Improving Work Zone Delineation on Limited Access Highways

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The purpose of this study was to investigate vehicle guidance through work zones by evaluating the effectiveness of two primary components of traffic control relative to delineation. First, a comparison of the steady-burn lights now used on top of temporary concrete barriers was made with experimental reflectorized panels. Second, the addition of closely spaced, raised pavement markers as a supplement to the existing pavement markings was evaluated. The study was limited to work zones on Interstates and four-lane highways. The results of this investigation have led to the recommendation that (a) steady-burn lights on temporary concrete barricades should be replaced with reflectorized panels fabricated with high-intensity sheeting and placed along the tangent sections only and (b) closely spaced, raised pavement markers should be used as a supplement to existing pavement striping in areas where the roadway alignment changes.

With traffic volumes increasing and many roads operating at or near capacity, the upsurge in highway construction, coupled with the rehabilitation of existing facilities, will result in greater exposure of motorists to work zone activities.

The seriousness of the problem of safety in work zones is reflected in FHWA statistics that show work zone fatalities rising from 489 in 1982 to 678 in 1985. Virginia statistics show that 29 people died and 167 were seriously injured in work zone accidents in 1985. Work zone safety is therefore of high priority, and it is important to find ways of protecting the motoring public and the work force.

One way of increasing work zone safety is to provide clear and positive guidance for motorists approaching and traversing the area. Whenever a work zone is present, motorists are required to travel a section of highway that may deviate from their expected travel path because of narrow lanes, closed lanes, and detours.

The magnitude of the problem is demonstrated by the following list, which encompasses the sources of confusion prevalent within work zones:

- Roadway geometry and alignment are different from the original and expected layout.
- There are conflicting travel cues, including different pavement colors and textures; pavement joints are not parallel to traffic flow or are not between lanes of travel.
- Old pavement markings often have not been erased, and erased markings create different roadway color and texture.
- There is a lack of visibility because of weather, lighting, dirt, and worn pavement markings.
- There is a lack of uniform application of markings within similar work zones.
- Drivers' views of markings are obstructed by a high volume of traffic or by trucks.
- Opposing headlight glare is greater than normal.

All of these sources of confusion impose an added burden on drivers at the same time that they are forced to perform a maneuver that may be unfamiliar and unexpected.

Therefore, it is important that every effort be made to reliably indicate the direction of road alignment and the severity of any change in direction. The *Manual on Uniform Traffic Control Devices* (MUTCD) states: "The intended vehicle path should be clearly defined during day, night, and twilight periods under both wet and dry pavement conditions."

The Virginia Department of Transportation provides an array of traffic control devices in work zones including signs, pavement markings, delineators, steady-burn lights, and barriers, all of which define travel lanes. Two components of this traffic control system that influence motorist guidance are steady-burn lights placed on top of the concrete barriers and pavement markings placed on the roadway. Because of the importance of using optimal delineation techniques in work zones, the effectiveness of these two traffic control systems was investigated.

Steady-Burn Lights

Steady-burn lights are used in Virginia to help delineate the vehicle path through and around obstructions in a construction or maintenance area. They are placed on top of precast concrete traffic barriers, at 80-ft centers on the barrier taper (between chevrons) and tangent sections. Although the steady-burn lights are quite visible, there are several reasons to questions their use:

- Lights are dependent on batteries, and thus require maintenance. When a light burns out, the 160-ft spacing leaves partial and often confusing guidance.
- Many states use steady-burn lights on a limited basis. For example, the New Jersey Department of Transportation (DOT) found that the use of 6- × 12-in. reflectorized panels instead of steady-burn lights caused no decrease in the proportion of vehicles using the lane adjacent to the temporary construction barrier and caused no damage in the mean speed and speed variance. The New Jersey DOT has been using the reflectorized panels on tangent sections of temporary concrete barriers for 5 years and has reported no problems. Lights are still used in the taper area.

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- Steady-burn lights cost from \$0.70 to \$1.40 per light per day.
- Recent research by the Virginia Transportation Research Council investigated the use of reflectorized panels as concrete barricade delineators (as a substitute for lights). It was found that the devices were feasible in terms of application and cost.

