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STATE-OF-THE-ART AND OBJECTIVES OF REFLECTIVE RAISED PAVEMENT MARKERS

by

Roger W. McNees

and

James S. Noel

Research Report 322-1
Study Number 2-18-322-1

Sponsored by

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October 1986

TEXAS TRANSPORTATION INSTITUTE
The Texas A&M University System
College Station, Texas 77843



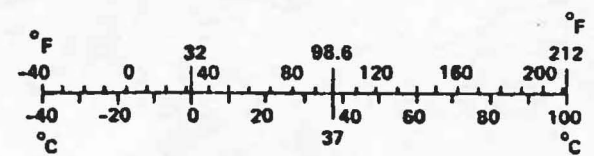
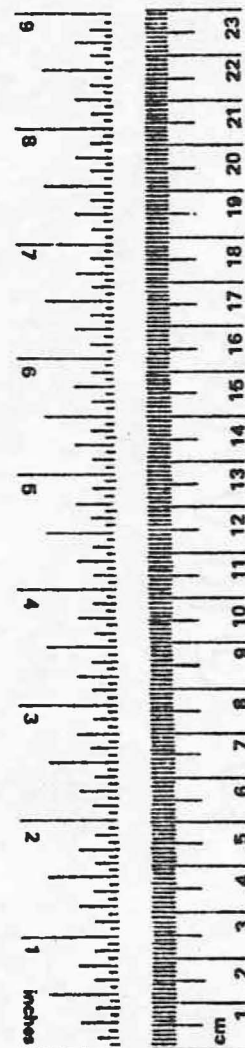
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

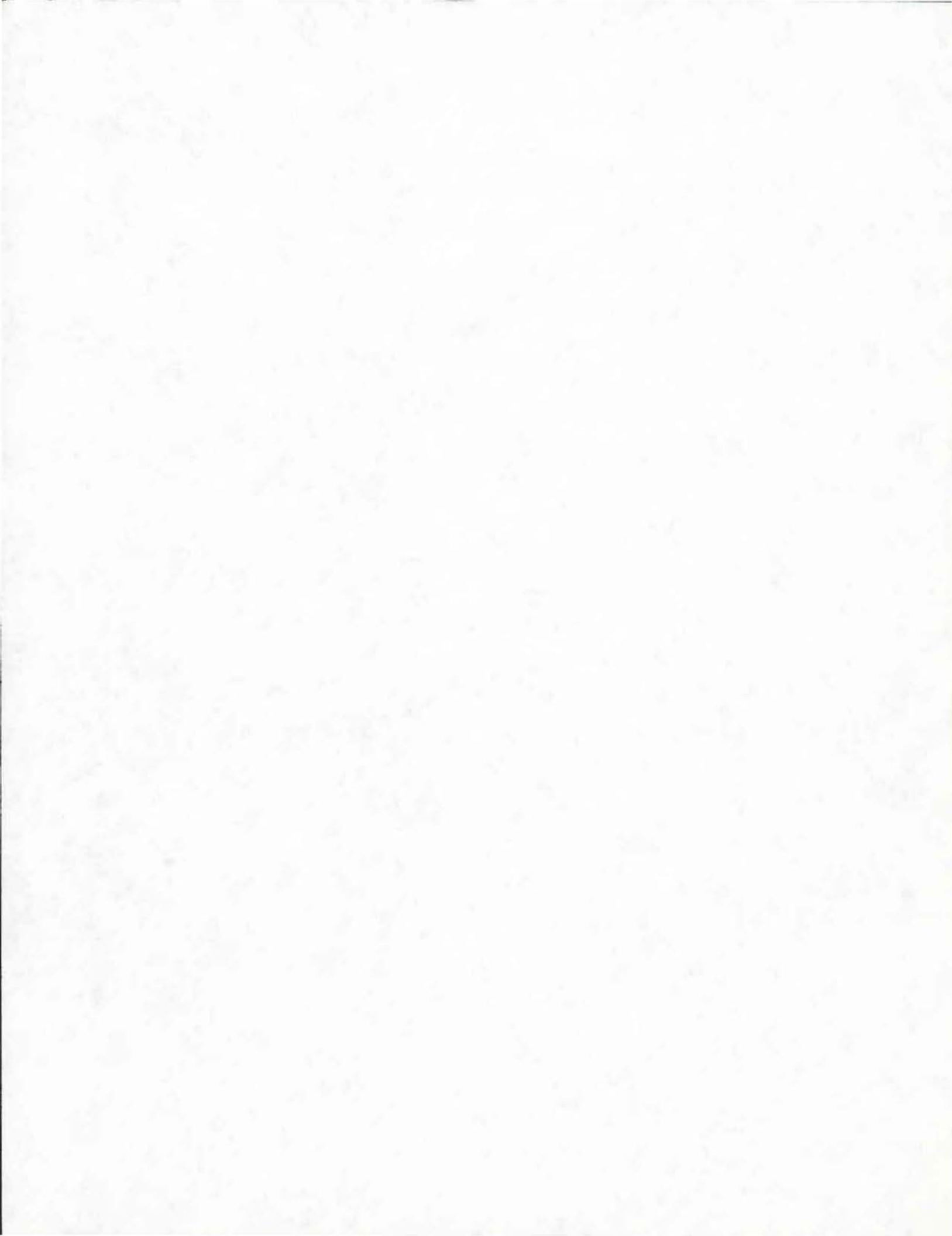
Symbol	When You Know	Multiply by	To Find	Symbol
LENGTH				
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
AREA				
in ²	square inches	6.5	square centimeters	cm ²
ft ²	square feet	0.09	square meters	m ²
yd ²	square yards	0.8	square meters	m ²
mi ²	square miles	2.6	square kilometers	km ²
	acres	0.4	hectares	ha
MASS (weight)				
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
VOLUME				
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft ³	cubic feet	0.03	cubic meters	m ³
yd ³	cubic yards	0.76	cubic meters	m ³
TEMPERATURE (exact)				
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
LENGTH				
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
AREA				
cm ²	square centimeters	0.16	square inches	in ²
m ²	square meters	1.2	square yards	yd ²
km ²	square kilometers	0.4	square miles	mi ²
ha	hectares (10,000 m ²)	2.5	acres	
MASS (weight)				
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
VOLUME				
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m ³	cubic meters	35	cubic feet	ft ³
m ³	cubic meters	1.3	cubic yards	yd ³
TEMPERATURE (exact)				
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



