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Influence of Experimental Pavement Markings on Urban Freeway Exit-Ramp Traffic Speeds

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Motor vehicle crashes on curved roadway sections occur more frequently and tend to be more severe than those on straight sections. Speed is a significant factor in many crashes that occur on curves. The effects on traffic speeds of special pavement markings intended to reduce speeds on freeway exit ramps with horizontal curves were examined. An experimental pavement marking pattern was employed that narrowed the lane width of both the curve and a portion of the tangent section leading into the curve by use of a gradual inward taper of existing edgeline or exit gore pavement markings or both. Traffic speeds were analyzed before and after installation of the pavement markings at four experimental ramps in New York and Virginia. Results indicated that the markings were generally effective in reducing speeds of passenger vehicles and large trucks. The markings were associated with significant reductions in the percentages of passenger vehicles and large trucks exceeding posted exit-ramp advisory speeds.

Motor vehicle crashes occur more frequently on curves and tend to be more severe than crashes that occur on straight roadway sections. Troxel et al. analyzed data from the Fatality Analysis Reporting System and National Automotive Sampling System and reported that more than twice as many occupants were involved in crashes per kilometer of curved road than were on straight sections; furthermore, crashes on curves resulted in nearly three times as many fatalities per kilometer as those on straight sections (*1*).

Speed is a significant factor in crashes on curves, as well as in the severity of these crashes (*2*). Freeway exit ramps often are designed with horizontal curves, which can become crash prone when traffic speeds are excessive for ramp geometry. A study of large truck crashes on highway ramps concluded that crash risk is related to the magnitude of the difference between truck speeds on the highway approaching the ramp and the ramp's posted advisory safe speed (*3*). Urban interchanges have much higher crash rates than do rural interchanges (*4*). Therefore, it is important to promote traffic speeds that are appropriate for ramp geometry and to discourage excessive speeds, especially on urban freeways.

Design of horizontal alignment is based primarily on the laws of mechanics and driver capabilities. Design controls for curves are determined by establishing limits on the rate of superelevation (banking) and on the coefficient of side friction between tire and road (*5*). Ramps are a special problem because of their often extreme curvature and the presence of vehicles decelerating from high speeds. AASHTO has established policies on ramp design considerations but acknowledges that desirable ramp design speeds are not always practicable (*5*). Sudden changes from straight alignments to sharp curves should be avoided (*6*). Analyses of truck crashes in Washington State found that loop ramps in particular have high crash rates compared with crash rates of other ramp types (*7*).

The speed at which a vehicle enters a curve is related more to the speed of its approach than to the sharpness of the curve (*8*). The primary method used to control the speeds of vehicles entering curves from tangent approaches is the posting of black and yellow advisory curve warning or exit-ramp speed signs (*9*). Because drivers often exceed posted advisory speeds, some researchers have questioned the validity of the criteria used to set advisory speeds on curves (*10*). At potentially hazardous locations such as sudden changes from straight alignments to sharp curves on freeways and other high-speed roads, standard signage may not be enough.

Advance curve warning signs and advisory delineation signs are frequently used to control traffic speeds on curves. However, a large body of research suggests that such traffic signs are largely ineffective. For example, Zador et al. reported that use of post-mounted delineators and chevrons tends to increase nighttime speed distributions (*11*). Lyles (*12*) and Agent and Creasey (*13*) studied various sign treatments for reducing traffic speeds in the vicinity of horizontal curves and found that they generally were ineffective. There is some evidence that common warning signs are poorly understood by drivers (*14*).

Special signs have been developed that can detect excessive truck speeds and display warning messages to speeding truck drivers at freeway exit ramps prone to truck rollover (*15*, *16*). Although these devices are beneficial, they are expensive to deploy and maintain and are designed specifically for the special needs of large trucks. Limited research has been published on the feasibility of installation of special pavement markings in advance of hazardous curves for the purpose of reducing excessive traffic speeds. In two separate studies, experimental transverse pavement markings—intended to create an illusion of acceleration and prompt drivers to slow down—were placed across roads in advance of curves (*17*, *18*). These marking schemes were associated with reductions in traffic speeds. Rockwell et al. also reported reductions in traffic speeds, most notably high speeds, resulting from pavement markings designed to make roadways appear narrower at the beginning of curves (*19*). More recently, Retting and Farmer reported that an experimental pavement marking was effective in reducing traffic speeds in the vicinity of a sharp horizontal curve on a two-lane rural road (*20*). However, none of these studies address traffic speeds on freeway exit ramps.