Because of these concerns, the possibility of replacing the steady-burn lights with reflectorized panels was investigated.

Pavement Markings

Pavement markings serve an important function because they help provide smooth, safe transitions from one lane to another, onto a bypass or detour, or into a reduced width of traveled way. Pavement striping is primarily used to clearly define the intended vehicle path during day, night, and twilight periods under both wet and dry pavement conditions.

One technique that can be used to enhance work zone delineation involves the use of raised pavement markers as a supplement to the pavement striping. These markers are bright and protrude above the road surface, providing improved visibility, especially during hazardous wet pavement conditions at night. In a previous study (*1*), it was the consensus of 11 highway agencies that the use of raised pavement markers in high-hazard locations enhanced the delineation and improved the overall safety of the locations. This study and many others (*2–4*) have been concerned with the advantages of using raised markers for roadway delineation; however, it is felt that there is still room for improvement in techniques for work zone delineation. The state of Virginia recently conducted preliminary studies using different raised marker devices and spacing as a supplement to existing edge line markings. These techniques provided positive guidance in the transition areas.

PURPOSE AND SCOPE

The purpose of this study was to investigate vehicle guidance through work zones by evaluating the effectiveness of two primary components of traffic control relative to delineation. First, a comparison was made between the steady-burn lights now used on top of temporary concrete barriers and experimental reflectorized panels. Only tangent sections of the work area were considered (no transitions). Second, the addition of closely spaced raised pavement markers as a supplement to the existing pavement markings was evaluated. Observations were limited to areas where the roadway alignment deviated from the original, i.e., lane and road transitions and detours. The study was also limited to work zones on Interstates and four-lane highways.

STEADY-BURN LIGHTS

Steady-burn lights and reflectorized panels were placed on top of temporary concrete barriers along the tangent sections only. These devices (see Figure 1) were compared at two sites. Site 1 (see Figure 2) was a four-lane divided highway with two lanes closed; therefore, the two southbound lanes carried two-way traffic separated by temporary concrete barriers on which the lights and panels were placed. The barrier was placed on the left side of traffic, and 37 delineators were spaced at 72-ft intervals.

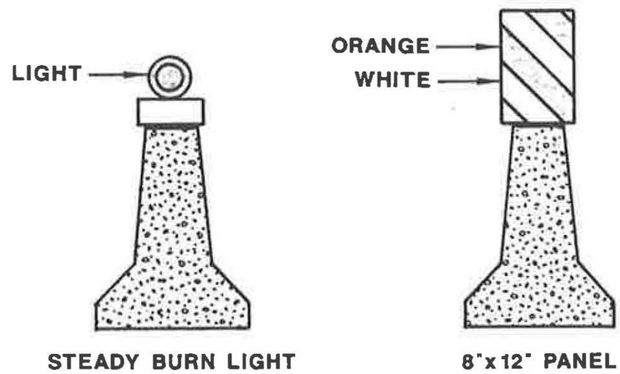

FIGURE 1 Concrete barrier delineators.

FIGURE 2 Site 1, Route 29, Leon, Virginia.

Site 2 (see Figure 3) was an Interstate highway that had temporary concrete barriers placed on the right shoulder. There were 17 delineators spaced 48 ft apart on top of the temporary concrete barricade. Old centerline markings, although partially visible during the day, were not expected to influence driver behavior at night.

Procedure

To measure the effectiveness of the steady-burn lights and reflectorized panels, traffic flow data were collected using a system of traffic counters with rubber tubes:

- *Vehicle Speed.* Vehicle speeds were recorded using two tubes as a speed trap.
- *Vehicle Placement.* The placement of vehicles relative to the lane line next to the concrete barrier was recorded using tubes of different lengths.

All data were collected on weekdays between the hours of darkness and 5:00 a.m. Videotapes were made of the test sections for the purpose of documentation.

FIGURE 3 Site 2, Interstate 85, Petersburg, Virginia.

