Raised Pavement Markers at High-Hazard Locations

Jerry G. Pigman*       Kenneth R. Agent†

*Kentucky Department of Transportation, jerry.pigman@uky.edu
†Kentucky Department of Transportation, ken.agent@uky.edu
This paper is posted at UKnowledge.
https://uknowledge.uky.edu/ktc_researchreports/1043
MEMORANDUM TO: G. F. Kemper
State Highway Engineer
Chairman, Research Committee

KYP-78-202; HPR-PL-1(14), Part III-B

Raised pavement markers have been installed on approximately 1,500 miles of highways during the
past five years. Installations have included supplements to lanelines and edgelines, replacement of lanelines
with raised markers, and in gore area delineation. In addition, use of markers as a traffic control measure
at lane drops (Research Report No. 384) was the subject of a study in which the effectiveness of reducing
erratic movements was shown. Another study (Report No. 425) dealt with the operational applicability
of raised markers and their effectiveness with respect to brightness and durability.

This study, to evaluate raised markers at high-hazard locations, was conducted in cooperation with
the Federal Highway Administration in accordance with Basic Agreement DOT-FH-11-9279 (copy included
in the Appendix). A series of horizontal curves on US 68 in Mercer County and a narrow bridge over the
Kentucky River on KY 627, near Boonesboro, were the sites of the installations. Visual observations,
speed data, encroachment data, and accident data were used to evaluate effectiveness. Because pressure-
sensitive, markers failed to adhere to the pavement and because of snowplow damage, five installations
were made at the two sites between October 1977 and August 1978. Considerable emphasis was placed on
documentation of the markers during various light and weather conditions.

Results provided sufficient data to support recommendations for delineation at similar sites on the
rural, two-lane and four-lane systems. Details pertaining to the number and spacing of markers required at
hazardous curves under various geometric conditions and at narrow bridges with varying accident potential
are presented in the report. Results from this study may be implemented by the Division of Traffic.
Inasmuch as considerable damage may be expected from snowplows, plow-resistant markers would be
needed in the program.
On January 10, 1979, a draft copy of this report was transmitted to Mr. Charles W. Niessner, Federal Highway Administration Contract Manager for the study. Glossy prints of all the photographs in the report were sent to Mr. Niessner at a later date.

Respectfully submitted,

Jas. H. Havens
Director of Research

JGP:gd
cc's: Research Committee
### Abstract

Even though a large number of potentially hazardous locations exist on rural, two-lane roads, guidelines have not been developed for use of raised pavement markers under night and during adverse weather conditions. The purpose of this study was to evaluate the use of raised markers at a sharp curve and narrow bridge in Kentucky. Visual observations, speed data, encroachment data, and accident data were used to evaluate the effectiveness of the markers.

Extensive visual observations of the sharp curve and narrow bridge in this study have provided data to support recommendations for improved delineation at similar sites on rural, two-lane and four-lane roads. The best delineation found for sharp curves is to place raised markers on the centerline at 40-foot (12.2-m) spacings. At narrow bridge sites (bridge width less than approach width), raised markers should be placed at a decreasing spacing when approaching the bridge. The number of markers required and the location at which they should begin were also determined.

A delineation improvement program for narrow bridges and sharp curves involving raised markers would mainly apply to rural areas. Snowplow damage could make use of conventional markers impractical.
Research Report
522

RAISED PAVEMENT MARKERS
AT HIGH-HAZARD LOCATIONS

by

Jerry G. Pigman
Research Engineer Chief

and

Kenneth R. Agent
Research Engineer Principal

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

The contents of this report reflect the views of the authors who are responsible for the facts and accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Bureau of Highways or the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

June 1979
INTRODUCTION

Raised pavement markers have become a fairly common delineation treatment in recent years and especially so in the states outside the "snowbelt." Some of the border states, such as Kentucky, have placed a significant number of the markers on several sections of highways. Raised markers have been installed on approximately 1,500 miles (2,400 km) of roadway during the past five years. Installations in Kentucky have included supplements to lanelines and edgelines, replacement of lanelines with raised markers, and gore area delineation. In addition, use of markers as a traffic control measure at lane drops was the subject of a Division of Research study in which their effectiveness in reducing erratic movements was shown (1). Installations were also shown to be relatively inexpensive. Another study by the Division of Research dealt with the operational applicability of raised pavement markers and their effectiveness with respect to brightness and durability (2). Seven types of markers were evaluated; the primary application was as a supplement to lanelines. They were also used as a traffic control measure at lane drops, as delineation for hazardous curves, and as directional arrows.

With widespread public approval of raised pavement markers has come the desire to delineate all roads in this manner. Installations in Kentucky have generally been limited to four-lane highways. Other states have made extensive installations of raised pavement markers on both two-lane and four-lane highways. The Florida Department of Transportation has recently reported that they intend to install markers throughout the state at 40-foot (12.2-m) spacings on centerlines (3). Damage resulting from snowplows and installation cost have prevented more widespread use of raised markers in Kentucky. An experimental installation of snowplowable markers on the Thornhill Bypass in Frankfort is Kentucky's first application of that type. They will provide data toward the economic feasibility of future installations.