The purpose of this study was to examine the effectiveness of special pavement markings intended to reduce speeds on urban freeway exit ramps with horizontal curves.

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METHODS

Setting

The study was conducted at four urban freeway exit ramps located in two communities: Fairfax County, Virginia (three ramps), and New York City (one ramp). Ramps were not identical in geometric design or layout of pavement markings before testing. At the entrance to each ramp, standard black and yellow advisory exit-ramp speed signs (*9*) were posted in accordance with respective state practices. The experimental pavement marking was intended to reinforce these existing advisory speeds.

Experimental Design

A before-and-after design with control was employed. At the Virginia ramps, traffic speeds were measured approximately 6 weeks before and 2 weeks after installation of the pavement markings. Traffic speeds were measured on the main highway also, approximately 152.4 m (500 ft) before the ramps. These upstream counters allowed analysis of highway speeds to identify and exclude time periods when traffic congestion impeded traffic flow and to control for factors that might affect speed, such as weather and seasonal variability in travel patterns. At the New York ramp, traffic speeds were measured approximately 6 weeks before and 2 weeks after installation of the pavement marking. Traffic speeds were also measured on the main highway, as well as at another ramp along the same freeway that did not have the pavement marking installed.

Experimental Treatment

An experimental pavement-marking pattern was employed that narrowed the lane width of the curve and a portion of the tangent section leading into the curve by use of a gradual inward taper of existing edgeline or exit gore pavement markings or both (Figures 1–4). At the Virginia ramps, thermoplastic marking materials were used, and glass beads were spread over the hot thermoplastic to enhance nighttime retroreflectivity. Also, temporary raised pavement markers were installed adjacent to the markings. At the New York ramp, the marking was installed by use of temporary (diluted) highway paint. Raised markers were not installed on the New York ramp because of the temporary nature of the paint employed at the site.

Instrumentation

Speed measurements were made by use of Timemark™ Delta Traffic Counters connected to pneumatic road tubes. Two road tubes were installed at each site and spaced 6.1-m (20-ft) apart. Janus™ software was used to process raw data from the traffic counters, including vehicle classification, gap, and speed. Measurement periods were free of precipitation. At each ramp, the road tubes were installed on the pavement in the vicinity of the exit gore and prior to the point of curvature.

