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SUBJECT: Research Report No. 433; "Transverse, Pavement Markings for Speed Control and Accident Reduction;" KYP-72-40; HPR-PL-1(11), Part III-B.

The report enclosed herewith describes the case history of an installation of reflective, cross lines on a pavement ahead of a hazardous curve. Speed-and-accident reductions achieved are especially noteworthy.

It would not seem too redundant to incorporate rumble strips in any future installations of this type. Recourse to these types of warning systems should, perhaps, be reserved for exceptionally hazardous situations -- lest they become too commonplace.

Respectfully submitted,

Jas. H. Havens
Director of Research

JHH:gd
Attachment
cc's: Research Committee

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16. Abstract

Transverse pavement markings were placed ahead of a sharp curve having a high-accident history. Speed and accident studies were conducted before and after. The markings were placed so that drivers otherwise failing to reduce speeds while approaching the curve would see transverse lines on the pavement at an increasing rate. The spacing of lines was intended to create an illusion of acceleration which would cause the driver to slow. The results indicated that pavement markings can be an effective speed-control measure and reduce accidents. At the single site studied, the obedience of drivers to this type of hazard warning was more effective than signing alone. Further uses of markings in this way may be warranted at locations where excessive speeds contribute to accidents. The length of roadway marked in this trial was 810 feet (247 m). Consideration should be given to increasing the distance in future installations. Although the striping tape performed satisfactorily, painted lines could be used as an alternate.

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Research Report
433

TRANSVERSE, PAVEMENT MARKINGS FOR SPEED CONTROL AND ACCIDENT REDUCTION

KYP-72-40, HPR-PL-1(11), Part III-B

by

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INTRODUCTION

Pavement markings were placed ahead of a high-accident location (a sharp curve). Speed and accident studies were conducted before and after. The markings were placed so that drivers otherwise failing to reduce speed would see the markings at an increasing rate. The spacing of lines was intended to create an illusion of acceleration which would cause the driver to slow. Speed is perceived by the visual senses; drivers sense forces resulting from changes in speed but relate and associate speed to the visual field. In laboratory experiments, it has been shown that a driver's perception of speed can be varied by introducing structured patterns onto the road surface *(1)*. Field tests have resulted in varying degrees of success *(2, 3)*. However, it has been found that improper approach to a curve is related to perceptual assessment problems *(4)*. Several site comparisons between uniform and illusionary marking patterns would have to be evaluated to conclusively demonstrate any illusionary effects. The idea of compressed spacing, therefore, remains somewhat inituitive. It has been employed in installations of rumble strips approaching toll booths and some intersections to intensify the warning. In the case history reported here, noises generated by the pavement markings were minimal; a few "rumbles" among the lines might have alerted a sleepy driver and prevented one of the accidents which occurred after the lines were installed. In the past there was some hesitancy among traffic engineers to use cross lines in this way; apparently some feared that such lines would be confused with "stop bars" and cause panic-type stops.

PROCEDURE

TEST LOCATION

Selection of the test location involved choosing a high-accident location where excessive speed was suspected of contributing to accidents and where warning signs have not solved the problem. A location on US 60 in Meade County (Milepost 12.7 to 12.9) was selected (1973 ADT = 4890). The problem curve (Figure 1) is at the beginning of a 1-mile (1.6-km) section which has been extremely hazardous. In the preceeding 6 years, 48 accidents occurred on this curve. All but two involved eastbound vehicles leaving the roadway or crossing the centerline and colliding with westbound vehicles. The eastbound approach was, therefore, critical. In 36 of the accident reports, speed was mentioned as a contributing circumstance. Investigating teams had recommended reconstruction since accident occurrence had not been reduced by other measures.

LAYOUT OF MARKINGS

In rural areas, warning devices should normally be placed about 750 feet (229 m) in advance of the hazard *(5)*. The total length of roadway to be marked should, therefore, be about 750 feet (229 m). The following formula was used to determine an adequate distance to mark:

$$D = (V_1^2 - V_2^2)/2d$$

where D = distance traveled in slowing from V_1 to V_2,
d = deceleration rate,
V_1 = speed at beginning of markings, and
V_2 = speed at ending of markings (beginning of curve).

A deceleration rate of 2 mph per sec (0.9 m/s per sec) can be achieved with very light braking. Deceleration in gear alone generally results in overall rates between 1.0 and 1.5 mph per sec (0.4 and 0.7 m/s per sec) *(6)*. It would be desirable to create a situation where braking would not be necessary. A deceleration rate of 1.25 mph per sec (0.6 m/s per sec) was selected. The speed (V_1) at the beginning of the markings was assumed to be the speed limit (55 mph (25 m/s)). The warning signs in advance of the curve had an advisory speed (V_2) of 35 mph (16 m/s). Using these values for velocity results in 720 feet (219 m) for D. A design was developed with a D of 810 feet (247 m). Assuming a d of 1.25 mph per sec (0.6 m/s per sec) and a V_1 of 55 mph (25 m/s) yields a V_2 of 31.6 mph (14 m/s), which is below the posted, advisory speed of 35 mph (16 m/s).

Stripes have to be spaced according to the desired perception and the travel speed. The objective was for the driver to slow as he approached the curve and maintain a constant rate of stripe advancement. At first, a stripe interval or rate of advancement of one stripe per second was thought to be adequate, and the stripes were actually installed in this way. However, upon viewing the installation as a driver, it appeared to be inadequate. As a matter of judgement, a rate of advancement of two stripes per second was selected. Spacing of the stripes would need to vary according to the distance traveled in one-half second. The spacing for a speed of 55 mph (25 m/s) would be approximately 40 feet (12 m). The spacing would then gradually decrease to approximately 25 feet (7.6 m) for a speed of 35 mph (16 m/s) at the curve. The spacing decreased to a minimum of 15 feet (4.6 m) because it was desired to slow the vehicle as much as possible. The width of the stripes was also decreased closer to the curve so that the stripes would appear the same width as the vehicle slowed.

A plan view of the transverse pavement marking site, showing the location of the markings in relation to the curve, is shown in Figure 2. The detailed layout of the markings showing the spacing and width of markings is given in Figure 3.

INSTALLATION

Reflective tape was used for the markings. The pavement surface was prepared by cleaning with a stiff broom. A primer was applied to the pavement to assure optimum adhesion of the tape. The tape was positioned by walking it down along a chalk guideline; it was then pressed to conform to the pavement surface by driving over the tape with an automobile. A finished stripe is shown in Figure 4. The installation was completed May 7, 1974. It was not possible to purchase the proper widths of tape for all stripes. In most cases, two widths of tape were used to form the stripe. Figure 5 shows the test location after installation of markings.