Even though a large number of potentially hazardous locations exist on the rural, two-lane roads, Kentucky has not developed guidelines for using these markers in those situations; that, of course, is the purpose of this study. Included in the APPENDIX is a copy of the contract with the Federal Highway Administration and also a copy of the Statement of Work for the study.

In a forthcoming report, methods of delineating hazardous stop approaches will be evolved (4). Raised pavement markers were one of the delineation devices used. Recommendations concerning improvement in delineating that type of hazardous location will be included there.

SITE SELECTION

A survey of hazardous locations was made. Sharp curves and narrow bridges were considered to be the most likely locations where visibility under adverse weather conditions could be improved by installation of raised markers. After a thorough survey of many high-hazard locations, several were rejected because of their distance from Lexington, and others were dismissed because various types of improvements were planned at the sites in the near future. Through process of elimination, two sites were selected for trial installation of raised pavement markers: (1) a series of horizontal curves between Milepost 13.0 and 14.2 on US 68 in Mercer County (near Pleasant Hill) and (2) a narrow bridge over the Kentucky River on KY 627 at the Clark County-Madison County line (near Boonesboro). During a period of three years preceding the installation, there were ten accidents at the Mercer County site and nine at the Boonesboro site. The Mercer County site is shown in Figures 1 and 2, and an aerial photograph is presented in Figure 3. Approaches to the narrow bridge at Boonesboro are shown in Figures 4 through 7, and an aerial photograph is presented in Figure 8.
Figure 1. Mercer County Site before Installation of Raised Pavement Markers (Eastbound).

Figure 2. Another View Mercer County Site before Installation of Raised Pavement Markers (Eastbound).
Figure 3. Aerial Photograph of Mercer County Site.
Figure 4. Boonesboro Site before Installation (Southbound Approach).

Figure 5. Boonesboro Site before Installation (Southbound Approach at Bridge).
Figure 6. Boonesboro Site before Installation (Northbound Approach).

Figure 7. Boonesboro Site before Installation (Northbound Approach at Bridge).
Figure 8. Aerial Photograph of Boonesboro Site.
INSTALLATION

The first installations were made in October of 1977. The Stimsonite Model 88-SS, pressure-sensitive marker was used at both sites (marker at left in Figure 9). The first installations in Mercer County included 40-foot (12.2 m) spacing of both edgeline and centerline throughout the section. At the narrow bridge site near Boonesboro, markers were placed at decreasing spacings closer to the bridge. The patterns were slightly different for the Clark and Madison County sites.

Since the pressure-sensitive markers only lasted a few months, primarily due to lack of adhesion to the pavement, it was necessary to replace the markers at both sites in the summer of 1978 with epoxy-type, Stimsonite, raised markers (at right in Figure 9). On June 22, 1978, 77 sets of markers were installed at 80-foot (24.4-m) spacings on the 1.2-mile (1.9-km) section in Mercer County. After determining that the 80-foot (24.4-m) spacing was not sufficient for the sharp curve sections, additional markers were installed on August 24, 1978. Single markers were installed on each edgeline, and a set of markers on the centerline at 80-foot (24.4-m) spacings over 1,200 feet (366 m) at the north end of the section, at 40-foot (12.2-m) spacings over 2,720 feet (829 m) in the middle section with sharp curves, and at 80-foot (24.4-m) spacings over 2,160 feet (658 m) at the south end. A summary of the number of markers, various spacings, and installation costs is presented in Table 1.

A second installation at Boonesboro was also necessary because of the loss of markers due to lack of adhesion to the pavement. Epoxy-type Stimsonite markers were installed on August 7, 1978. Details of the number of markers and patterns of placement for this installation are also presented in Table 1. The patterns used in August 1978 resulted in approximately half the number of markers being used compared to the installation in October 1977.

A total of five separate installations were made between October 1977 and August 1978. At the Mercer County site, three installations were made using 1,056 markers at a cost of $2,554.41. At the Boonesboro site, two installations were made using 761 markers at a cost of $1,828.13. The costs cited here include all expenses associated with the various installations. The average cost was $2.41 per marker.