Data Analysis

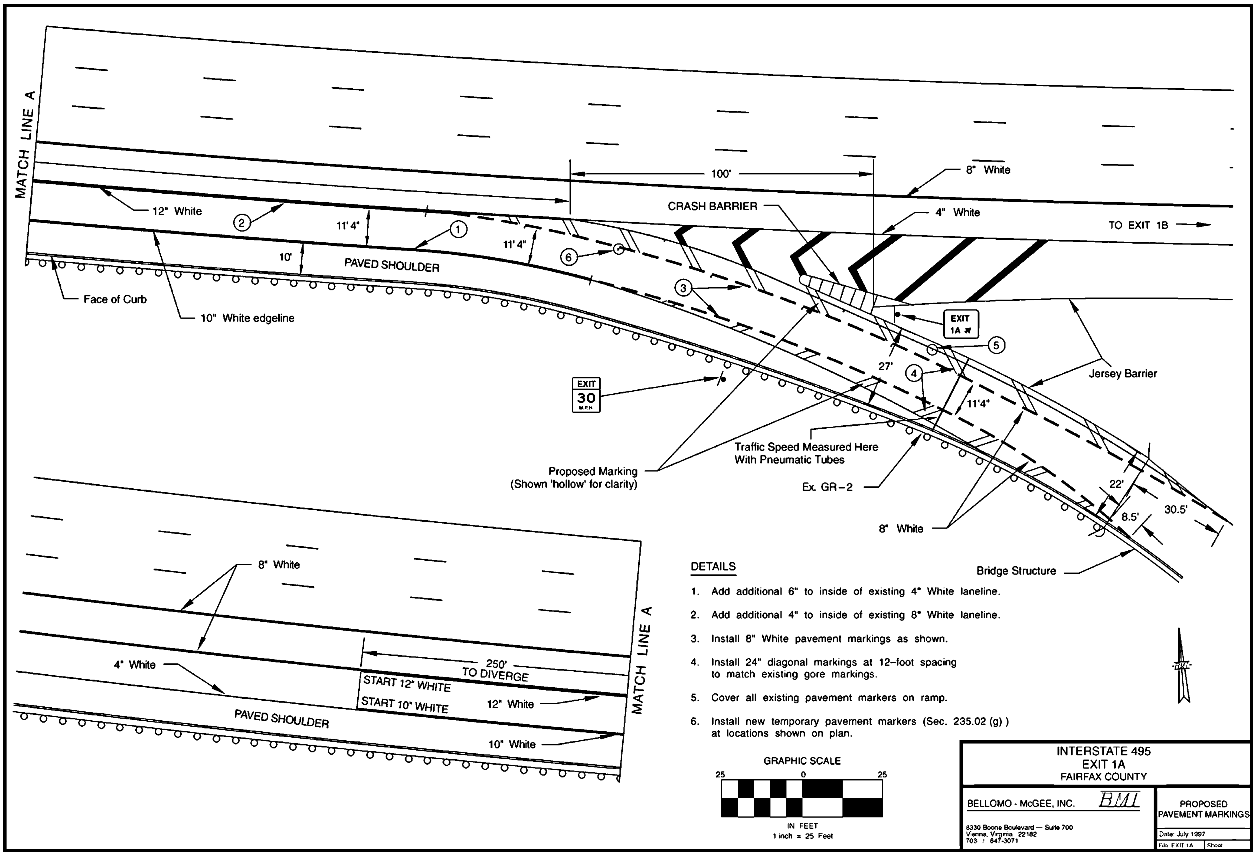
Speed data were analyzed for vehicles classified as passenger vehicles and large trucks based on vehicle wheelbase and number of axles. The total number of observations was 84,188 passenger vehicles (an average of 5,262 per site) and 3,557 large trucks (an average of 222 per site). A minimum gap of 3 s between vehicles was employed. Summary measures included mean speed, 90th percentile speed, and percentage of vehicles exceeding given speed thresholds. Logistic regression models were used to measure the effect of the pavement marking on the likelihood that a passenger vehicle exceeded the posted advisory speed by 16 km/h (10 mph) or that a large truck exceeded the posted advisory speed by 8 km/h (5 mph). For example, the odds of a passenger vehicle exceeding the advisory speed by more than 16 km/h (10 mph) was modeled on an exponential function of three indicator variables: whether or not the vehicle was on the ramp, whether or not the speed was measured after installation of the pavement marking, and whether or not the vehicle was on the ramp after installation of the pavement marking. Speed thresholds were set somewhat higher than the advisory speed limits because vehicle speeds were measured before points of curvature. Different thresholds for passenger vehicles and large trucks were selected to reflect differences in vehicle handling characteristics and operating speeds.

At Virginia Ramp B, there was a large and unexplained decrease in the number of large trucks observed by the speed monitoring equipment after installation of the pavement marking, compared with a modest increase in truck volume observed at the upstream counter. This may have been the result of equipment malfunction or misclassification of large trucks by the speed monitoring equipment. Therefore, large truck speeds are not reported for Virginia Ramp B.

RESULTS

Table 1 summarizes changes in mean speeds, 90th percentile speeds, and percentages of passenger vehicles exceeding posted advisory speeds by more than 16.1 km/h (10 mph) after installation of the pavement markings. Passenger vehicle speeds were reduced significantly at the New York ramp and at two Virginia ramps but remained unchanged at the third Virginia ramp. The proportion of passenger vehicles exceeding the posted speed by more than 16.1 km/h (10 mph) decreased from 83 to 66 percent at the New York ramp, from 40 to 27 percent at Virginia Ramp A, and from 27 to 21 percent at Virginia Ramp C. Significant changes in the proportion of passenger vehicles exceeding the posted speed by more than 16.1 km/h (10 mph) were not observed at Virginia Ramp B. During the same time periods at the Virginia upstream sites and at the New York control site, the percentages of passenger vehicles exceeding posted speeds by more than 16.1 km/h (10 mph) either remained the same or increased.