DATA COLLECTION

Accident data for a 6-year period before installation of the markings as well as the year after installation were obtained. Radar speed data before and after installation were also collected. Speeds were measured at locations where the markings began and ended. Care was taken to shield the radar units from view. The first set was taken before the stripes were applied, the second set was obtained 1 week after striping, and the third set was taken 6 months later. The vehicle description was noted along with its speed so that the drop in speed from the beginning to the ending of the markings could be determined for each vehicle. Both day and night speed data were taken. The percentage of vehicles which applied brakes upon entering the curve was also obtained.

DATA ANALYSIS

The difference in the accident experience before and after installation of the markings was studied. The average drop in speed over the test section was determined and tested statistically. The average, 50th-percentile, and 85th-percentile speeds at the beginning of the curve were determined. A statistical test was used to determine if the average speed had dropped significantly. The 10-mph (4.5-m/s) pace and percentage of vehicles in the 10-mph (4.5-m/s) pace were determined. The speed data of the before period were compared to both after periods. Day and night data were analyzed separately. The brakelight application data were also analyzed statistically.

RESULTS

ACCIDENTS

This site had been considered a high-accident location for a number of years. As stated earlier, 48 accidents occurred during the 6 years preceding installation of the markings. Of these, 33 involved eastbound, single vehicles not negotiating the curve, 11 were two-vehicle accidents caused by an eastbound vehicle crossing into the opposing lane, and two were rear-end accidents involving eastbound vehicles. There were two multi-vehicle accidents in which a westbound vehicle was at fault. Only accidents in which the eastbound vehicle was at fault were considered. There was a large number of severe accidents (typical of accidents involving single vehicles). The severity index *(7)* was 3.68. The statewide average for accidents at curves is 3.13 *(8)*. Thirteen accidents (28 percent) occurred during wet road conditions, and two accidents (4 percent) occurred during icy road conditions. These percentages were similar to statewide averages. A very high percentage of accidents occurred at night (54 percent). This percentage is above the statewide average (30 percent) and indicated that improved nighttime delineation was necessary. Speeding was listed (in 36 accident reports) most often as a contributing circumstance. Driving while intoxicated was listed in 23 reports, driving on the wrong side of the road was listed in 19, and inattentiveness was mentioned in 14 cases.

During the year after installation of the markings, three accidents occurred in which the eastbound vehicle was at fault. All three were single vehicle accidents and involved injuries. Two accidents involved driving while intoxicated; in the remaining accident, the driver fell asleep. Speeding was listed as a contributing circumstance in one of the accident reports. There were two multi-vehicle accidents which resulted from a westbound vehicle crossing the centerline. This type of accident would not have been prevented by the pavement markings. These accidents, however, may indicate a problem with the westbound approach.

The high severity of accidents at the curve resulted from inadequate containment provided by guardposts connected with cable (Figure 6) which are placed to prevent an errant vehicle from going over a steep embankment. The errant vehicle went over or through the guardposts in 17 of 25 collisions.

The history of accidents in which the eastbound vehicle was at fault is given in Figure 7. The accident data were divided into 6-month time intervals. The number of accidents ranged between a high of nine and a low of one for the 6-month intervals. The lowest number of accidents during any 12-month period was three accidents, which occurred the year after installation of the markings. Two 12-month periods before the installation had four accidents. A high of 15 accidents occurred during a 12-month period. Accidents averaged between seven to eight per year during the 6 years preceding installation of the markings. This corresponds to three accidents in the year-after period (a reduction of 61 percent). Comparing only the years immediately before and after installation, there was a reduction from four accidents the year before to three accidents the year after. The accidents involving intoxicated drivers suggest that some accidents will continue at this location regardless of any traffic control device used. The site is eastbound between some popular liquor establishments and a military base.

SPEEDS

Speed data were taken before, 1 week after, and 6 months after installation. The 6-months-after data were taken to determine the novelty-and-surprise effect of the installation. In 6 months, local drivers would become accustomed to the markings.

An important indicator of the effectiveness of transverse markings was the difference in speed reduction from the start and end of the striping (Table 1). There was a significant reduction in speed after installation of the markings; however, speed increased slightly from the 1-week-after to the 6-months-after study periods. Statistical tests showed that the speed reductions for both day and night driving were significant at the 0.005 level (P = 0.995) for both after study periods *(9)*. Details of the statistical tests are given in APPENDIX A.

The distribution of speed reductions for day and night conditions are presented in Figures 8 and 9, respectively. It is clear that the initial effect of the markings did dissipate somewhat, but a substantial reduction continued 6 months after installation of the markings. The before, nignttime speed data showed the reason for the high number of accidents during darkness. About one-third of the vehicles did not reduce speed before the beginning of the curve, and the median speed reduction was only 1.4 mph (0.6 m/s). After installation of the markings, very few vehicles failed to reduce speed when approaching the curve.

Effectiveness of the markings may also be judged from speeds at the beginning of the curve (end of transverse markings). Results of this analysis are presented in Table 2. The 50th-percentile, 85th-percentile, and average speeds reduced from the before to both after periods. Statistical tests showed that the drop in average speeds (day and night) was significant at the 0.005 level (P = 0.995) for both after periods (APPENDIX A).

An important aspect of traffic speed is uniformity. An index to uniformity is the 10-mph (4.5-m/s) pace which indicates the 10-mph (4.5-m/s) speed range in which the greatest percentage of vehicles are operating. Increasing the percentage of vehicles in the pace means that the average variance in speeds has decreased; this may contribute to a reduction in accidents *(6)*. At the test location, the percentage of vehicles in the pace during daytime increased in both after periods. The nighttime data showed a large increase of vehicles in the pace 1 week after installation, but 6 months later the percentage dropped below the before period.

Distribution of vehicle speeds at the beginning of the curve is shown in Figures 10 and 11. The before daytime speed data showed that about 10 percent of the vehicles slowed to the advisory speed of 35 mph (16 m/s) at the beginning of the curve. The percentage increased to about 60 after installation of the markings. The nighttime data shows that 19 percent of the vehicles were traveling 35 mph (16 m/s) or less before installation of the markings. The percentage increased to 57 percent immediately after installation and 32 percent 6 months later.

BRAKELIGHT APPLICATIONS

It was desirable to create a situation where the driver would decelerate in the approach to the curve and could negotiate the curve without brake application. Geometrics of the location, however, were such that almost all drivers applied brakes. As shown in Figure 2, a 12-degree curve is followed by a 20-degree curve. Almost all drivers applied their brakes upon entering the 20-degree curve. A steep downgrade at this point added to the problem. The percentage of brakelight applications is shown in Table 3. The brakelight percentage decreased from 81 before to 68 immediately after installation. The decrease is statistically significant at the 0.025 level (P = 0.975) *(10)*. Six months later, the percentage of brakelight applications increased to 71. The decrease from the 81 percent before was not statistically significant. Details of the statistical tests are given in APPENDIX B.

BENEFIT VERSUS COST

The cost of materials and labor required for the installation of the transverse markings was low. The only materials necessary were the tape and primer. Several rolls of different tape widths were required. The cost was $372. Cost of the primer was $37. Labor cost was $200. The total cost of the installation was $609.