Figure 9. Stimsonite Raised Pavement Markers Used in This Study (Pressure-Sensitive Type on Left and Epoxy Type on Right).
TABLE 1
SUMMARY OF PATTERNS OF INSTALLATION AND COSTS

<table>
<thead>
<tr>
<th>LOCATION</th>
<th>DATE</th>
<th>PATTERN OF INSTALLATION</th>
<th>NUMBER INSTALLED</th>
<th>TYPE OF MARKER</th>
<th>INSTALLATION COSTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>US 68</td>
<td>10-28-77</td>
<td>153 sets of 4 markers (one on each edgeline and two on centerline) at 40-foot spacing</td>
<td>612</td>
<td>Stimsonite Model 88-SS</td>
<td>$1288</td>
</tr>
<tr>
<td>Mercer Co.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>US 68</td>
<td>6-28-78</td>
<td>77 sets of 2 markers on centerline at 80-foot spacing</td>
<td>154</td>
<td>Stimsonite Model 88</td>
<td>$507</td>
</tr>
<tr>
<td>Mercer Co.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>US 68</td>
<td>8-24-78</td>
<td>Additional raised pavement markers were installed throughout the section to comprise the following patterns: 15 sets of 4 at 80-foot spacings 68 sets of 4 at 40-foot spacings 27 sets of 4 at 80-foot spacings</td>
<td>290</td>
<td>Stimsonite Model 88</td>
<td>$759</td>
</tr>
<tr>
<td>Mercer Co.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>KY 627</td>
<td>10-19-77</td>
<td>South Approach: 200 feet at 10-foot spacings 400 feet at 20-foot spacings 400 feet at 40-foot spacings</td>
<td>503</td>
<td>Stimsonite Model 88-SS</td>
<td>$1126</td>
</tr>
<tr>
<td>Boonesboro</td>
<td></td>
<td>Bridge: 10-foot spacings on concrete 20-foot spacings on metal</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>North Approach: 160 feet at 10-foot spacings 520 feet at 20-foot spacings 320 feet at 40-foot spacings</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>KY 627</td>
<td>8-7-78</td>
<td>South Approach: 200 feet at 20-foot spacings 400 feet at 40-foot spacings 400 feet at 80-foot spacings</td>
<td>258</td>
<td>Stimsonite Model 88</td>
<td>$702</td>
</tr>
<tr>
<td>Boonesboro</td>
<td></td>
<td>Bridge: 20-foot spacings</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>North Approach: 160 feet at 20-foot spacings 520 feet at 40-foot spacings 320 feet at 80-foot spacings</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

DATA COLLECTION

Data collection consisted of spot-speed measurements and observations of lane encroachments. Spot speed data were taken at both sites on several occasions with radar meters. At the Mercer County site, speed data were collected at two sites from an automobile positioned near two series of S-shaped curves. At the Boonesboro site, speed data were collected at both approaches to the narrow bridge. Lane encroachment data were collected before and after installation of the markers in 1977 and 1978. Encroachments were divided into three categories: mild, moderate, and severe. A mild encroachment was defined as the situation in which less than one-fourth of the vehicle crossed over the centerline. The degree of encroachment was considered moderate when 1/4 to 3/4 of the vehicle crossed over the centerline and severe when more than 3/4 of the vehicle crossed over the centerline.

RESULTS

VISUAL OBSERVATIONS AND PHOTOGRAPHS

The primary means of judging the effectiveness of the raised pavement markers was by visual examination. Both daytime and nighttime photographs were taken to document the observations. The daytime, before photographs and aerial photographs were shown previously (Figures 1 through 8). The sharp curve site in Mercer County consisted of a series of curves approximately 1.2 miles (1.9 km) in length. A nighttime photograph of one section of the hazardous curve was taken before installation of the markers (Figure 10). The photograph illustrates the observation that additional markers would be of benefit. The initial installation involved placing two amber markers on the centerline and one silver-white marker on each edgeline at a spacing of 40 feet (12.2 m). Nighttime photographs of this pattern are shown in Figures 11 and 12.
As noted earlier, the markers remained in place only a few months. The next installation consisted of placing two amber markers on the centerline at a spacing of 80 feet (24.4 m). No markers were placed on the edgeline. Nighttime photographs of this installation are shown in Figures 13 and 14. Additional markers were then added to make the installation almost identical to the initial installation. The only change was placement of the markers at a spacing of 80 feet (24.4 m) for a short section in advance of the start of the curves. Initially, all the markers were placed at a 40-foot (12.2-m) spacing. Photographs showing rainy, nighttime conditions following this installation are shown in Figures 15 and 16. These photographs show the dramatic improvement in delineation provided during inclement weather. Another alternative investigated was the placement of two amber markers on the centerline at a 40-foot (12.2-m) spacing with no markers on the edgeline. Photographs of this alternative are given in Figures 17 and 18. Daytime observations were also conducted after each installation. Daytime photographs of the hazardous curve site after installation of the markers at a 40-foot (12-m) spacing on the centerline and edgeline are shown in Figures 19 and 20.

Figure 10. Nighttime Photograph of Mercer County Site before Installation.
Figure 11. Nighttime Photograph of Mercer County Site after First Installation (Two Amber Markers on Centerline and One Crystal Marker on each Edgeline at 40-Foot (12.2-m) Spacings).

Figure 12. Another View of First Installation in Mercer County.
Figure 13. Nighttime Photograph of Mercer County Site after Second Installation (Two Amber Markers on Centerline at 80-Foot (24.4-m) Spacings).