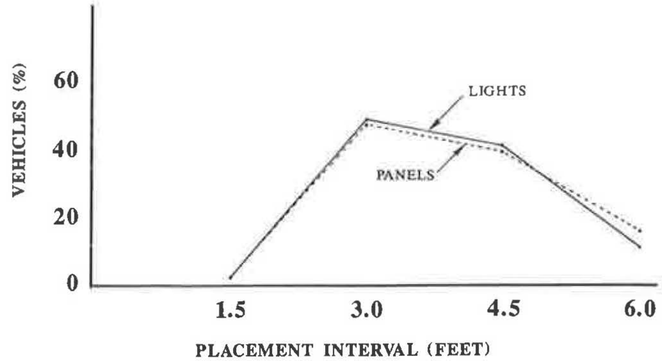

FIGURE 4 Percent vehicle placement from 8:00 p.m. to 1:00 a.m. (Site 1—Leon).

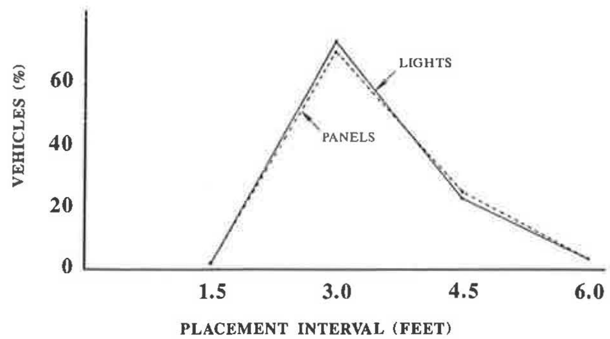

FIGURE 5 Percent vehicle placement from 1:00 a.m. to 5:00 p.m. (Site 1—Leon).

Results

Vehicle Placement

Vehicle placement was determined at Site 1 by observing the number of vehicles at 0- to 1.5-, 1.5- to 3.0-, 3.0- to 4.5-, and 4.5- to 6.0-ft intervals from the edgeline for each delineation treatment. Figures 4 and 5 show the percentage of vehicles within each interval from 8:00 p.m. to 1:00 a.m. and from 1:00 a.m. to 5:00 a.m., respectively. Data were collected for two weekdays for each time period and each set of delineators. The results indicated no difference in vehicle placement using the steady-burn lights or the reflectorized panels. It is interesting to note that there was a difference in placement between the two time intervals, probably because of heavy truck traffic during the early morning hours.

Vehicle placement from 9:00 p.m. to 1:00 a.m. and 1:00 a.m. to 5:00 p.m. for the steady-burn lights and reflectorized panels at Site 2 is shown in Figures 6 and 7, respectively. Two weekdays of data were collected for each period and delineation treatment. There were differences in vehicle placement for both periods. The 2- to 4-ft interval and the 9:00 p.m. to 1:00 a.m. time period had 5.4 percent more vehicles for the reflectorized panels, whereas the 6- to 8-ft interval had 5.8 percent fewer vehicles. Also, for the 1:00 to 5:00 a.m. time period, 6 percent more vehicles were found for the reflectorized panels with a placement interval of 4 to 6 ft, and 6 percent fewer vehicles were shown for the 6- to 8-ft interval. This indicates that fewer vehicles were straying from the lane adjacent to the concrete barricades using reflectorized panels as compared with the steady-burn lights.

Vehicle Speeds

The average vehicle speeds observed at Sites 1 and 2 from 8:00 p.m. to 1:00 a.m. are as follows:

	Speed (mph) by Treatment	
Site	*Lights*	*Panels*
1	53.4	53.0
2	55.7	56.3

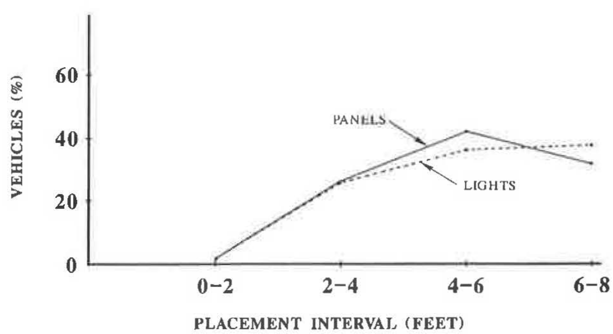

FIGURE 6 Percent vehicle placement from 9:00 p.m. to 1:00 a.m. (Site 2—Petersburg).