Table 2 summarizes changes in mean speeds, 90th percentile speeds, and percentages of large trucks exceeding posted advisory speeds by more than 8 km/h (5 mph) after installation of the pavement markings. Large truck speeds were reduced significantly at the New York ramp and at two Virginia ramps. The proportion of large trucks exceeding the posted speed by more than 8 km/h (5 mph) decreased from 77 to 55 percent at the New York ramp, from 35 to 18 percent at Virginia Ramp A, and from 49 to 30 percent at Virginia Ramp C. During the same time periods at the Virginia upstream sites and at the New York control site, the percentages of large trucks exceeding the posted speeds by more than 8 km/h (5 mph) either remained the same or increased. Large truck speeds are not reported for Virginia Ramp B because of the large and unexplained decrease in the number of trucks observed by the speed monitoring equipment. This decrease may have been caused by equipment malfunction or by misclassification of trucks by the speed monitoring equipment.



DETAILS

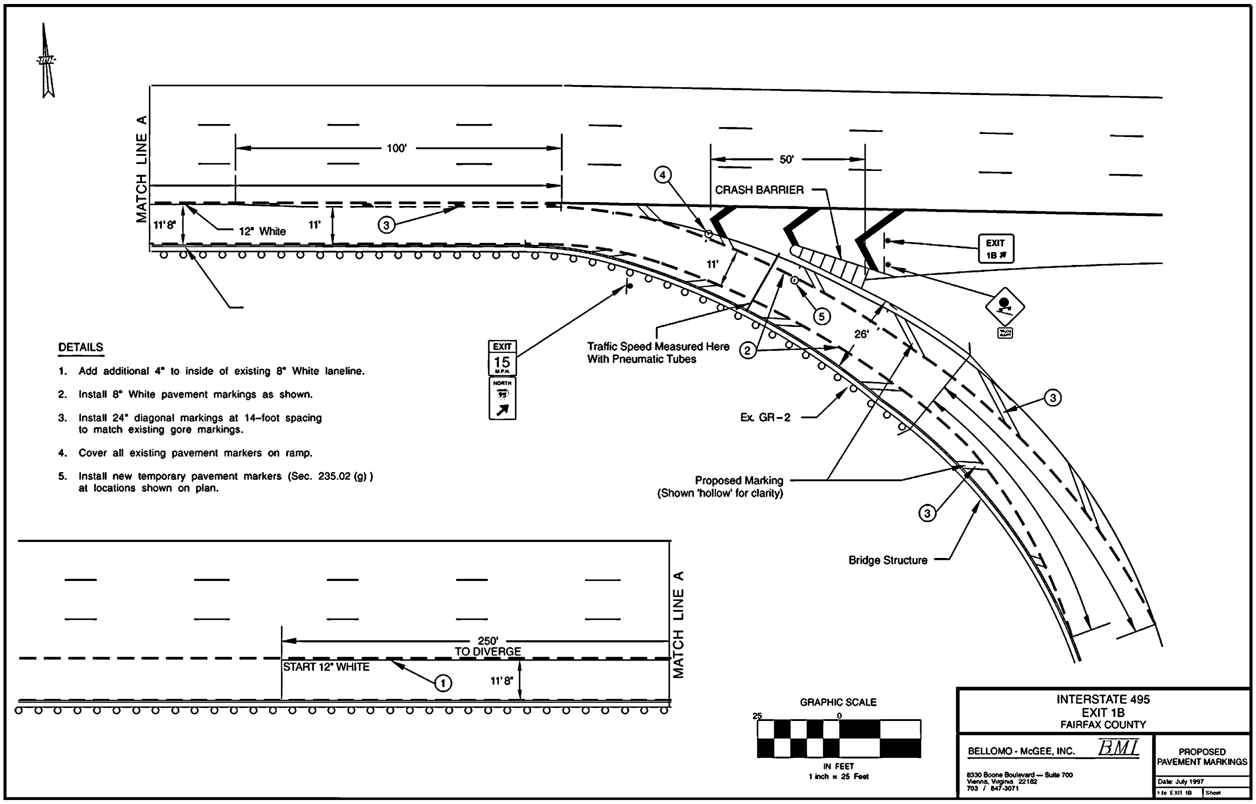
1. Add additional 6" to inside of existing 4" White laneline.
2. Add additional 4" to inside of existing 8" White laneline.
3. Install 8" White pavement markings as shown.
4. Install 24" diagonal markings at 12–foot spacing to match existing gore markings.
5. Cover all existing pavement markers on ramp.
6. Install new temporary pavement markers (Sec. 235.02 (g)) at locations shown on plan.