Figure 14. Another View of Second Installation in Mercer County.
Figure 15. Rainy, Nighttime Conditions at Mercer County Site (40-Foot (12.2-m) Spacing of Markers on Centerline and Edgelines).

Figure 16. Another View during Rainy, Nighttime Conditions at Mercer County Site.
Figure 17. Nighttime Photograph of Mercer County Site (Two Amber Markers on Centerline at 40-Foot (12.2-m) Spacings).

Figure 18. Another View of Mercer County Site with Only Centerline Markers.
Figure 19. Daytime View of Mercer County Site after Installation of Markers.

Figure 20. Another Daytime View of Mercer County Site after Installation of Markers.
Based on the visual observations, several conclusions were reached. First, it seemed apparent that markers placed at 80-foot (24.4-m) centers on the centerline and no markers on the edgeline did not provide sufficient delineation (Figures 13 and 14). At some points on the sharpest curves, only one or two sets of markers were visible. It also seemed apparent that two amber markers placed on the centerline and a silver-white marker placed on each edgeline at a spacing of 40 feet (12.2 m) provided more delineation than was necessary (Figures 11 and 12). The mixture of centerline and edgeline markers appeared confusing at some of the sharp curves. Two amber markers on the centerline as shown in Figures 17 and 18 provided the best delineation. Another problem with using both centerline and edgeline markers was the reduction in the effective lane width. The test site had a width of approximately 20 feet (6.1 m). When markers were placed on the centerline and edgeline, the effective lane width was only about 8 feet (2.4 m). The daytime photographs showed that the markers provided only a very small improvement in delineation during the day. However, the rumble effect caused by running over the markers served to alert the driver that he was encroaching on the opposing lane.

Based on visual observations, the general conclusion was reached that raised pavement markers provide a significant improvement in nighttime delineation at sharp curves. The best spacing consisted of placing two amber markers on the centerline at a 40-foot (12.2-m) spacing. An alternative to this design would be to place one marker between the paint stripes instead of two markers on the outside of each stripe. A photograph of a curve with one amber marker placed on the centerline at a 40-foot (12.2-m) spacing is shown in Figure 21. Placing only one marker has certain disadvantages. The rumble effect caused by running over the markers, which warns the driver that he is encroaching on the opposing lane, would be reduced if only one marker was used. Also, using two markers provides a safeguard in case one of the markers is damaged or lost. It should also be noted that the amber lens is less bright than silver-white lens. For a sharp curve on a four-lane highway, using one silver-white marker placed at a 40-foot (12.2-m) spacing on the lane line would be adequate. For two-lane highways where amber centerline markers are used, visual inspections at the study location indicated that two markers are needed to provide adequate delineation for locations with very sharp curves. The study location had curves with degrees of curvature in excess of 20 degrees. However, due to economic considerations, using one marker at a 40-foot (12.2-m) spacing should be adequate at other locations. The degree of curvature at which two markers is necessary was determined based on a table giving the maximum degree of curve for a given design speed (5).

Figure 21. Nighttime Photograph of Mercer County Site with One Amber Marker Placed on the Centerline at 40-Foot (12.2-m) Spacings.
The Boonesboro site was a narrow bridge; both approaches were on curves. Also, the southbound approach was on a steep grade (Figure 4). Nighttime photographs taken before installation of the raised pavement markers show that diagonally-striped post delineators had been added on the curved section on the southbound approach (Figures 22 and 23). The need for additional delineation was clearly shown on the northbound approach (Figures 24 and 25). Two installations were made. In both cases, the markers started 1,000 feet (305 m) in advance of the bridge.

Figure 22. Nighttime Photograph of Boonesboro Site before Installation of Markers (Southbound Approach).

Figure 23. Nighttime Photograph of Boonesboro Site before Installation of Markers (Southbound Approach at Bridge).
Figure 24. Nighttime Photograph of Boonesboro Site before Installation of Markers (Northbound Approach at Bridge).

Figure 25. Nighttime Photograph of Boonesboro Site before Installation of Markers (Northbound Approach at Bridge).
For the northbound approach, the initial installation consisted of markers on the centerline and edgelines at a decreasing spacing toward the bridge (Figures 26 and 27). The spacing started at 40 feet (12.2 m), then decreased to 20 feet (6.1 m) and finally 10 feet (3 m). In the second installation, the spacings were 80 feet (24.4 m), 40 feet (12.2 m), and 20 feet (6.1 m) as shown in Figure 28 and 29. Visual inspections showed that the increased spacings provided adequate delineation. On the southbound approach, the marker spacings in the initial installation were 20 feet (6.1 m) and 40 feet (12.2 m) (Figures 30 and 31). The spacings were increased to 40 feet (12.2 m) and 80 feet (24.4 m) in the second installation (Figures 32 and 33). Again, the larger spacings seemed to give adequate delineation. Daytime observations after installation again showed that raised pavement markers provide only small improvement in daytime delineation. However, photographs taken during rainy, daytime conditions, when the weather conditions made it appear similar to dawn or dusk, showed that the markers did provide added delineation (Figures 34 and 35). One question concerning the marker pattern would be whether markers were needed on both the edgeline and centerline. Since a primary objective of the markers in advance of a narrow bridge was to delineate the decrease in pavement width, the markers were obviously needed on the edgeline. However, the problem with head-on accidents on narrow bridges on two-lane highways could be worsened if additional delineation were provided only on the edgelines. Therefore, it would seem that markers should also be placed on the centerline.