A conservative estimate of the benefits obtained from the markings would be the savings in accident costs in the year after installation. The markings should remain effective for longer than 1 year. The average, yearly accident cost for the 6-year period accurately reflects the long-term accident experience before installation of the markings. Excluding the two accidents where the westbound vehicle was at fault, there were 46 accidents in the 6-year period which might have been prevented. Using 1973 National Safety Council accident cost figures, an average annual accident cost of $41,567 for the 6 years before installation of the markings was calculated. This resulted from 22 property-damage-only accidents at $500 per accident, 46 injuries at $3,400 per injury, and one fatality at $82,000. The three accidents in the 1-year period afterwards resulted in a cost of $13,600 (four injuries). This yields a net savings of $27,967. This amount compared to a total cost of $609 gives a benefit-cost ratio of 45.9.

PAVEMENT STRIPING TAPE PERFORMANCE

Daytime photographs of the test location 1 year after installation of the markings are shown in Figure 12. Although some damage to the marking tapes has occurred, they continue to provide good daytime delineation. Six months after installation, the tape was completely intact. After 1 year of use, a few of the markings became noticeably worn (Figure 13). Most of the damage was considered minor (Figure 14). Several of the markings were in excellent condition. Only 6 of the 30 markings (20 percent) had enough damage to be readily noticeably when driving the highway. Eighteen of the stripes (60 percent) were either completely intact or had very minor damage. The remaining six had minor damage. Nighttime photographs of the markings 1 and 2 months after installation are presented in Figures 15 and 16, respectively. A slight wear was noticed in the wheel paths 2 months after installation (Figure 16). The condition 1 year after installation is shown in Figure 17. A significant amount of wear had taken place in the wheel paths, but the markings remained reflective. Skid resistance was not measured.

CONCLUSIONS

Results showed that transverse stripes effectively controlled speed and reduced accidents. At the very least, they alert drivers to the upcoming hazard more effectively than signing. Further use of this traffic control method would be warranted at locations where excessive speeds have contributed to accidents. Consideration should be given to increasing the warning distance in future installations. A distance of about 1200 feet (365 m) may be desirable. Rumble stripes might be included with the markings. Although the striping tape performed satisfactorily, painted stripes could be used as an alternate. Even though the markings may wear out in the wheel tracks, areas between and at the sides would tend to remain indefinitely and provide very lasting effects.

Figure 1. Test Location before Installation of Marking Stripes.

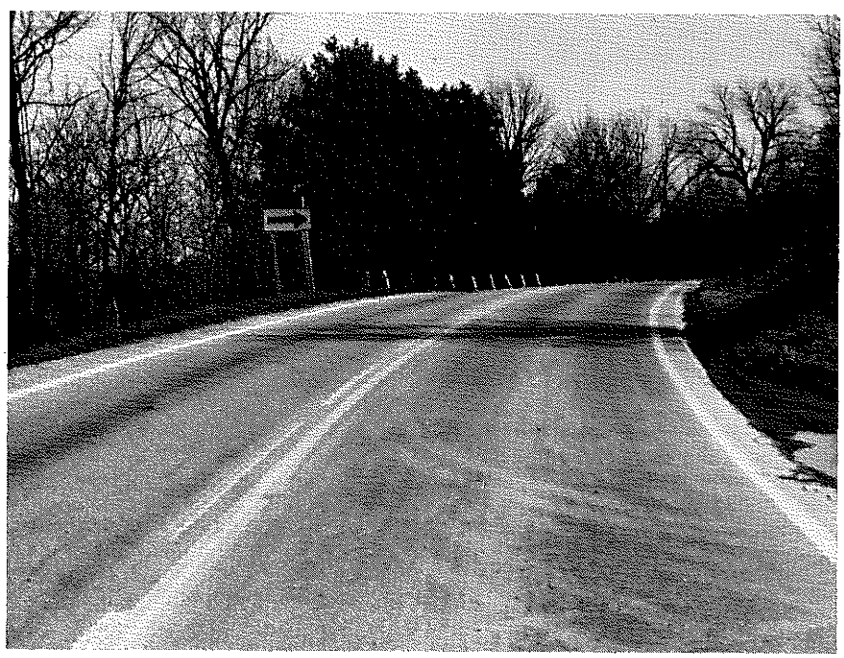


Figure 4. Applied Transverse Marking Tape.

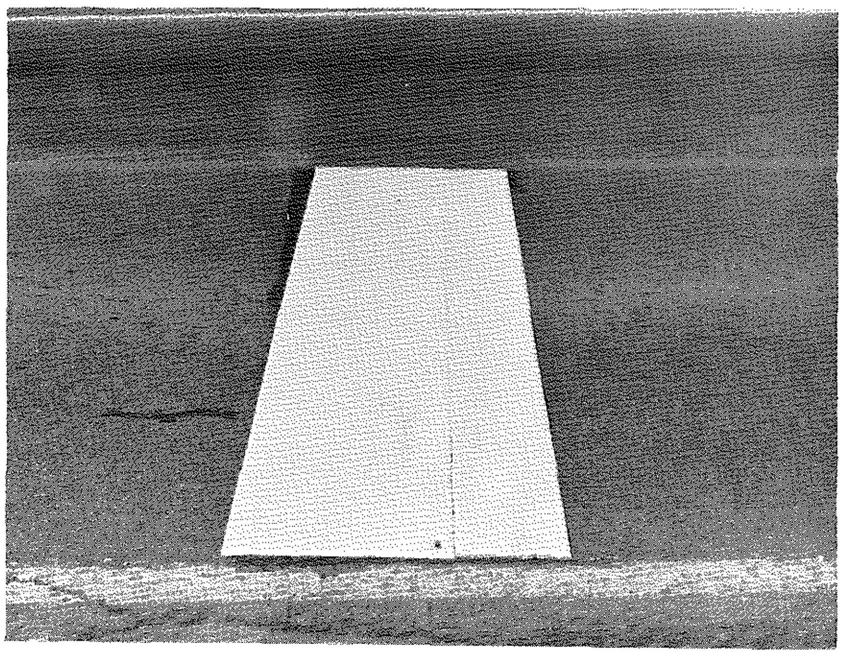


Figure 5. Test Location after Installation of Marking Stripes.

Figure 6. Guardposts Connected with Cable at the Curve.

