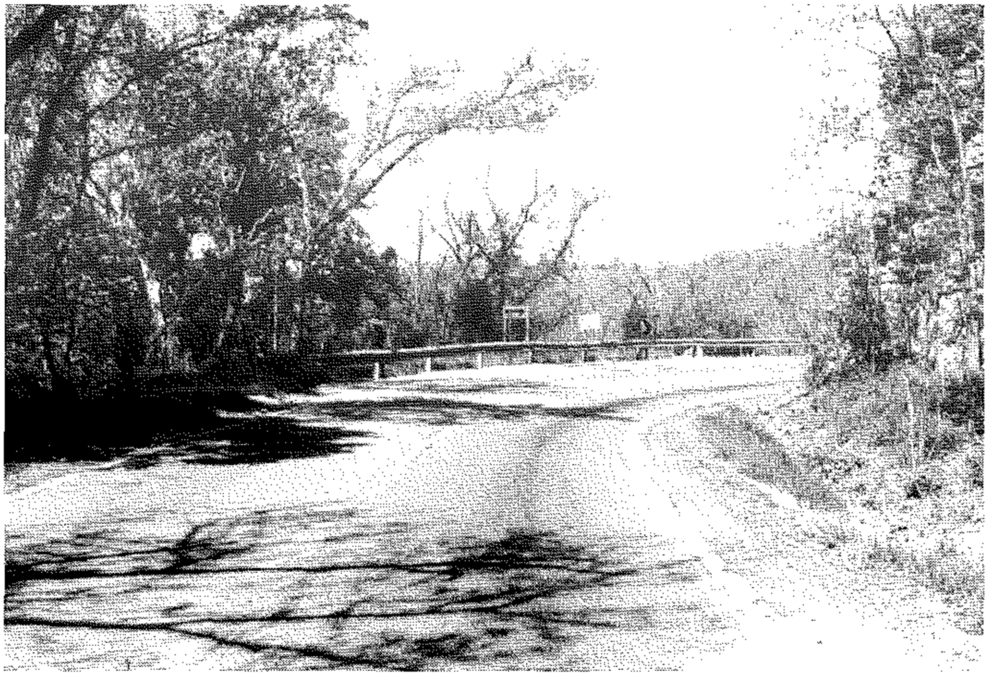


Nighttime

Figure 23. Daytime and Nightime Photographs of US 421 Location with No Added Delineation.

Figure 24. Nighttime Photograph of Post Delineators at US 421 Location Placed in a STD Configuration.

Figure 25. Nighttime Photograph of Post Delineators at US 421 Location Placed in an AE Configuration.



Daytime

Nighttime

Figure 26. Daytime and Nighttime Photographs of Chevron Signs at US 421 Location Placed in a STD Configuration.

Daytime

Nighttime

Figure 27. Daytime and Nighttime Photographs of Chevron Signs at US 421 Location Placed in an AE Configuration.

Daytime

Nighttime

Figure 28. Daytime and Nighttime Photographs of US 62 Location with No Added Delineation.

Figure 29. Nighttime Photograph of Post Delineators at US 62 Location Placed in a STD Configuration.

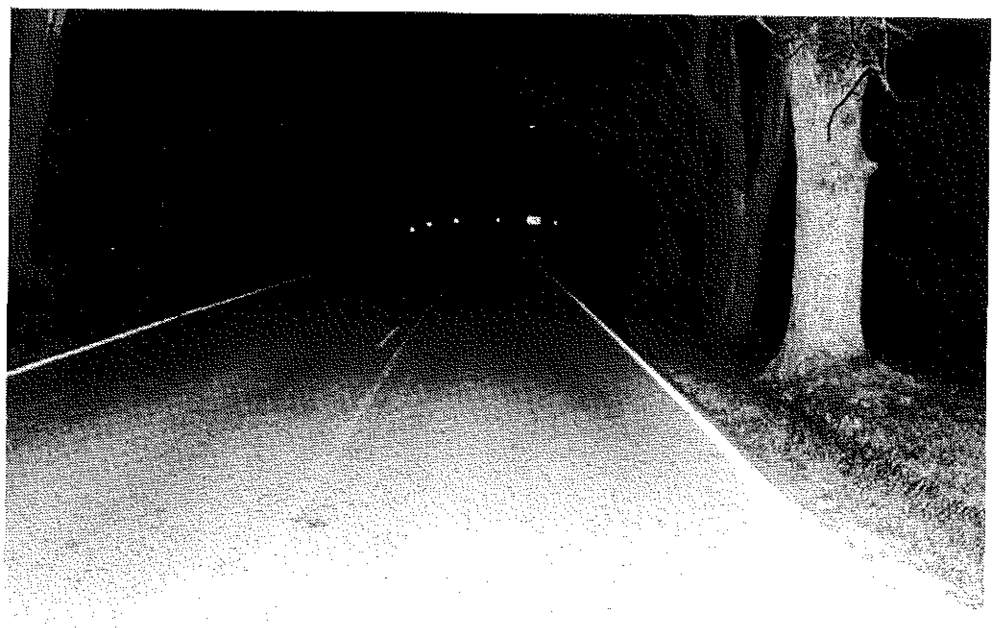


Figure 30. Nighttime Photograph of Post Delineators at US 62 Location Placed in an AE Configuration.

Daytime

Nighttime

Figure 31. Daytime and Nighttime Photographs of Chevron Signs at US 62 Location Placed in a STD Configuration.

Daytime

Nighttime

Figure 32. Daytime and Nighttime Photographs of Chevron Signs at US 62 Location Placed in an AE Configuration.