The spacing of the markers on the approach would depend on the accident potential of the specific bridge. At bridges having a particularly high potential for accidents, such as the study location which had curved approaches, the optimum spacing of the markers might vary from 80 feet (24.4 m) farthest from the bridge down to 20 feet (6.1 m) nearest the bridge. However, as a general rule, it appears that decreasing the spacing from 80 feet (24.4 m) to 40 feet (12.2 m) would be adequate.

SPEEDS

Results from speed studies are given in Table 2. The data showed that the average speeds before and after installations of the markers were very similar at both sites. The small differences were found to be statistically insignificant at the 0.95 level. The markers caused some drivers to reduce speeds. However, the improved visibility would allow some drivers to increase speed. These two effects seemed to cancel each other, and the result was not significant change in average speed.

Different results were obtained when the 85th-percentile speeds were compared. This is the speed below which 85 percent of all vehicles travel, and above which 15 percent travel. This speed better describes the percentage of drivers travelling at higher speeds. There were no statistically significant differences in the daytime speeds for the before and after periods. However, statistically significant reductions in the nighttime speeds were found at both test sites. This finding shows that the markers did reduce the number of high-speed drivers during nighttime conditions. These high-speed drivers would have the highest accident potential.
Figure 26. Nighttime Photograph of Boonesboro Site after First Installation (Northbound Approach).

Figure 27. Nighttime Photograph of Boonesboro Site after First Installation (Northbound Approach at Bridge).
Figure 28. Nighttime Photograph of Boonesboro Site after Second Installation (Northbound Approach).

Figure 29. Nighttime Photograph of Boonesboro Site after Second Installation (Northbound Approach at Bridge).
Figure 30. Nighttime Photograph of Boonesboro Site after First Installation (Southbound Approach).

Figure 31. Nighttime Photograph of Boonesboro Site after First Installation (Southbound Approach).
Figure 32. Nighttime Photograph of Boonesboro Site after Second Installation (Southbound Approach).

Figure 33. Nighttime Photograph of Boonesboro Site after Second Installation (Southbound Approach at Bridge).
Figure 34. Rainy, Daytime (Dawn) Conditions at Boonesboro Site after Second Installation (Southbound Approach).

Figure 35. Rainy, Daytime (Dawn) Conditions at Boonesboro Site after Second Installation (Southbound on Bridge).
TABLE 2
SPEEDS BEFORE AND AFTER INSTALLATION OF RAISED, PAVEMENT MARKERS

<table>
<thead>
<tr>
<th>Site</th>
<th>Time</th>
<th>Before Average Speed (mph) (m/s)</th>
<th>After Average Speed (mph) (m/s)</th>
<th>Before 85th Percentile Speed (mph) (m/s)</th>
<th>After 85th Percentile Speed (mph) (m/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hazardous Curve</td>
<td>Day</td>
<td>34.7 (15.5)</td>
<td>34.0 (15.2)</td>
<td>39.4 (17.6)</td>
<td>39.5 (17.7)</td>
</tr>
<tr>
<td></td>
<td>Night</td>
<td>32.8 (14.7)</td>
<td>33.4 (14.9)</td>
<td>38.4 (17.2)</td>
<td>37.2 (16.6)</td>
</tr>
<tr>
<td>Narrow Bridge</td>
<td>Day</td>
<td>34.0 (15.2)</td>
<td>35.3 (15.7)</td>
<td>40.4 (18.1)</td>
<td>39.2 (17.5)</td>
</tr>
<tr>
<td></td>
<td>Night</td>
<td>32.0 (14.3)</td>
<td>32.4 (14.5)</td>
<td>36.8 (16.4)</td>
<td>35.5 (15.9)</td>
</tr>
</tbody>
</table>

ENCROACHMENTS

Vehicle encroachments, classified as mild, moderate, or severe, were collected before and after installation of the markers. Observations were made at two curves on the section of sharp curves and at the curves at both approaches to the narrow bridge. The data refer to encroachment over the centerline. A summary of the encroachment rates at both sites is presented in Table 3.

At the sharp curve site, the moderate and severe encroachment rate was reduced by about one-half in both daytime and nighttime. The percent reduction was slightly higher at nighttime. The moderate and severe encroachment rates were higher at nighttime. The mild encroachment rate was almost identical in the before and after periods.