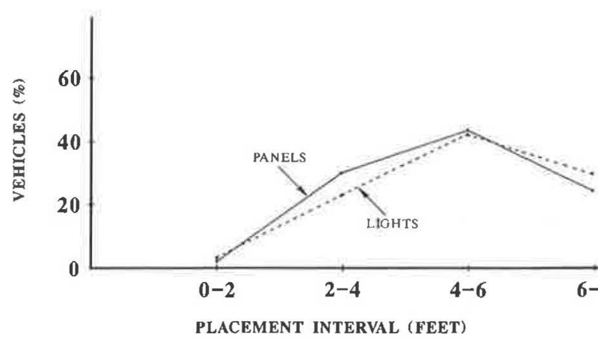

FIGURE 7 Percent vehicle placement from 1:00 a.m. to 5:00 a.m. (Site 2—Petersburg).

Two weekdays of data were collected for the steady-burn lights and reflectorized panels. The results showed no significant difference in speeds between the two delineation treatments.

Videotapes of Test Sites

Videotapes were made at two test sites to compare the lights versus the reflectorized panels. Videotapes were made at Site 1 (Leon, southbound) during daytime, night/dry, and night/wet conditions, and at Site 2 (Petersburg) during daytime and night/dry conditions.

RAISED PAVEMENT MARKERS

The use of raised pavement markers as a supplement to the existing work zone pavement markings was investigated for three sites. The raised markers were placed within the transition areas or where the alignment deviated from the original. The temporary markers were plastic with curve-corner face reflectors and were placed using a butyl pad.

Site 1 was a detour for a four-lane divided highway; the northbound lanes were closed (see Figure 8). The S-shaped detour had preformed tape along the right edgeline and a painted stripe along the left edgeline. The schematic in Figure 9 shows the location and spacing of the raised pavement markers and data collection points.

Site 2 was a four-lane highway with the right lane closed (see Figure 10). Raised pavement markers were added to the existing markings along both the right transition and left centerline. The schematic in Figure 11 shows the location and spacing of the markers.

Site 3 was an Interstate, with left lane closure and raised markers supplementing the existing left edgeline transition (see Figure 12). The markers were placed directly on the new preformed tape. The schematic in Figure 13 shows the marker placement and data collection points.

Procedure

To measure the effectiveness of the pavement striping and striping supplemented with raised pavement markers, traffic flow data were collected using a system of traffic counters with rubber tubes:

- *Vehicle Speed.* Vehicle speeds were recorded using two tubes as a speed trap.
- *Vehicle Placement.* The placement of vehicles relative to the lane line next to the concrete barrier was recorded using different length tubes.

FIGURE 8 Site 1, Rt. 29, Leon, Northbound.

FIGURE 10 Site 2, Route 1, Fredericksburg.

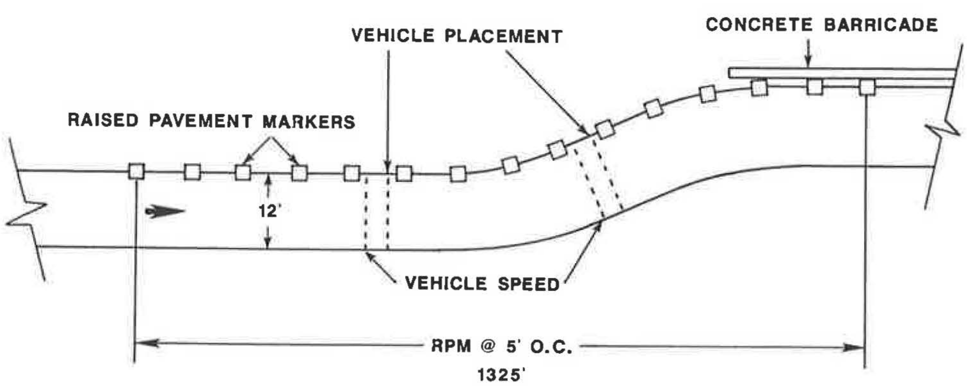

FIGURE 9 Schematic of Site 1, Leon.

