

Research Report

539

**TRANSVERSE PAVEMENT MARKINGS FOR SPEED  
CONTROL AND ACCIDENT REDUCTION**

by

**Kenneth R. Agent  
Research Engineer Chief**

**Division of Research  
Bureau of Highways  
DEPARTMENT OF TRANSPORTATION  
Commonwealth of Kentucky**

**offered for publication by  
the Transportation Research Board**

**February 1980**

## 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 intuitive. The objective of this study was to determine if these markings would affect speeds and accidents at a field installation.

## 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, Kentucky, was selected (ADT = 4,890). The problem curve is at the beginning of a 1.6-km (1-mile) section which has been extremely hazardous. The location had been identified as a high-accident location and conventional signing and marking had been installed. In the preceding 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 through operational measures.

### LAYOUT OF MARKINGS

In rural areas, warning devices should normally be placed about 229 m (750 feet) in advance of the hazard (5). The total length of roadway to be marked should, therefore, be about 229 m (750 feet). 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 0.9 m/s per sec (2 mph per sec) can be achieved with very light braking. Deceleration in gear alone generally results in overall rates between 0.4 and 0.7 m/s per sec (1.0 and 1.5 mph per sec) (6). It would be desirable to create a situation where a minimum of braking would be necessary. The speed ( $V_1$ ) at the beginning of the markings was assumed to be the speed limit (25 m/s (55 mph)). The warning signs in advance of the curve had an advisory speed ( $V_2$ ) of 16 m/s (35 mph). A design was developed with a  $D$  of 247 m (810 feet). This gives a  $d$  of 0.75 m/s per sec (1.67 mph per sec) assuming a  $V_1$  of 25 m/s (55 mph) and a  $V_2$  of 16 m/s (35 mph).

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 stripes were installed in this manner. 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 25 m/s (55 mph) would be approximately 12 m (40 feet). The spacing would then gradually decrease to approximately 7.6 m (25 feet) for a speed of 16 m/s (35 mph at the curve). The spacing decreased to a minimum of 4.6 m (15 feet) because it was desired to slow the vehicle as much as possible. The width of the stripes was also decreased to a minimum width of 0.6 m (2 feet) closer to the curve so that the stripes would appear the same width as the vehicle slowed. A total of 30 stripes were installed over a distance of 247 m (810 feet) in advance of the beginning of the curve. Reflective tape was used for the markings.

#### DATA COLLECTION

Accident data for a 6-year period before installation of the markings as well as the year after installation were obtained. Resurfacing in the second year after installation of the markings prevented collection of additional accident data. 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.

### 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 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 in the following analysis. 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.

The history of accidents in which the eastbound vehicle was at fault was summarized. 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.

#### **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. The average nighttime speed reduction increased from 1.1 m/s (2.4 mph) before to 4.2 m/s (9.3 mph) in the first week after installation and then decreased slightly to 3.0 m/s (6.8 mph) in the 6-months-after period. The average daytime speed reduction increased from 3.8 m/s (8.5 mph) before to 6.8 m/s (15.3 mph) in the first week after and then decreased to 5.5 m/s (12.3 mph) in the 6-months-after period. 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).

The distribution of speed reductions for day and night conditions was determined. It was 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, nighttime 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 0.6 m/s (1.4 mph) 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). 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. The average nighttime speeds decreased from 18.1 m/s (40.5 mph) before to 15.7 m/s (35.1 mph) in the 1-week-after period; then it increased to 17.0 m/s (39.1 mph) in the 6-month-after period. The average daytime speeds decreased from 18.5 m/s (41.3 mph) to 15.2 m/s (33.9 mph) in the 1-week-after period and then increased to 15.6 m/s (34.8 mph) in the 6-months-after period.

Distribution of vehicle speeds at the beginning of the curve was determined. The before daytime speed data showed that about 10 percent of the vehicles slowed to the advisory speed of 16 m/s (35 mph) 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 16 m/s (35 mph) or less before installation of the markings. The percentage increased to 57 percent immediately after installation and 32 percent 6 months later.

#### **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. The total cost of the installation was approximately \$600.

A conservative estimate of the total benefits obtained from the markings would be the savings in accident costs in the year after installation. The markings would 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 National Safety Council accident cost figures, an average annual accident cost of \$42,000 for the 6 years before installation of the markings was calculated. Only one year of "after" accident data was available to approximate the accident cost. The three accidents in the 1-year period afterwards resulted in a cost of \$14,000. This yields a net savings of \$28,000. This amount compared to a total cost of \$600 gives a benefit-cost ratio of 45.9.

## PAVEMENT STRIPING TAPE PERFORMANCE

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. Most of the damage was considered minor. Nighttime observations showed slight wear in the wheel paths 2 months after installation. After 1 year, a significant amount of wear had taken place in the wheel paths, but the markings remained reflective.

## CONCLUSIONS

Results showed that transverse stripes can effectively reduce speeds. At the single site investigated, the obedience of drivers to this type of hazard warning was more effective than to signing alone. At the very least, they alert drivers to the upcoming hazard more effectively than signing. Further use of this traffic control method may 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 365 m (1,200 feet) may be desirable.

## REFERENCES

1. Denton, G. G.; *The Influence of Visual Pattern on Perceived Speed*, Transport and Road Research Laboratory Report LR 409, Crowthorne, Berkshire, 1971.
2. Denton, G. G.; *The Influence of Visual Pattern on Perceived Speed at Newbridge, M8 Midlothian*, Transport and Road Research Laboratory Report LR 531, Crowthorne, Berkshire, 1973.
3. Enustun, N.; *Three Experiments with Transverse Pavement Stripes and Rumble Bars*, Michigan Department of State Highways, October 1972.
4. Shinar, D.; McDowell, E. D.; and Rockwell, T. H.; *Improving Driver Performance on Curves in Rural Highways through Perceptual Changes*, College of Engineering, Ohio State University Project EES 428, December 1973.
5. **Manual on Uniform Traffic Control Devices for Streets and Highways**, U. S. Department of Transportation, Federal Highway Administration, 1971.
6. **A Policy on Geometric Design of Rural Highways**, American Association of State Highway Officials, 1965.
7. Agent, K. R.; Deacon, J. A.; and Deen, R. C.; *A High-Accident Spot-Improvement Program*, *Transportation Engineering Journal*, American Society of Civil Engineers, May

1976.

8. Agent, K. R.; and Deen, R. C., *Relationships between Roadway Geometrics and Accidents, Record 541*, Transportation Research Board, 1975.
9. Pignataro, L. J.; *Traffic Engineering Theory and Practice*, Prentice-Hall, Inc., 1973.