INTERSTATE 495
EXIT 1A
FAIRFAX COUNTY

BELLOMO - McGEE, INC. BMI
8330 Boone Boulevard — Suite 700
Vienna, Virginia 22182
703 / 847-3071

PROPOSED
PAVEMENT MARKINGS
Date: July 1997
File EXIT 1A
Sheet

FIGURE 1 Virginia Ramp A.



DETAILS

1. Add additional 4" to inside of existing 8" White laneline.
2. Install 8" White pavement markings as shown.
3. Install 24" diagonal markings at 14–foot spacing to match existing gore markings.
4. Cover all existing pavement markers on ramp.
5. Install new temporary pavement markers (Sec. 235.02 (g)) at locations shown on plan.

INTERSTATE 495
EXIT 1B
FAIRFAX COUNTY

BELLOMO - McGEE, INC. BMI
8330 Boone Boulevard — Suite 700
Vienna, Virginia 22182
703 / 847-3071

PROPOSED
PAVEMENT MARKINGS
Date: July 1997
File EXIT 1B
Sheet

FIGURE 2 Virginia Ramp B.

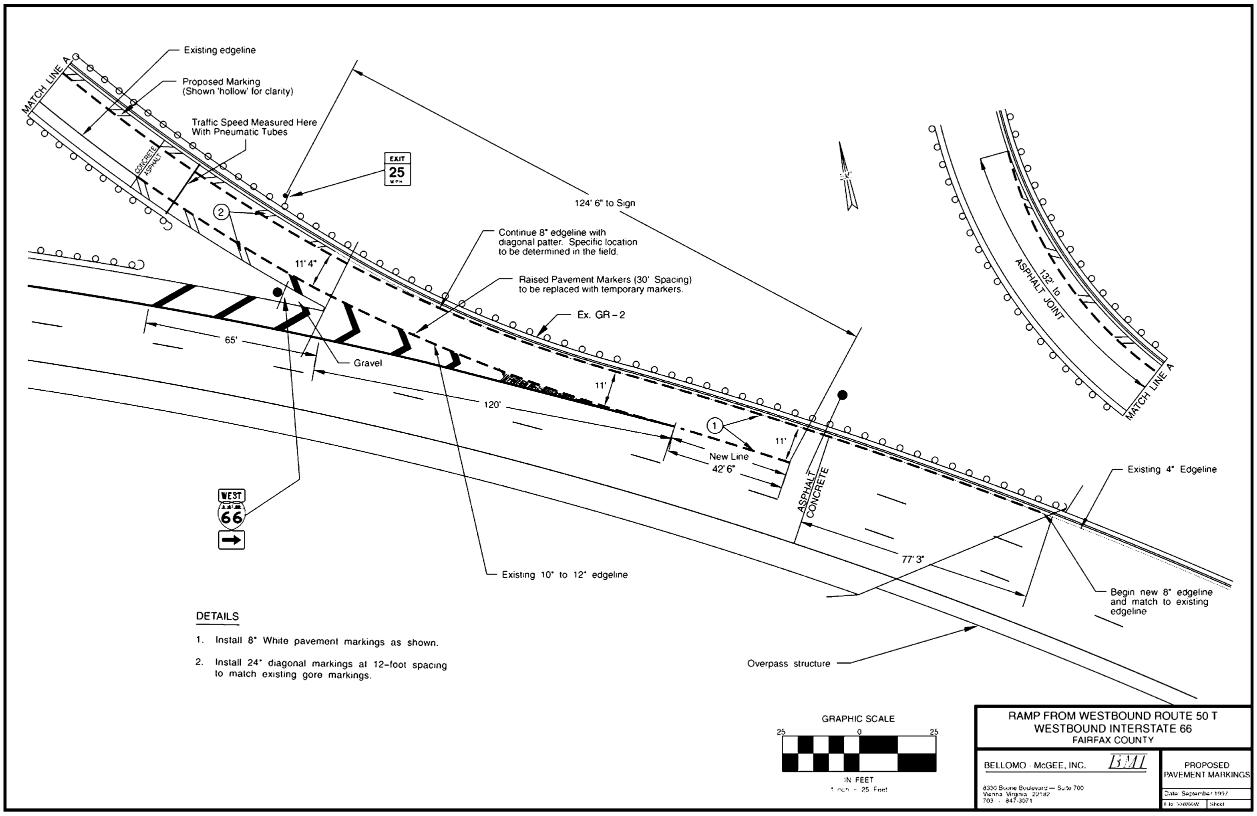
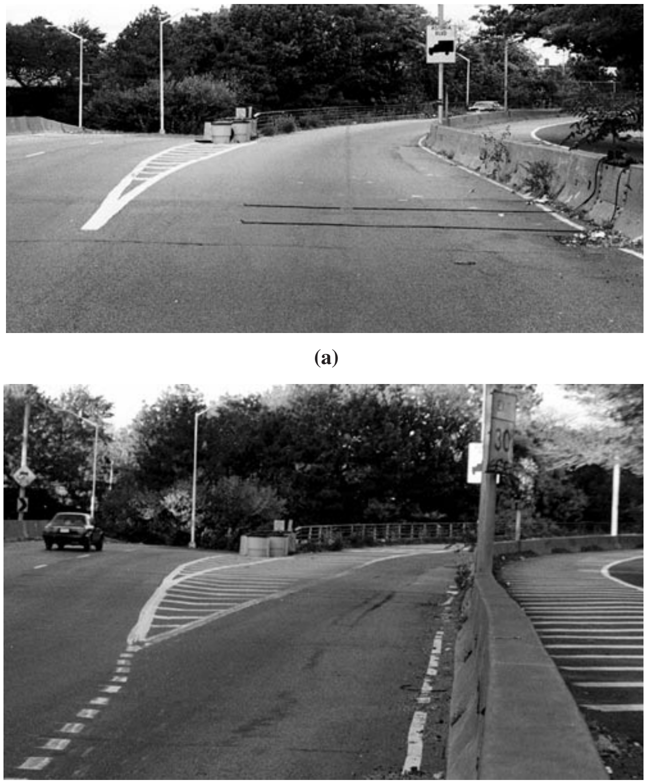