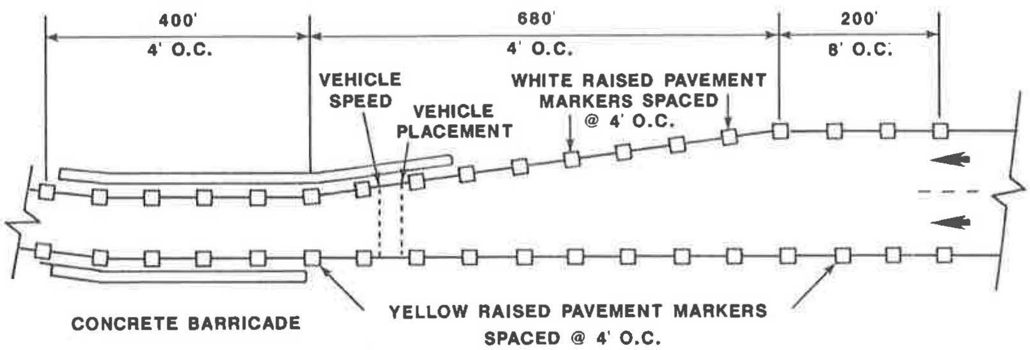

FIGURE 11 **Schematic of Site 2, Fredericksburg.**

FIGURE 12 **Site 3, Interstate 81, Salem.**

- *Position of Weave.* The position of weave within the transition area was recorded by dividing the area into zones and determining the magnitude of weaving within each zone.

Because of the importance of delineation during night/wet conditions, it was hoped that each variable could be tested under wet conditions; however, lack of rain limited data collection to dry conditions.

All data were collected on weekdays between darkness and 5:00 a.m. Videotapes were made of the test sections for the purpose of documenting the pavement markings observed.

Results

Vehicle Placement

Vehicle placement was measured for Sites 2 and 3. Figures 14 and 15 show vehicle placement for Site 2 from 9:00 p.m. to 1:00 a.m. and from 1:00 to 5:00 a.m. For both time intervals, there were more vehicles in the 2- to 4-ft interval for the raised pavement markers as compared with no raised markers. Fewer vehicles were in the 6- to 8-ft interval from 9:00 p.m. to 1:00 a.m. and in the 4- to 6-ft interval from 1:00 to 5:00 a.m. for the raised markers. A 12-ft pavement width at the point where the placement was taken meant that vehicles were staying closer to the center of the lane.

Placement for Site 3 is shown in Figures 16 and 17. Little difference in vehicle placement was found for each time period.

Discussion of Results

The raised pavement markers are most effective during night/wet conditions, because the water significantly reduces the retroreflection capabilities of the pavement striping, leaving the raised pavement marker, which protrudes above the water, as a primary source of reflected light. The unavailability of appropriate wet conditions during testing prevented data from being obtained during the time when raised pavement markers are the most effective. Figure 18 shows an example of the raised pavement markers used at Site 1 (Leon, northbound)