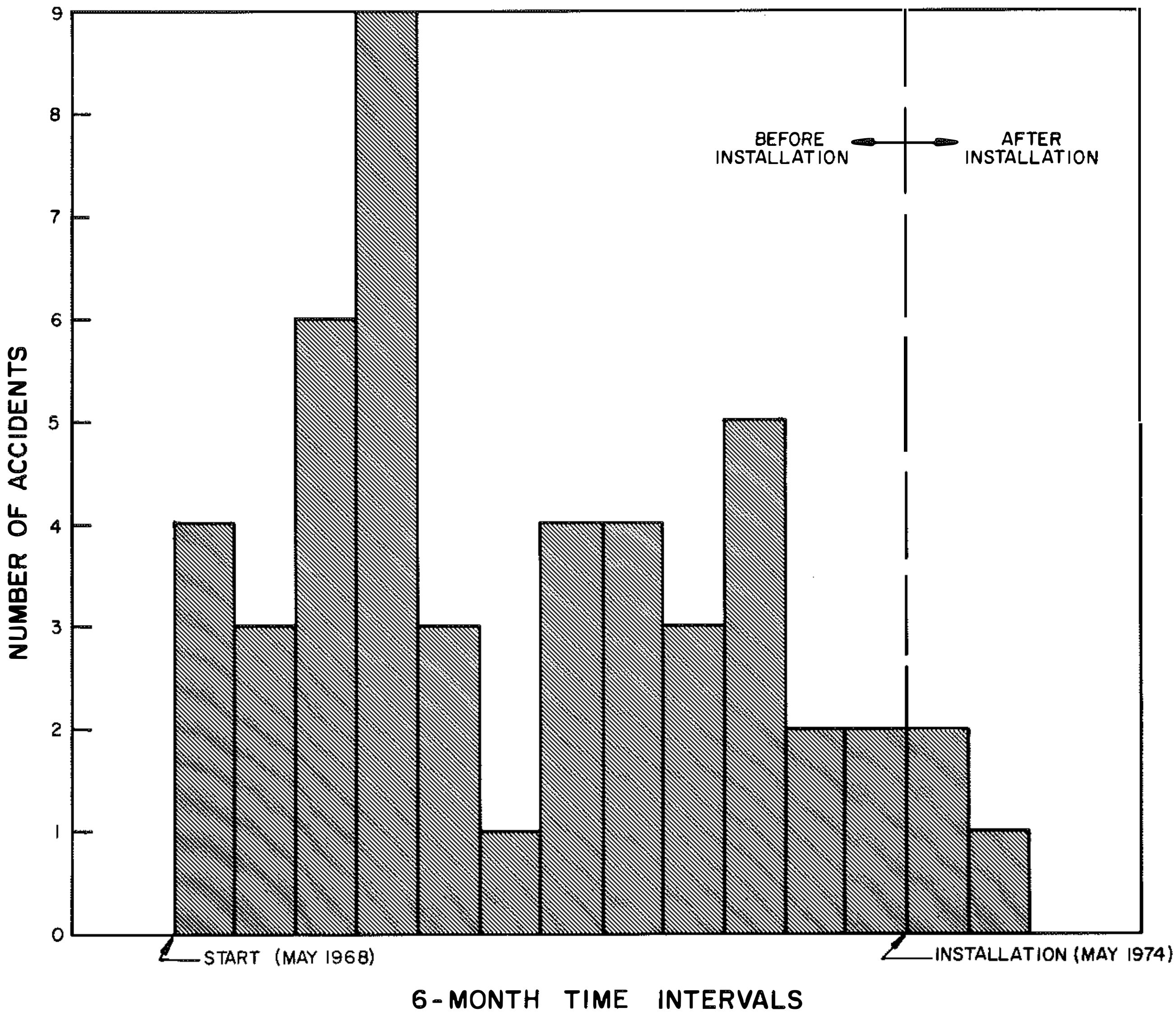


Figure 7. Accident History of Transverse Markings Test Location (Accidents in which Eastbound Vehicles Were at Fault).

TABLE 1. AVERAGE SPEED REDUCTIONS OVER TEST SECTION BEFORE AND AFTER INSTALLATION OF THE TRANSVERSE PAVEMENT MARKINGS

TIME PERIOD	AVERAGE SPEED REDUCTIONS mph (m/s) DAY	NIGHT
Before Installation	8.5 (3.8)	2.4 (1.1)
1 Week after Installation	15.3 (6.8)	9.3 (4.2)
6 Months after Installation	12.3 (5.5)	6.8 (3.0)

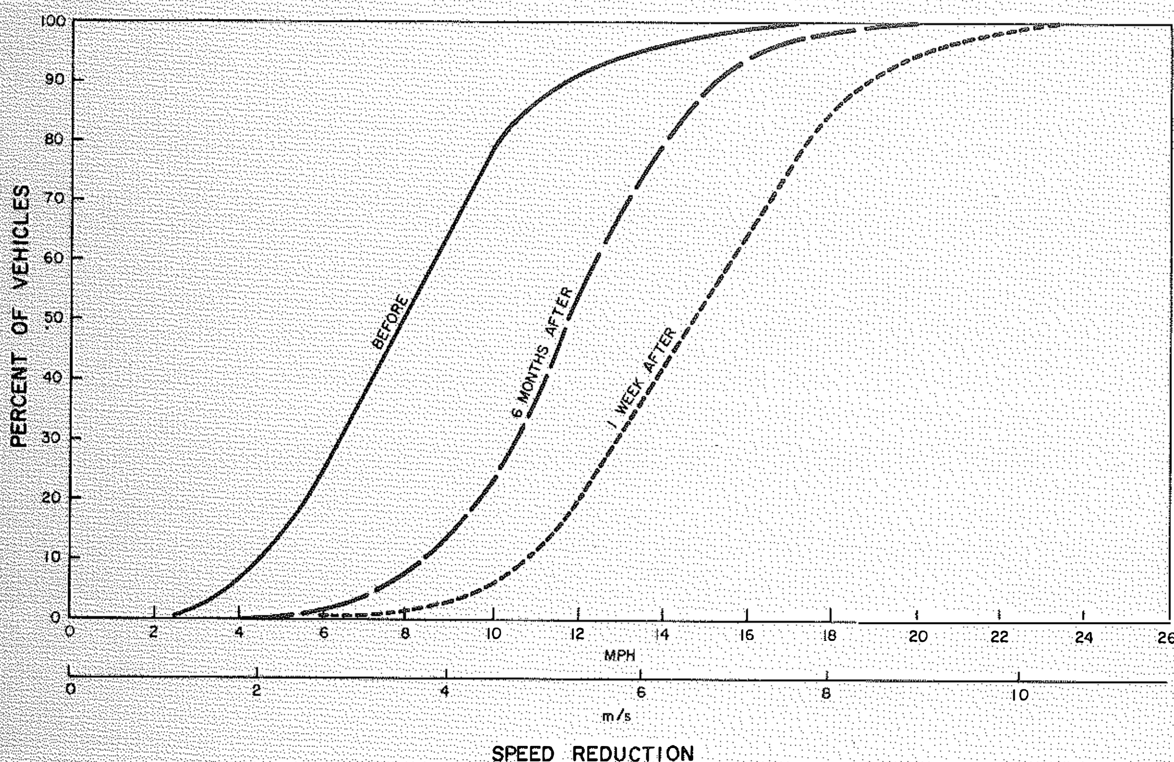


Figure 8. Daytime Speed Reductions before and after Installation of Markings.