* 1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price \$2.25, SD Catalog No. C13.10:286.



SUMMARY OF RESULTS

This report is the first in a series of four and presents the problem statement of this research. Included are the objectives of the research project, research methodology to be used, and an annotated bibliography. A comprehensive list of references is also included.

The other reports in this series are:

Research Report 322-2 "Reflectivity Retention of Reflective Raised Pavement Markers".

Research Report 322-3 "Retention of Reflective Raised Pavement Markers".

Research Report 322-4F "Executive Summary, Significant Results, and Assorted Tests and Procedures For Reflective Raised Pavement Markers".

IMPLEMENTATION

The laboratory studies and field tests were developed to address the more pressing problems involved with the purchasing, retention and maintenance of reflective raised pavement markers. The results of the studies in these reports indicate modification to existing department practices and procedures which will increase the operational efficiency of the markers on Texas roads and reduce driver confusion. These results if implemented will result in a substantial savings in money and lives in the state.

DISCLAIMER

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 Federal Highway Administration. This report does not constitute a standard, specification or regulation.

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INTRODUCTION

The Texas driving public has come to appreciate the use of raised reflective pavement markers (RPMs) and reflective traffic buttons (RTBs) to supplement the primary traffic markings used on its highways. The reflective raised pavement markers ability to enhance lane delineation at night, especially in wet weather, makes the task of driving under these conditions easier and more comfortable. Their presence is extremely useful when approaching curves, exits, intersections and during power failures on urban freeways.

The experience in Texas, as in other states, has been that the initial installation of the markers is extremely expensive. Two factors serve to compound the cost problem. One is the rapid deterioration of the RPM's effectiveness under moderate traffic volumes, and the other is the excessive loss rates, particularly on asphaltic pavement surfaces. Because several parameters are suspected of contributing significantly to these problems, it is difficult to isolate the influence that each has on a specific highway.

In 1965, the Texas State Department of Highways and Public Transportation (SDHPT) entered into an agreement with the Federal Highway Administration (FHWA) to share in the cost of installing RPMs on a new section of interstate highway through downtown Houston. Since that time, several million RPMs and RTBs have been installed on Texas highways. The installation costs for most of these were shared by the Pavement Marking Safety (PMS) Program.

The SDHPT engineers quickly recognized that the performance of the markers were erratic and often unsatisfactory. Simple observations by those responsible for highway maintenance and safety convinced them that the wear and/or loss rates were excessive. In several of the districts, individual engineers have undertaken comparisons of the various types of markers to find out whether the specific influences that caused premature failures could be isolated.