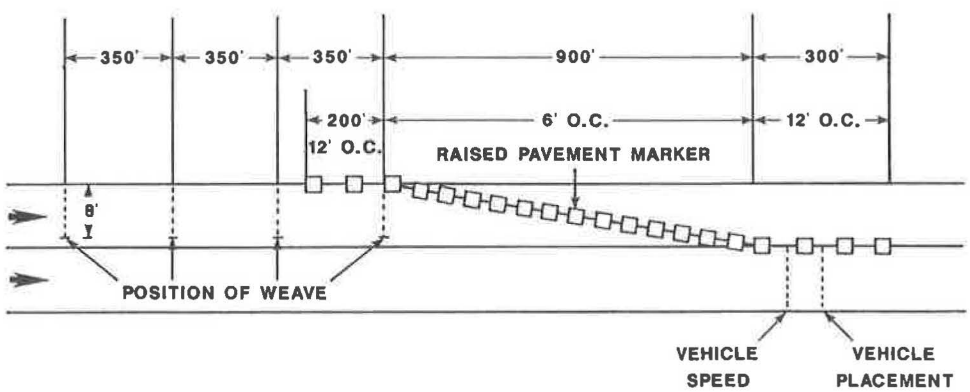

FIGURE 13 **Schematic of Site 3, Salem.**

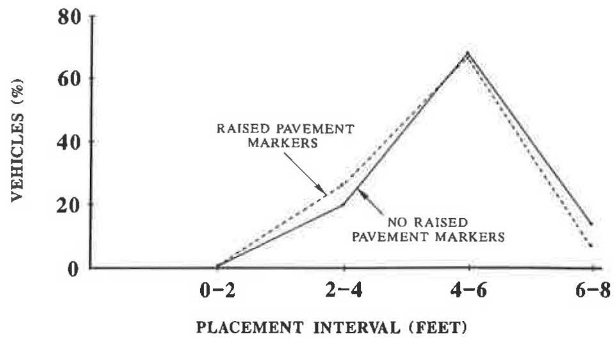

FIGURE 14 Percent vehicle placement from 9:00 p.m. to 1:00 a.m. (Site 2—Fredericksburg).

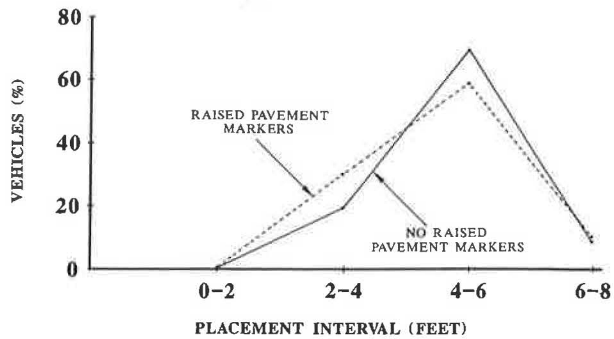

FIGURE 15 Percent vehicle placement from 1:00 to 5:00 a.m. (Site 2—Fredericksburg).

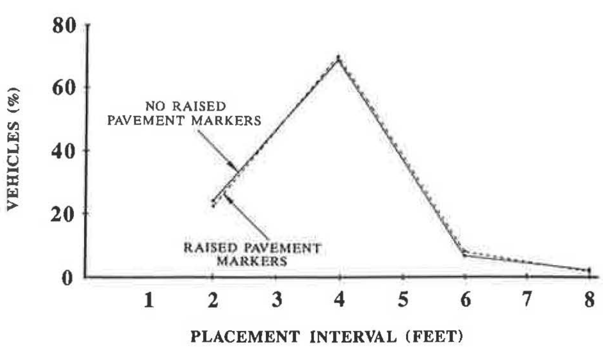

FIGURE 16 Percent vehicle placement from 9:00 p.m. to 1:00 a.m. (Site 3—Salem).

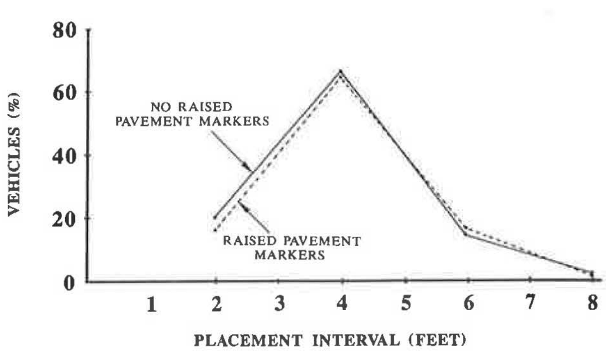

FIGURE 17 Percent vehicle placement from 1:00 to 5:00 a.m. (Site 3—Salem).

during wet conditions. The positive guidance capabilities are obvious; note the low visibility of the painted line. Existing pavement striping at Site 2 was judged to be average, with some parts below average primarily because of poor pavement conditions (cracks, scaling, irregular surface resulting from milling, dirt accumulation, etc.). Therefore, it was felt that the addition of the raised markers at Site 2 would increase delineation by creating a brighter path for motorists to follow. This observation seems to be supported by the placement data, which show that a higher percentage of vehicles traveled in the center of the lane, with less encroachment on the centerline.

Site 3 revealed little difference in vehicle placement with and without the raised pavement markers. This site, however, had new preformed tape for the transition on which the raised markers were placed. This material remained very bright during the test period and provided good guidance. Because of the brightness of the tape, the raised pavement markers did not provide the contrast needed for increased delineation. Under wet pavement conditions, especially heavy rain, the brightness of the pavement striping would be greatly diminished, leaving the raised markers as the primary source of guidance.