At the narrow bridge site, there were no severe encroachments. After installation, the moderate encroachment rate dropped slightly in the day. There was a dramatic decrease in the moderate encroachment rate at nighttime. In the after period, there was a large increase in the mild encroachment rate. The observers felt that this was due to the fact that mild encroachments were more easily determined in the after period because of the noise made when striking the markers on the centerline. These minor encroachments probably occurred in the before period but were not noted. The moderate and severe encroachments are the types which need to be prevented, and their rates were reduced substantially. Evidently, the rumble effect of the markers alerted drivers that they were crossing into the opposing lane.

TABLE 3
ENCROACHMENT RATES BEFORE AND AFTER INSTALLATION OF RAISED, PAVEMENT MARKERS

<table>
<thead>
<tr>
<th>Site</th>
<th>Time</th>
<th>Mild Encroachment Rate (Encroachments/100 Vehicles)</th>
<th>Moderate Encroachment Rate (Encroachments/100 Vehicles)</th>
<th>Severe Encroachment Rate (Encroachments/100 Vehicles)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hazardous Curve</td>
<td>Day</td>
<td>Before 29</td>
<td>5.1</td>
<td>3.8</td>
</tr>
<tr>
<td></td>
<td>After</td>
<td>30</td>
<td>2.7</td>
<td>1.9</td>
</tr>
<tr>
<td></td>
<td>Night</td>
<td>Before 27</td>
<td>9.2</td>
<td>4.6</td>
</tr>
<tr>
<td></td>
<td>After</td>
<td>28</td>
<td>4.0</td>
<td>2.2</td>
</tr>
<tr>
<td></td>
<td>Day</td>
<td>Before 23</td>
<td>1.8</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>After</td>
<td>33</td>
<td>1.6</td>
<td>0</td>
</tr>
<tr>
<td>Narrow Bridge</td>
<td>Day</td>
<td>Before 18</td>
<td>4.4</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Night</td>
<td>After 37</td>
<td>1.0</td>
<td>0</td>
</tr>
</tbody>
</table>
ACCIDENT ANALYSIS

Both study location had been identified previously as high accident locations under Kentucky's High-Accident Spot-Improvement Program. An investigation of the accident history of the sharp curve section showed that ten accidents had occurred in a three-year period preceding installation of the markers. All but one of those accidents directly involved the sharp curvature. Six accidents were single vehicles running off the road after failing to negotiate the curve. The remaining three related accidents were two-vehicle accidents which resulted when one vehicle crossed into the opposing lane (on the curve). The high severity was typical of single-vehicle accidents (6). Three of the accidents were at night while one was at dusk. The expected percentage during darkness would be about 30 percent (6). An extremely high number of the accidents (eight) occurred during wet pavement conditions. Also, three of the four non-daytime accidents occurred during wet-pavement conditions. Normally, slightly more than 20 percent of the accidents would be expected to occur on wet pavements (6, 7). Nine of the ten accidents occurred at the curves on the west end of the section. As shown in Figure 36, viewing from a westbound direction, there is a series of very sharp curves on a downhill grade at this location. Six of the nine accidents involved a westbound vehicle being at fault. Speeding, followed by driver inattention and alcohol involvement were listed as the contributing factors to the accidents. In the one-year period after initial installation of the markers, only one non-injury accident occurred at this location. That accident occurred at the same location as almost all of the previous accidents, and it was during daylight hours on a wet pavement, and speeding and driver inattention were listed as the contributing factors. A nighttime photograph of the location was shown in Figure 17. The photograph shows the increased delineation provided by installation of the markers at the previously recommended spacing. It should be noted that the initial installation had to be replaced, and for a period of about four months, there were no markers on the pavement.

Figure 36. Series of Sharp Curves at the Mercer County Site Where Most Accidents Occurred (Westbound Direction).
At the narrow bridge site, nine accidents involving the bridge and its approach occurred during the three-year period preceding the installation. This site was termed hazardous because of the reduction in roadway width at the bridge and the curved approaches to the bridge. Both of these factors contributed to the accidents. The southbound approach has a steep grade which contributed to the problem. Also, an unusually high number of large trucks travel this road, which further aggravaed the problem associated with the narrow bridge. Four of the nine accidents occurred at nighttime. Three of the accidents involved a wet pavement. None of the accidents occurred during wet, daytime conditions. Six of the nine accidents were related to the southbound approach. There was one fatal accident, but the overall severity of the accidents was not high (severity index of 2.22). The fatal accident involved a northbound vehicle failing to negotiate the approach curve. Speeding was listed as the major factor, followed by driver inattention. Six of the accidents occurred on the bridge while the remaining three occurred on the curved approach. Four of the six accidents on the bridge involved large trucks. There were two non-injury accidents in the one-year period following installation of the markers. Both were on the southbound approach and involved large trucks. One accident involved brake failure on the steep downgrade and resulted in a rear-end accident at the entrance to the bridge. The other involved a rear-end accident during extremely heavy fog. Both of these accidents were unusual and may not be related to the bridge. A number of delineation improvements were completed about one year before initial installation of the markers. They were made on the southbound approach and corresponded to the opening of the three-lane section on the steep grade approach to the bridge. The improvements involved a flashing beacon, an oversized "Narrow Bridge" sign, and diagonally-striped post delineators on the bridge. These improvements may affect the accident reduction. Also, the initial marker installation had to be replaced; and, during the five-month period, there were no markers on the pavement. One of the "after" accidents occurred during this time period.