Figure 9. Nighttime Speed Reductions before and after Installation of Markings.

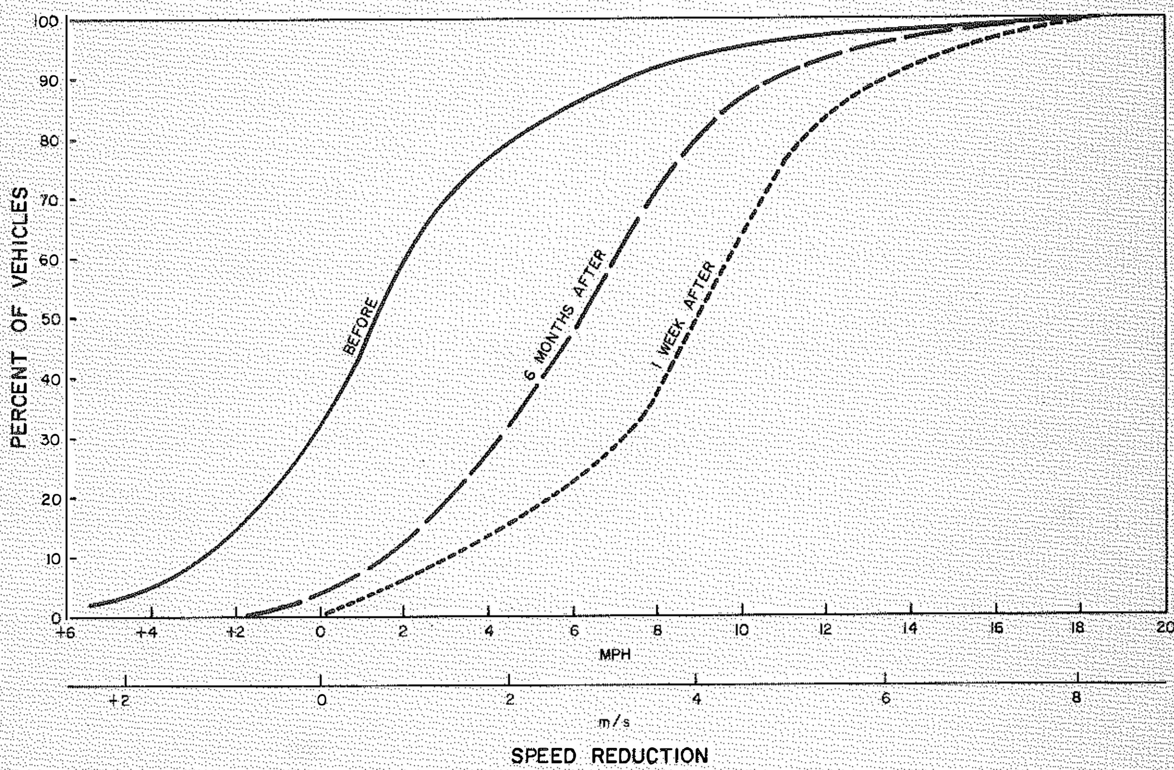


TABLE 2. ANALYSIS OF SPEEDS AT START OF CURVE BEFORE AND AFTER INSTALLATION OF THE TRANSVERSE PAVEMENT MARKINGS

TIME PERIOD	50TH-PERCENTILE SPEED mph (m/s)		85TH-PERCENTILE SPEED mph (m/s)		AVERAGE SPEED mph (m/s)		10-mph (4.5-m/s) PACE mph (m/s)		PERCENT IN PACE	
	DAY	NIGHT	DAY	NIGHT	DAY	NIGHT	DAY	NIGHT	DAY	NIGHT
Before Installation	41.2 (18.4)	39.3 (17.6)	46.2 (20.7)	44.1 (19.7)	41.3 (18.5)	40.5 (18.1)	36-46 (16.1-20.6)	34-44 (15.2-19.7)	70	71
1 Week after Installation	33.5 (15.[illegible])	34.5 (15.4)	38.0 (17.0)	37.8 (16.9)	33.9 (15.2)	35.1 (15.7)	29-39 (13.0-17.5)	28-38 (12.5-17.0)	76	84
6 Months after Installation	34.3 (15.3)	37.0 (16.5)	38.0 (17.0)	42.9 (19.2)	34.8 (15.6)	38.1 (17.0)	29-39 (13.0-17.5)	32-42 (14.3-18.8)	79	67

Figure 10. Daytime Speeds at Beginning of Curve.

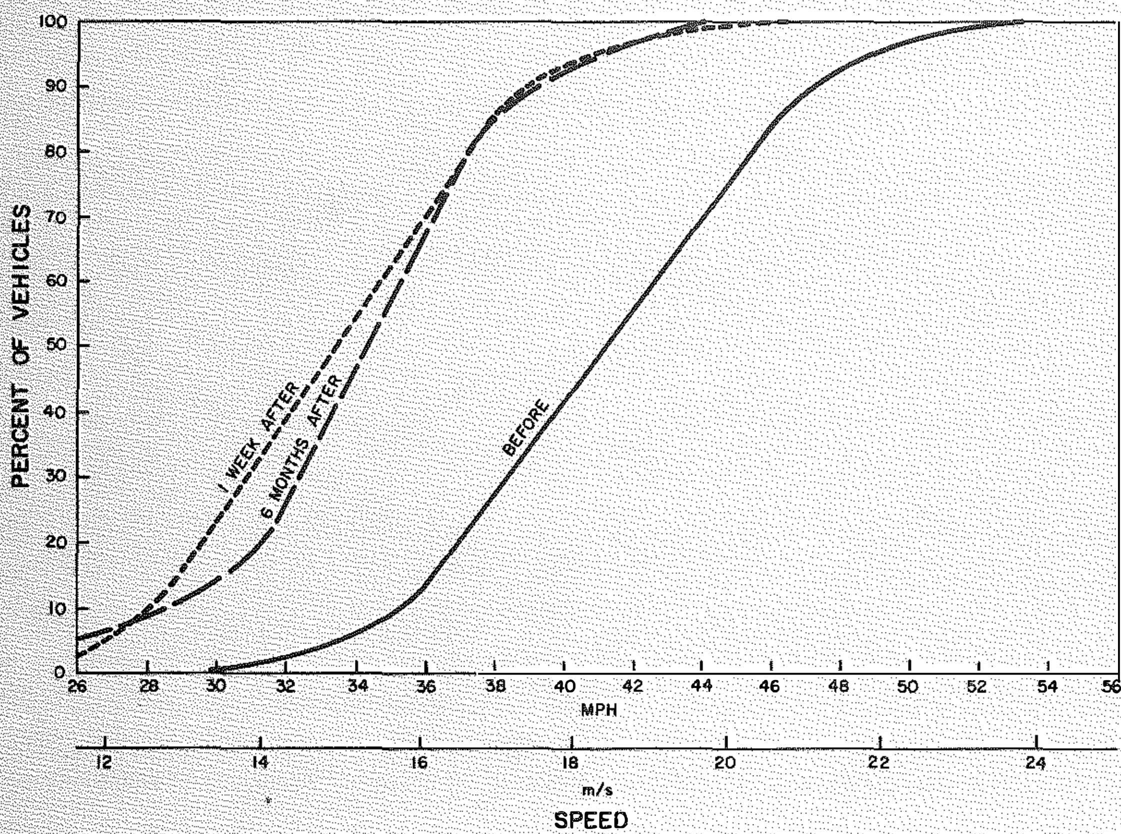


Figure 11. Nighttime Speeds at Beginning of Curve.