FIGURE 3 Virginia Ramp C.


(a)

(b)

FIGURE 4 New York experimental ramp, (*a*) before and (*b*) after.

DISCUSSION OF RESULTS

Motor vehicle crashes on curved freeway ramps are a significant and costly problem. Many factors contribute to such crashes, including driver impairment, fatigue, inattention, visual deficits, and speed. Although most driver factors are outside the direct influence of transportation engineers, it is apparent from the present study and prior research that strategically placed pavement markings can influence driver speed selection at the time that drivers enter curved roadway sections. The pavement markings used in this study were generally effective in decreasing speeds of passenger vehicles and large trucks approaching points of curvature. These markings were associated with significant reductions in the percentages of passenger vehicles and large trucks exceeding posted exit-ramp advisory speeds by at least 16 and 8 km/h (10 and 5 mph), respectively. However, traffic speeds were not reduced at one location (Virginia Ramp B). One explanation may be that on this ramp the road tubes were placed (and speeds measured) at a point before where markings could affect vehicle speed (road tubes could not be installed closer to the point of curvature because of the portland cement road surface).

The present research was limited by the small number of experimental ramps and the inability to distinguish short-term or potential novelty effects from long-term effects. However, even short-term effects are useful, because warning devices generally are designed for drivers unfamiliar with road dangers such as sudden changes from straight alignments to sharp curves. Reductions in average traffic speeds, and in the proportion of high traffic speeds reported in this study, are highly significant given the exponential relationship between fatality risk and change in velocity during collisions (*21*).