Vehicle Speeds

The average vehicle speeds for the three sites are as follows:

	Vehicle Speed (mph) by Treatment	
Site	*No Raised Pavement Markers*	*Raised Pavement Markers*
1a, Leon	41.5	43.5
1b, Leon	43.6	50.0
2, Salem	56.3	55.7
3, Fredericksburg	43.6	45.6

Site 1 had two speed observation points. Speeds were observed for all sites between the hours of 9:00 p.m. and 1:00 a.m. The same weekday was used for comparing each delineation treat-

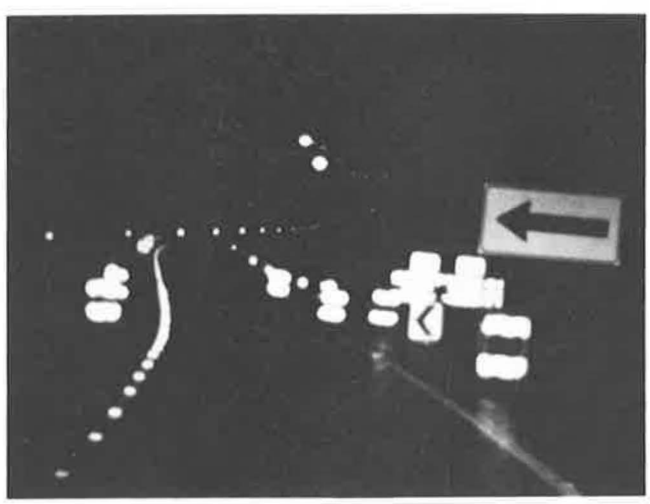

FIGURE 18 Raised pavement markers and night/wet conditions at Leon.

TABLE 1 POSITION OF WEAVE FOR RAISED PAVEMENT MARKERS VERSUS NO RAISED PAVEMENT MARKERS

	Percentage of Vehicles by Position (ft from taper)							
	1,050		700		350		0	
Time	No RPMs	RPMs	No RPMs	RPMs	No RPMs	RPMs	No RPMs	RPMs
9:00 p.m. to 1:00 a.m.	3.6	3.6	2.7	2.7	1.7	1.6	0.5	0.4
1:00 a.m. to 5:00 p.m.	1.5	0.7	1.0	0.4	0.5	0.5	0.2	0.4

NOTE: RPM = raised pavement marker.

ment. Posted advisory speed limits were 25, 55, and 45 mph for Leon, Salem, and Fredericksburg, respectively.

These results show an increase in average speed for Sites 1a, 1b, and 3. Little difference (0.6 mph) was observed at Site 2. The raised pavement markers provided more contrast or brightness than the painted lines on which they were placed at Sites 1 and 3, thus accounting for the speed differential. Also, delineation at the Site 1 detour was felt to be more critical because of the narrow lanes, S-shaped curves, and downhill topography. As noted earlier, the relative brightness of the tape edgeline at Site 2 caused the raised markers to be less effective, resulting in the small difference in speeds at that site.

Position of Weave

The position of weave was observed for Site 3 by recording the number of vehicles in the left lane at the taper and at distances of 350, 700, and 1,050 ft from the beginning of the taper. Table 1 presents the percentage of vehicles in the left lane from 9:00 p.m. to 1:00 a.m. and from 1:00 to 5:00 a.m. Two time intervals were used because of the different characteristics of early and late night traffic.

These data indicate that the addition of the raised pavement markers did not change the position of weave of vehicles approaching the left lane closure.

Videotapes of Test Sections

Videotapes were made of the test sections showing pavement striping versus pavement striping and raised pavement markers. At Site 1, Leon, northbound, videotapes were made during daytime, night/dry, and night/wet conditions. Videotapes were made at Site 2, Fredericksburg, during daytime and night/wet conditions and at Site 3, Salem, during daytime and night/dry conditions.

CONCLUSIONS

Steady-Burn Lights versus Reflectorized Panels

Analysis of vehicle placement data at two sites showed no difference at one site, whereas the other revealed less straying from the lane with the reflectorized panels. Speed data comparisons showed no differences in speeds at the two sites; therefore, it was concluded that the reflectorized panels were at least equal or superior to the steady-burn lights.