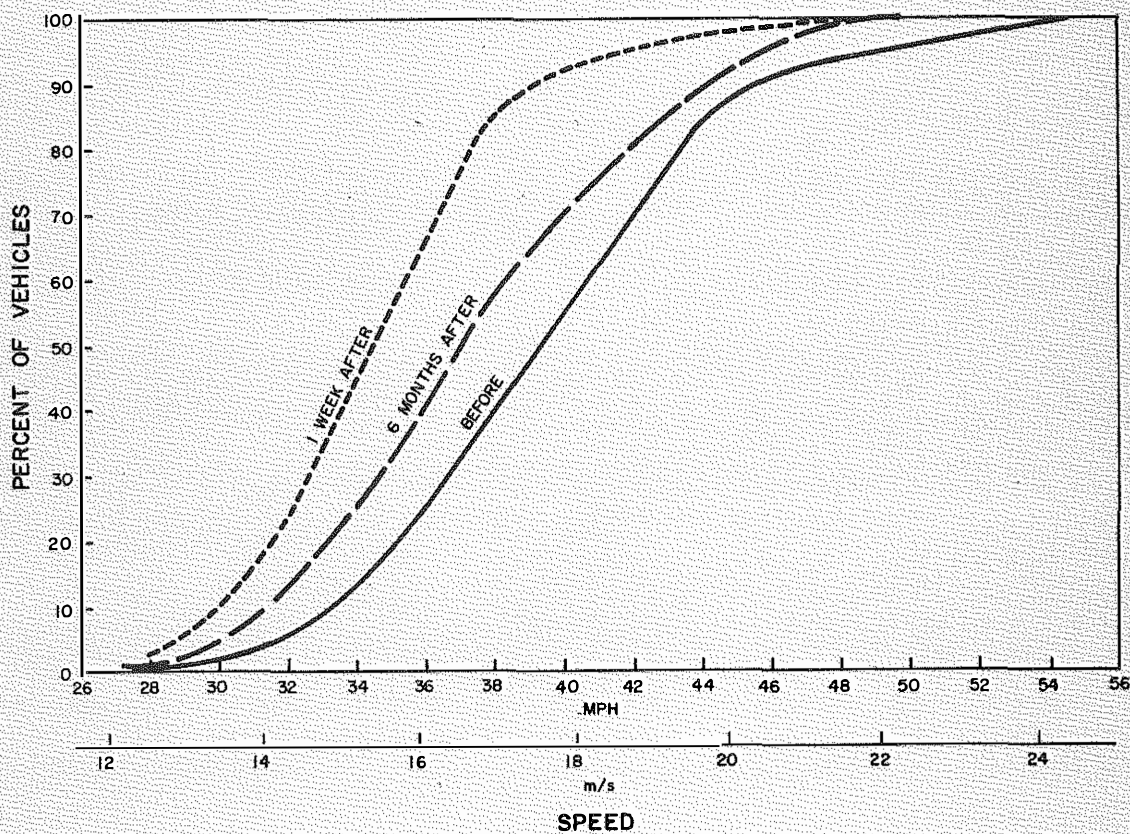


TABLE 3. PERCENTAGE OF VEHICLES APPLYING BRAKES UPON ENTERING THE CURVE (DAYTIME)

TIME PERIOD	BRAKELIGHT APPLICATIONS (PERCENT)
Before Installation	80.8
1 Week after Installation	68.3
6 Months after Installation	71.0

Figure 12. Test Location I Year after Installation of Stripes.

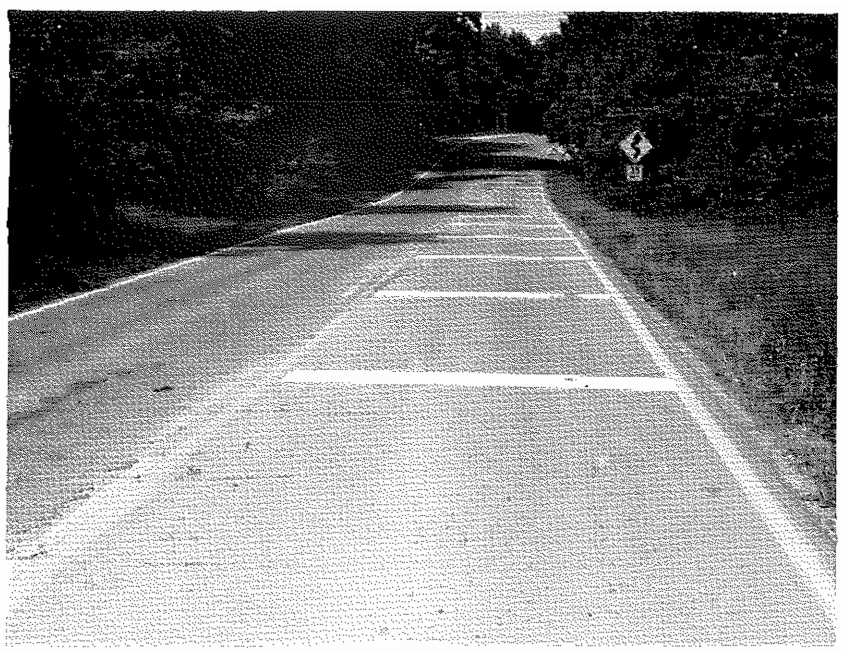
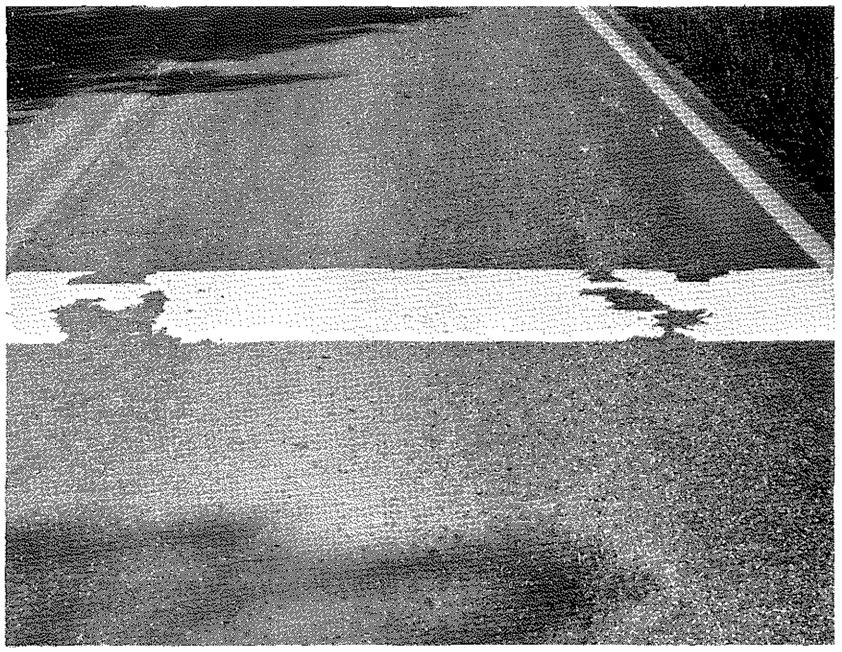