TABLE 1 Speeds of Passenger Vehicles Before and After Installation of Pavement Markings

Site	Location	Posted Advisory Speed (mph)	Period	Mean	Standard Deviation	90th Percentile	Percentage Exceeding Posted Advisory Speed by >10 mph
Virginia A	Ramp	30	Baseline	39.0	4.2	44.5	40
			After	37.5	4.1	42.5	27*
	Upstream	55	Baseline	57.7	5.4	64.8	8
			After	57.4	5.5	64.8	7
Virginia B	Ramp	15	Baseline	26.5	2.6	29.8	74
			After	26.6	2.6	29.8	75
	Upstream	55	Baseline	57.4	5.4	63.4	6
			After	57.4	5.5	64.8	7
Virginia C	Ramp	20	Baseline	28.3	2.7	31.7	27
			After	27.9	2.8	31.4	21*
	Upstream	55	Baseline	57.1	6.0	64.8	8
			After	59.7	6.8	67.7	18
New York	Experimental	20	Baseline	44.3	4.7	50.7	83
			After	42.2	5.7	49.5	66*
	Control	30	Baseline	30.2	4.5	35.1	51
			After	30.1	4.6	35.1	52

*Change was statistically significant at the 0.05 level of significance.
1 mph = 1.61 km/h.

TABLE 2 Speeds of Large Trucks Before and After Installation of Pavement Markings

Site	Location	Posted Advisory Speed (mph)	Period	Mean	Standard Deviation	90th Percentile	Percentage Exceeding Posted Advisory Speed by > 5 mph
Virginia A	Ramp	30	Baseline	33.5	3.8	38.2	35
			After	31.8	3.8	36.5	18*
	Upstream	55	Baseline	54.4	4.7	60.8	11
			After	54.7	5.3	60.8	14
Virginia C	Ramp	20	Baseline	24.4	3.2	28.6	49
			After	23.6	2.4	26.6	30*
	Upstream	55	Baseline	51.5	6.1	59.6	8
			After	55.0	6.5	63.4	24
New York	Experimental	20	Baseline	37.4	3.4	41.4	77
			After	35.5	4.0	40.6	55*
	Control	30	Baseline	25.8	4.0	30.0	58
			After	26.5	3.7	31.6	65

*Change was statistically significant at the 0.05 level of significance.
1 mph = 1.61 km/h.

Therefore, even seemingly small reductions in mean traffic speeds are likely to result in significant safety benefits.

In traffic-control device design, recognition and understanding of what drivers expect is important (*22*). If unusually sharp curves or sudden changes from straight alignments to sharp curves are not differentiated by special warnings, driver expectancy may be violated and drivers may not slow sufficiently. Rumble strips may also be useful for alerting drivers to certain roadway features such as sharp horizontal curves, at which drivers normally would reduce speed (*23*).

The most effective method for improving safety on hazardous ramps is roadway realignment. Geometric improvements such as curve flattening and superelevation have been associated with significant reductions in crashes and crash severity (*2*, *24–25*). However, these measures are not always feasible due to financial, environmental, and right-of-way restrictions. Special pavement markings, such as those evaluated in this study, that are capable of reducing speeds should be considered as an interim measure for potentially hazardous freeway ramps before road reconstruction and where adequate geometric design features cannot be provided.