The limited accident data and the short after period in which the markers were in place does not allow for a complete statistical analysis on the effectiveness of the markers in reducing accidents. However, the overall reduction in accidents indicates that the markers had a positive influence.

SUMMARY AND CONCLUSIONS

1. Visual observations before installation of the raised pavement markers confirmed that additional delineation would be beneficial.

2. At the sharp curve site, markers placed at 80-foot (24.4-m) centers on the centerline and no markers on the edgeline did not provide sufficient delineation. Two amber markers placed on the centerline and a silver-white marker placed on each edgeline at a spacing of 40 feet (12.2 m) provided more delineation than was necessary. The mixture of centerline and edgeline markings appeared confusing at some of the sharp curves. The best delineation consisted of markers placed on the centerline at 40-foot (12.2-m) centers. For two-lane highways where amber centerline markers are used, visual observations indicate that two markers are needed to provide adequate delineation for locations with very sharp curves. Using one marker at the 40-foot (12.2-m) spacing should be adequate at other locations. On a four-lane highway, one silver-white marker placed at a 40-foot (12.2-m) spacing on the lane line would be adequate.

3. At the narrow bridge site, the markers were placed at a decreasing spacing nearer the bridge. A spacing of from 80 feet (24.4 m) down to 40 feet (12.2 m) was found to be adequate unless the bridge had a particularly high potential for accidents where the spacing should decrease to 20 feet (6.1 m). Markers were found to be needed in advance of the bridge on the edgeline to delineate the decrease in pavement width and on the centerline to minimize the risk of head-on accidents.

4. The markers provide only a very small improvement in delineation during the day. However, the warning provided by the rumble effect would still be evident during the daytime.

5. Observations during rainy, nighttime conditions showed the dramatic improvement in delineation provided by the raised pavement markers during inclement weather. Observations during rainy daytime when the weather conditions made it appear similar to dawn or dusk showed that the markers did provide added delineation.

6. The average speeds did not change significantly after installation of the markers. However, statistically significant reductions in the nighttime, 85th-percentile speeds were found at both test sites.
7. Moderate and severe encroachments over the centerline were reduced significantly after installation of the markers. The rumble effect of the markers alerted drivers that they were crossing into the opposing lane. Encroachment rates were reduced during both daytime and nighttime conditions, but the largest overall reduction occurred at nighttime.

8. The limited accident data during the short after period did not allow for a complete statistical analysis of the effectiveness of the markers in reducing accidents. However, the overall reduction in accidents in the after period indicated that the markers had a positive influence.

9. The self-adhesive type of raised pavement marker remained in place for only a short period of time. Their use should be limited to roadways with very smooth surfaces.

10. Damage from snowplows to the type of raised pavement markers used may make them impractical for delineation of narrow bridges and sharp curves in rural areas. Therefore, the feasibility of using snowplowable markers for rural, two-lane and four-lane highways should be considered.

**RECOMMENDATIONS**

Extensive visual observations of the sharp curves and narrow bridge in this study provided sufficient data to support recommendations for improved delineation at similar sites on the rural, two-lane and four-lane roads. The best delineation found for a sharp curve is to place markers on the centerline at 40-foot (12.2-m) spacings. On two-lane roads where amber centerline markers are used, either one or two markers may be used at this spacing. At very sharp curves (12 degrees or greater) or curves having numerous accidents related to the curvature, two markers placed on the outside edge of the centerline stripes are needed to provide adequate delineation. For less than 12-degrees curves, one amber marker placed at this spacing between the centerline paint stripes would be adequate. On a four-lane highway, one silver-white marker placed at a 40-foot (12.2-m) spacing on the lane edge would be adequate. The markers should be placed at the 40-foot (12.2-m) spacing from the point of the curve to the point of the tangent. For a short section in advance of the start of the curve, one marker should be placed on the centerline at an 80-foot (24.4-m) spacing. It is recommended that the markers begin 800 feet (244 m) in advance of the curve.