Figure 13. Damaged Marking Stripe.



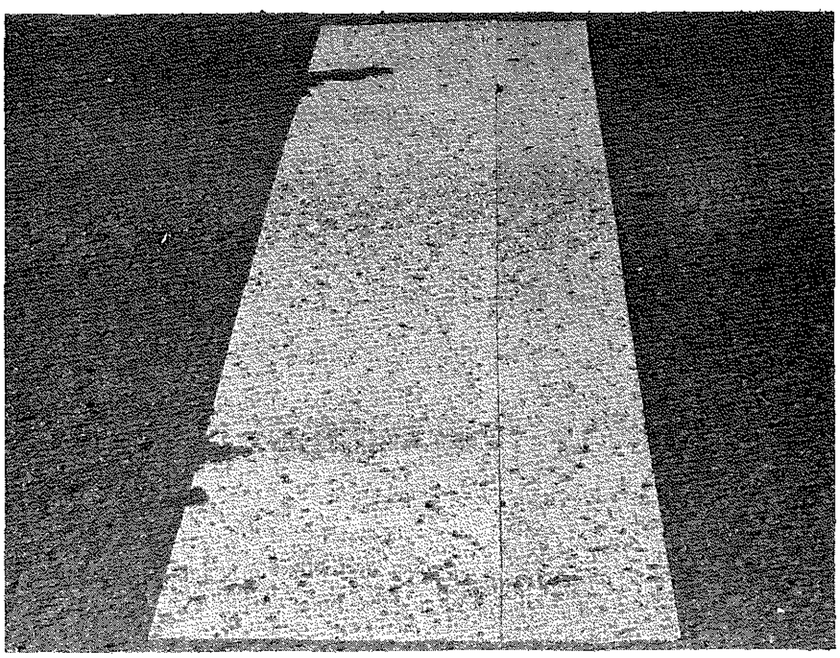
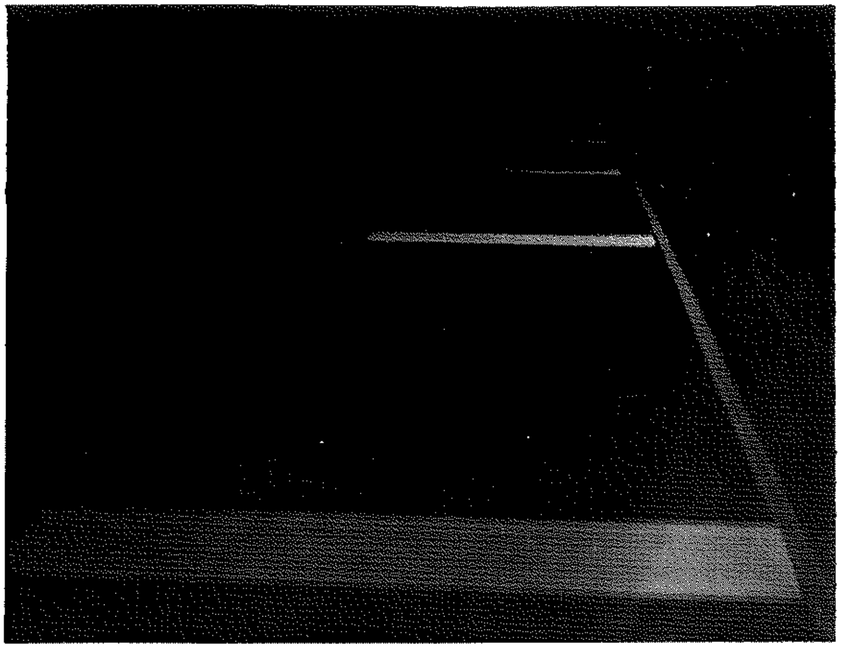


Figure 14. Minor Damage to Marking Stripe.

Figure 15. Nighttime Photograph of Stripes, 1 Month after Installation.



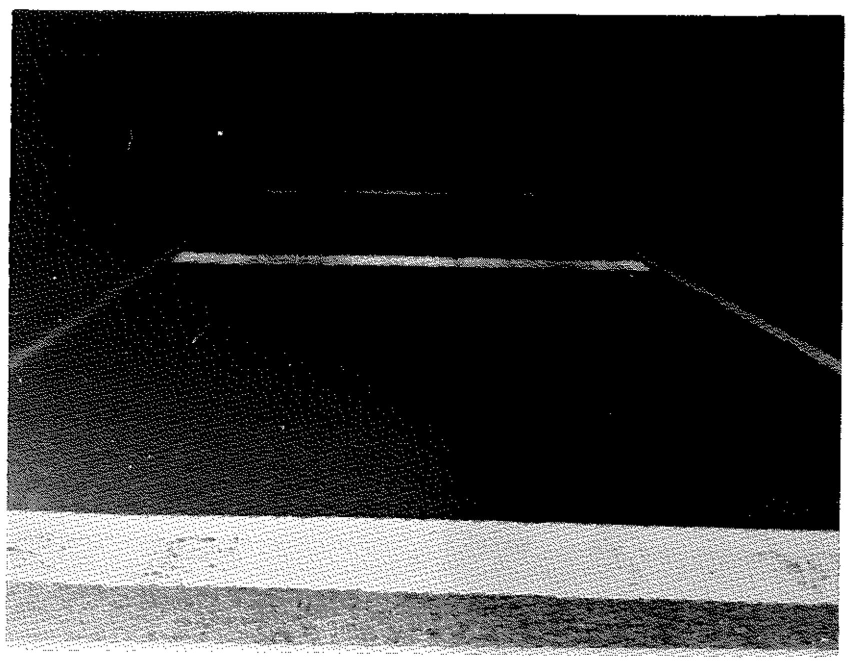


Figure 16. Nighttime Photograph of Stripes, 2 Months after Installation.