A Technical Advisory Committee (TAC) was appointed consisting of people in the SDHPT who have had experience with marker behavior. It was the committee's task to work with the Texas Transportation Institute (TTI) in collecting the information and data already available within the Department concerning the problems encountered with RPMs.

The TAC membership consists of:

Richard Oliver, Chairman	File D-18	Matthew Barton	District 14
John Wright	File D-4	Sam Pennartz	District 15
Joe Raska	File D-9	Sawyer Wimberly	District 19
Jon Underwood	File D-10	Manny Aguilera	District 24
James Walding	File D-18A	H. Dexter Jones	District 12
Randy Keir	File D-18T		

STATEMENT OF THE PROBLEM

Distinct and separate problem areas associated with the use of markers have been identified. Specifically these are:

- * Retention
- * Resistance to wear and breakage
- * Costs for both initial installation and maintenance
- * Functionality (ability to present positive route guidance)

The factors associated with these problems and the extent of the problems have been defined and will be discussed in later sections of this report.

RETENTION

Several factors related to the problem of marker retention were indicated. One of the problems was not directly related to the markers themselves. There were very few marker-to-epoxy failures observed where the failure was attributed to the marker itself. However, in some instances, moisture absorbed by the ceramic markers prior to installation is believed to have accelerated this type of failure. Other observed modes of failure included epoxy-to-pavement adhesion failure and failure within the pavement itself (Figure 1).

Three factors found to be most significant to retention failures were deficient installation procedures, defective epoxies, and weak pavement materials. Missing reflective pavement markers (RPMs) were a statewide problem and accounted for 25% to 75% of the RPM systems judged to be ineffective. There was great variation in the number of types of retention failures, often in the same locale, between different types of pavement surfaces. The RPMs were found to have a much greater retention problem than the raised traffic button (RTBs).

Installation errors were found statewide. Personal observations of the application of RPMs on surfaces having dirt particles, excessively darkened premixed epoxy, and insufficient epoxy to completely cover the bonding surfaces were all noted. Figure 2 shows a ceramic marker bonded over an existing paint stripe, Figure 3 shows markers installed on a seam, Figure 4 shows an RPM with the bonding surface incompletely covered, indicated by a pocket knife blade inserted under a corner, and Figure 5 illustrates one type

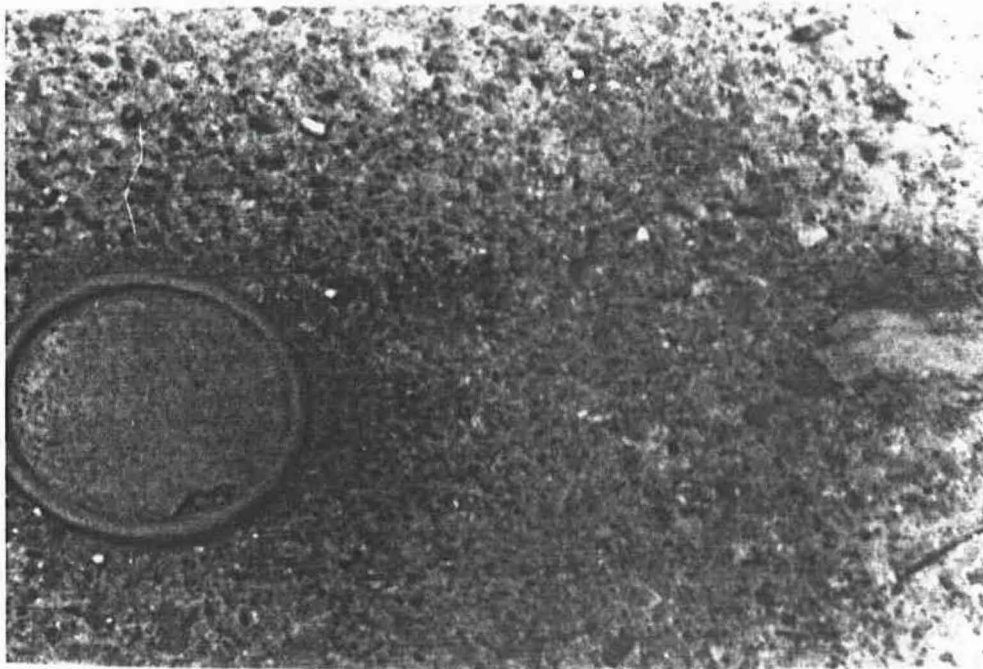


Figure 1. Two Types of Raised Pavement Marker Retention Failures. On the Left the RTB Clearly Separated from the Epoxy. On the Right a Portion of the Portland Cement Concrete Pavement was Extracted with the RPM and Epoxy.