At narrow bridge sites (bridge width less than the approach width), raised pavement markers should be placed at a decreasing spacing when approaching the bridge. The spacing would depend on the accident potential of the specific bridge site. At bridges with a particularly high accident potential, the spacing of the markers should vary from 80 feet (24.4 m) farthest from the bridge down to 20 feet (6.1 m) nearest the bridge. However, as a general rule, decreasing the spacing from 80 feet (24.4 m) to 40 feet (12.2 m) may be adequate. The markers should be placed on each edgeline, and one marker should be placed on the centerline at each spacing. At all sites, the markers should begin 1,000 feet (305 m) in advance of the bridge. Normally, the first 400 feet (122 m) of road would be marked at 80-foot (24.4-m) spacing and the final 600 feet (183 m) would be at a 40-foot (12.2-m) spacing. On the bridge, only the single centerline marker placed at a 40-foot (12.2-m) spacing should be used. At bridge sites considered as high-hazard locations, a 20-foot (6.1-m) spacing should be used on the edgelines for the final 200-foot (61-m) section in advance of the bridge. The centerline markings should remain the same.

**REFERENCES**

1. Pigman, J. G.; and Agent, K. R.; *Raised Pavement Markers as a Traffic Control Measure at Lane Drops;* Report 384, Division of Research, Kentucky Department of Transportation; January 1974.


3. Telephone conversation with representatives of the Florida Department of Transportation, December 1976.


7. Rizenbergs, R. L.; and Burchett, J. L.; *Statewide Survey of Skid Resistances of Pavements;* Report 512; Division of Research, Kentucky Department of Transportation, November 1978.
APPENDIX

BASIC AGREEMENT CONTRACT AND STATEMENT OF WORK
The Kentucky Department of Transportation is hereby assigned
Task Order No. Two under Basic Agreement DOT-FH-11-9279. The
requirements of the Task Order are as follows:

1. TITLE AND STATEMENT OF WORK

"Raised Pavement Markers at High Hazard Locations." See the
attached for Statement of Work.

2. REPORTS

Reporting requirements attached.

3. PERIOD OF PERFORMANCE

All work and services required hereunder shall be completed on or

4. CONSIDERATION AND PAYMENT

The cost of this Task Order shall be in the cost-reimbursement
amount of sixteen thousand dollars ($16,000).

The appropriation number is 942-42-22-1F-31I3-7240-7-2582.

Requests for payment under this Task Order are to be submitted
to the Federal Highway Administration, Office of Contracts and

5. CONTRACTING OFFICER'S TECHNICAL REPRESENTATIVE

The contract manager for this Task Order is Mr. Charles
W. Niessner, Office of Development, Federal Highway
Administration.

COMMONWEALTH OF KENTUCKY
DEPARTMENT OF TRANSPORTATION
BY: Calvin G. Grayson
TITLE: Secretary
DATE: 7/26/77

U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION
BY: L. W. Bolyard, Sr. Contract
Negotiator, Services
TITLE: Procurement Division, OC&P
DATE: 9/2/77
Statement of Work
Use of Raised Pavement Markers at Hazardous Locations

Introduction
Numerous potentially hazardous locations exist on our highway system particularly at night under adverse weather conditions. On the rural two-lane roads these locations include sharp horizontal curves, combinations of horizontal and vertical curves, unexpected T-type intersections and narrow bridges. Whereas gore areas and lane drops present potential hazards on the Interstate and freeway systems. The use of raised reflectorized pavement markers in conjunction with edge-line and centerline striping would greatly enhance the delineation of these locations and improve the overall safety.

Contract Objective
To evaluate the use of raised reflective pavement markers at hazardous locations as a means of providing improved roadway delineation and added safety.

Scope
The project includes the purchase and installation (including replacements) of raised reflective pavement markers at hazardous locations and an evaluation of the effectiveness of the installation.
Delineation of Contractor Tasks

To accomplish the contract objective, the contractor shall perform the following tasks:

Task A - Site Selection

Select two or three locations within the State that are considered hazardous and where improved roadway delineation may reduce the hazard.

Task B - Purchase and Installation

Purchase and install the markers at the locations selected in Task A. For this study, marker spacing on curves and tangents may be varied from normal delineation practices in order to provide a more visible lane line. Replace markers as deemed necessary during evaluation period to maintain continuity of the desired delineation.

Task C - Evaluation

The evaluation shall consist of a visual examination supplemented with both day and night photographs or slides and/or 16mm color film. It will also include an evaluation of the costs, accident data before and after (if significant), the ability to guide traffic and produce public acceptance. The evaluation period shall be for one year after the installation is initially completed.
Reporting Requirements

1. Quarterly letter-type progress reports shall be submitted to the contract manager. The report shall contain as a minimum:
   a. work completed
   b. major problems
   c. significant findings

2. At the conclusion of the evaluation period, a final report shall be prepared. This report shall be submitted within 45 days of the completion of the evaluation period. The report shall include as a minimum:
   a. A brief description and sketch of the installation(s).
   b. Sketch or photograph of the type of marker that was installed.
   c. Cost data on the initial installation and replacement.
   d. Comments on the method of installation, accident data, maintenance problems, effectiveness of markers and recommended spacing.

All work under this task order shall be completed on or before Dec. 31, 1978.