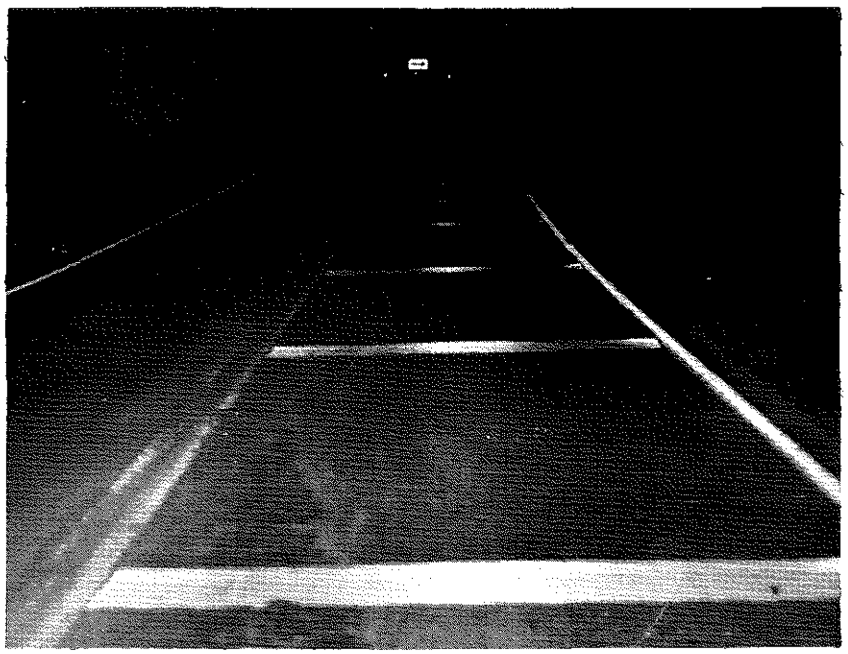


Figure 17. Nighttime Photograph of Stripes, 1 Year after Installation.

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APPENDIX A

STATISTICAL TESTS FOR SPEED DATA

The normal approximation was used to evaluate the significance between the average speed reductions and speed at the beginning of the curve *(9)*. If the sample size is sufficiently large ($n \geq 30$) and both $\bar{x}_1$ and $\bar{x}_2$ (sample means from the before and after studies, respectively) are mean values of samples from populations having the same distribution (no significant difference in before or after population), the value $(\bar{x}_1 - \bar{x}_2)$ approaches a mean of 0 and a standard deviation of σ_D. The value σ_D is given by

$$\sigma_D = \sqrt{(S_1{}^2/n_1) + (S_2{}^2/n_2)}$$

where S = variance and
n = sample size.

Given that $(\bar{x}_1 - \bar{x}_2)$ is greater than 2.576 σ_D, it is at most 0.5 percent probable that this difference occurred by chance, if the two samples are representative of the same distribution. The assumption that $\bar{x}_1$ and $\bar{x}_2$ are from the same distribution is, therefore, rejected, and the difference observed is taken as significant ($P = 0.995$). The following tables give the calculated values:

TABLE A1. STATISTICAL TESTS FOR SPEED REDUCTIONS

COMPARISON	N_1	$\bar{x}_1$	σ_1	N_2	$\bar{x}_2$	σ_2	σ_D	$2.576\,\sigma_D$	$\bar{x}_1 - \bar{x}_2$	SIGNIFICANT
Day -- Before to 1 Week After	97	8.5	2.92	98	15.3	3.34	0.45	1.16	6.8	Yes
Day -- Before to 6 Months After	97	8.5	2.92	99	12.3	2.87	0.41	1.06	3.8	Yes
Night -- Before to 1 Week After	79	2.4	4.55	77	9.3	4.05	0.69	1.78	6.9	Yes
Night -- Before to 6 Months After	79	2.4	4.55	101	6.8	4.02	0.65	1.67	4.4	Yes

TABLE A2. STATISTICAL TESTS FOR SPEEDS AT START OF CURVE

COMPARISON	N_1	$\bar{x}_1$	σ_1	N_2	$\bar{x}_2$	σ_2	σ_D	$2.576\,\sigma_D$	$\bar{x}_1 - \bar{x}_2$	SIGNIFICANT
Day -- Before to 1 Week After	210	41.3	4.79	200	33.9	4.36	0.45	1.16	7.4	Yes
Day -- Before to 6 Months After	210	41.3	4.79	108	34.8	4.26	0.53	1.37	6.5	Yes
Night -- Before to 1 Week After	101	40.5	5.46	77	35.1	4.28	0.73	1.88	5.4	Yes
Night -- Before to 6 Months After	101	40.5	5.46	108	38.1	4.94	0.72	1.85	2.4	Yes

APPENDIX B

STATISTICAL TESTS FOR BRAKELIGHT DATA

Statistical tests were used to compare two observed proportions *(10)*. The case where the sample sizes are unequal and large was used. Statistical procedures answered the question: Does the characteristic proportion for product B exceed that for product A? The proportions referred to were the number of brakelight applications in the total volume of vehicles before and after installation of the transverse markings.

To perform this test, the observed classification of the items was recorded in a two-row, two-column table as shown in Table B1. For purposes of this study, n_B and n_A were the total number of vehicles in the period before and after installation of the stripes, respectively. The incidents of brakelight applications were r_A and r_B; s_A and s_B were incidents not involving a brakelight application. The procedure and calculations involved were as follows:

1. Choose a, the significance level of the test.
2. Look up ${x_{1-2a}}^2$ for one degree of freedom.
3. Compute $X^2 = [n\ [|r_A s_B - r_B S_A| - n/2]^2]$ $/\ (n_A rn_B s)$,

   $P_A = r_A/n_A$,

   and

   $P_B = r_B/n_B$.
4. If $x^2 \geqslant {x_{1-2a}}^2$ and P_B is larger than P_A, decide that P_B exceeds P_A; otherwise, there is no reason to believe the proportions differ. Results of the statistical tests are given in Table B2.

TABLE B1. OBSERVED FREQUENCIES FROM TWO SAMPLES IN TWO MUTUALLY EXCLUSIVE CATEGORIES (A 2 X 2 TABLE)

	CATEGORY I	CATEGORY II	TOTAL
Sample from A	r_A	s_A	$n_A = r_A + s_A$
Sample from B	r_B	s_B	$n_B = r_B + s_B$
Total	r	s	n

TABLE B2. STATISTICAL TESTS FOR BRAKELIGHT APPLICATIONS

COMPARISON	a	r_B	s_B	n_B	P_B	r_A	s_A	n_A	P_A	x^2	x^2_{1-2a}	SIGNIFICANT
Before to 1 Week After	0.025	84	20	104	.81	82	38	120	.68	3.87	3.84	Yes
Before to 6 Months After	0.05	84	20	104	.81	76	31	107	.71	2.22	2.71	No