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REFERENCES

1. Troxel, L. A., M. H. Ray, and J. F. Carney. *Accident Data Analysis of Side-Impact, Fixed-Object Collisions*. Report DOT-RD-91-122. FHWA, U.S. Department of Transportation, Washington, D.C., 1994.
2. Zegeer, C. V., R. Stewart, D. Reinfurt, F. Council, T. Neuman, E. Hamilton, T. Miller, and W. Hunter. *Cost Effective Geometric Improvements for Safety Upgrading on Horizontal Curves*. Report DOT-RD-90-021. FHWA, U.S. Department of Transportation, Washington, D.C., 1990.
3. Garber, N., M. A. Chowdhury, and R. Kalaputapu. *Accident Characteristics of Large Trucks on Highway Ramps*. AAA Foundation for Traffic Safety, Washington, D.C., 1992.
4. Cirillo, J. A. Interstate System Accident Research—Study II. In *Highway Research Record 188*, HRB, National Research Council, Washington, D.C., 1967, pp. 1–7.
5. *A Policy on Geometric Design of Highways and Streets*. AASHTO, Washington, D.C., 1990.
6. Twomey, J. M., M. L. Heckman, and J. C. Hayward. *Safety Effectiveness of Highway Design Features, Volume IV: Interchanges*. Report DOT-RD-91-047. FHWA, U.S. Department of Transportation, Washington, D.C., 1992.
7. Janson, B. N., W. Awad, J. Robles, J. Kononov, and B. Pinkerton. Truck Accidents at Freeway Ramps: Data Analysis and High-Risk Site Identification. *Journal of Transportation and Statistics*, Vol. 1, No. 1, January 1998, pp. 75–92.
8. Puvanachandran, V. M. Effect of Road Curvature on Accident Frequency: Determining Design Speeds to Improve Local Curves. *Road and Transport Research*, Vol. 4, 1995, pp. 76–83.
9. *Manual on Uniform Traffic Control Devices*. Report DOT-SA-89-006. FHWA, U.S. Department of Transportation, Washington, D.C., 1988.
10. Chowdhury, M. A., D. Warren, H. Bissell, and S. Taori. Are the Criteria for Setting Advisory Speeds on Curves Still Relevant? *ITE Journal*, Vol. 68, No. 2, 1998, pp. 32–45.
11. Zador, P. L., H. S. Stein, P. H. Wright, and J. W. Hall. Effects of Chevrons, Post-Mounted Delineators, and Raised Pavement Markers on Driver Behavior at Roadway Curves. In *Transportation Research Record 1114,* TRB, National Research Council, Washington, D.C., 1987, pp. 1–10.
12. Lyles, R. W. *An Evaluation of Warning and Regulatory Signs for Curves on Rural Roads*. Report DOT-RO-80-009. FHWA, U.S. Department of Transportation, Washington, D.C., 1980.
13. Agent, K. R., and T. Creasey. *Delineation of Horizontal Curves—Interim Report*. Report UK-TRP-864. University of Kentucky, Lexington, 1986.
14. Stokes, R. W., M. J. Rys, and E. R. Russell. Motorist Understanding of Selected Warning Signs. *ITE Journal*, Vol. 66, No. 8, 1996, pp. 36–41.
15. Freedman, M., P. Olson, and P. L. Zador. *Speed Actuated Rollover Advisory Signs for Trucks on Highway Exit Ramps*. Insurance Institute for Highway Safety, Arlington, Va., 1992.
16. Strickland, R. R., and H. W. McGee. Evaluation Results of Three Prototype Automatic Truck Rollover Warning Systems. In *Transportation Research Record 1628*, TRB, National Research Council, Washington, D.C., 1998, pp. 41–49.
17. Agent, K. R. *Transverse Pavement Markings for Speed Control and Accident Reduction*. Kentucky Department of Transportation, Lexington, 1975.
18. Hungerford, J. C., and T. H. Rockwell. *Modification of Driver Behavior by Use of Novel Roadway Delineation Systems*. Report HS-031-121. U.S. Department of Transportation, Washington, D.C., 1980.
19. Rockwell, T. H., J. Malecki, and D. Shinar. *Improving Driver Performance on Rural Curves through Perceptual Changes—Phase III*. Ohio Department of Transportation, Columbus, 1975.
20. Retting, R. A., and C. M. Farmer. Use of Pavement Markings to Reduce Excessive Traffic Speeds on Hazardous Curves. *ITE Journal*, Vol. 68, No. 9, September 1998, pp. 30–36.
21. Joksch, H. C. Velocity Change and Fatality Risk in a Crash—A Rule of Thumb. *Accident Analysis and Prevention*, Vol. 25, No. 1, 1993, pp. 103–104.
22. Alexander, G. J., and H. Lunenfeld. *Driver Expectancy in Highway Design and Traffic Operations*. Report DOT-TO-86-1. FHWA, U.S. Department of Transportation, Washington, D.C., 1986.
23. Harwood, D. W. *NCHRP Synthesis of Highway Practice 191: Use of Rumble Strips to Enhance Safety*. TRB, National Research Council, Washington, D.C., 1993.
24. Zegeer, C. V., J. M. Twomey, M. L. Heckman, and J. C. Hayward. *Safety Effectiveness of Highway Design Features, Volume II: Alignment*. Report DOT-RD-91-045. FHWA, U.S. Department of Transportation, Washington, D.C., 1992.
25. McGee, H. W., W. E. Hughes, and K. Daily. *NCHRP Report 374: Effect of Highway Standards on Safety*. TRB, National Research Council, Washington, D.C., 1995.

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