Use of Raised Pavement Markers to Supplement Existing Striping

The addition of raised pavement markers influenced vehicle placement at Site 2 by causing fewer centerline encroachments, although little change was noted for Site 3.

Vehicle speeds increased at both observation points at Sites 1 and 3; whereas no change was seen at Site 2. The increase in speed indicates that the drivers were more comfortable and confident of the roadway alignment and the path to follow.

For the night/dry conditions under which the raised markers were tested, positive results favored the use of raised pavement markers for supplementing existing striping.

The temporary raised markers were applied to the surface of the preformed tape at one site and over new paint at another, using butyl pads in both cases with good retention and durability. However, the site where the markers were placed over paint that had been applied to deteriorated pavements, old paint lines, and milled pavement surfaces had definite problems with marker retention. The primary problem was the failure of the paint to adhere to the pavement or old painted surface, thereby causing the marker, along with the underlying striping, to become detached, specially when hit by vehicle tires.

Although it was not within the scope of the project to test methods of adhesion, marker retention and durability will have to be considered if raised markers are to be used.

RECOMMENDATIONS

Steady-Burn Lights versus Reflectorized Panels

It is recommended that consideration be given to replacing the steady-burn lights on temporary concrete barricades with reflectorized panels. The panels should be at least the size of the ones used in this study, and fabricated with high intensity sheeting. They should be positioned at the same intervals as the steady-burn lights; however, they should be placed along the tangent sections only. Steady-burn lights should continue to be placed in the taper areas. Stripes on the panel should slope down toward the pavement. A recent study (*5*) showed that the cost of steady-burn lights was 10 to 20 times the cost of reflectorized panels (8 by 12 in.); therefore, the Department would realize a substantial savings from the use of the panels.

Use of Raised Pavement Markers to Supplement Existing Striping

The use of raised pavement markers as a supplement to existing striping showed signs of helping motorists negotiate work zone areas where there are changes in roadway alignment. These results were for dry conditions; wet conditions should lead to even greater advantages.

The use of closely spaced, raised pavement markers is a definite advantage to motorists because of the positive guidance provided as they approach and drive through work zones that present a variety of often confusing roadway alignment changes.

Because of the importance of providing positive motorist guidance and a safe driving environment within work zones, it is recommended that the Department use raised pavement markers as a supplement to existing pavement striping in areas where the roadway alignment changes (transitions, detours, etc.). There are still many questions relative to location, spacing, retention, durability, and type of raised marker. Until these questions can be answered, it is recommended that the markers be spaced on 4- to 5-ft centers in areas where there are curves or transitions and 8- to 10-ft centers for tangent sections. The method of application to the roadway should allow the marker to be placed or replaced in a minimum amount of time and with a minimum amount of disruption to the traffic flow. Adhesives that can be attached to the marker and can then be hand applied are preferable. The marker should be placed on the surface of the edgeline marking if it is judged to be securely adhered to the pavement surface. For questionable striping, the marker can be placed adjacent to the line, making sure that the pavement is free of dirt and grime.

ACKNOWLEDGMENTS

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REFERENCES

1. C. W. Niessner. *Raised Pavement Markers at Hazardous Locations.* Report FHWA–TS–84–215. FHWA, U.S. Department of Transportation, Washington, D.C., Dec. 1984.
2. W. L. Mullownay. *Effect of Raised Pavement Markers on Traffic Performance.* Report FHWA/NJ–83/001. New Jersey Department of Transportation, June 1982.
3. R. R. Hall. *The Delineation of Rural Roads and Curve Negotiation at Night.* Report No. 103, Australian Road Research Board, Nunawading, Victoria, Nov. 1979.
4. C. W. Niessner. *Construction Zone Delineation (Raised Pavement Markers).* FHWA, Office of Research and Development, U.S. Department of Transportation, Washington, D.C., June 1978.
5. F. D. Shepard. *Delineation Systems for Temporary Barriers in Work Zones.* VHTRC 86–R43. Virginia Highway Transportation Research Council, Charlottesville, June 1986.

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