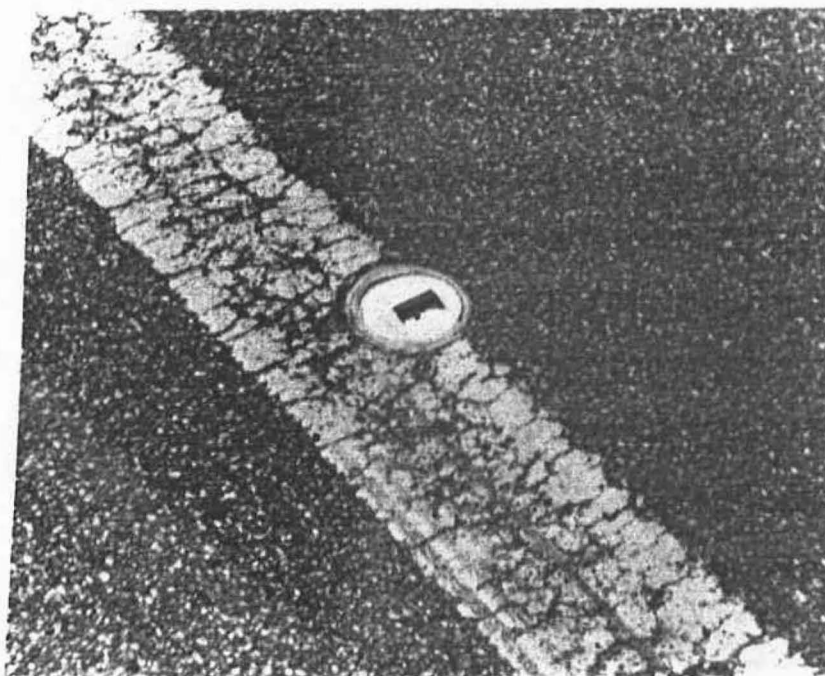


Figure 2. A RTB Bonded Over an Existing Paint Stripe.

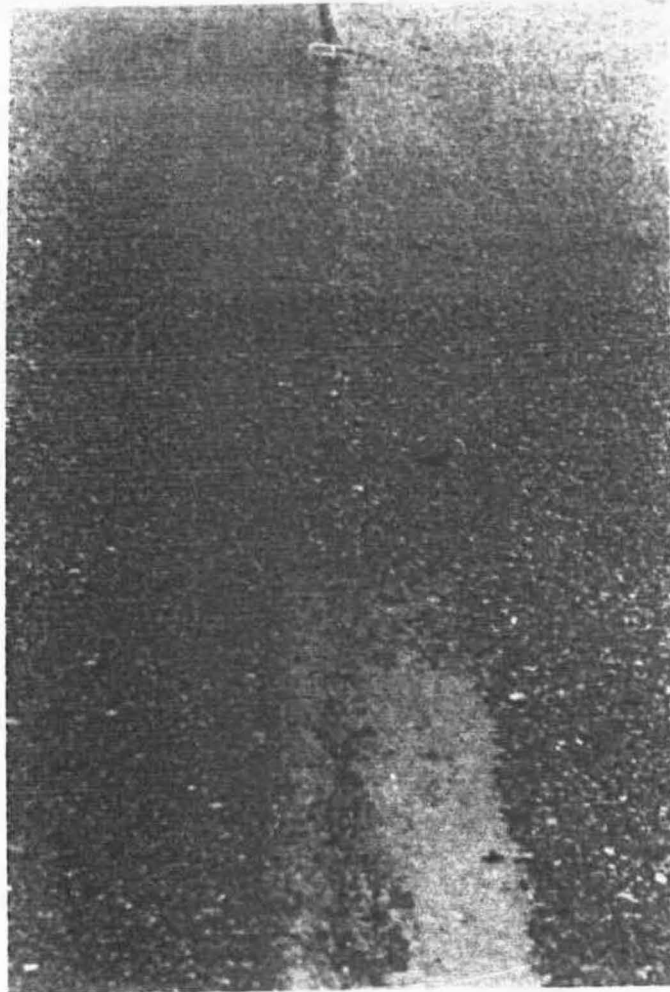
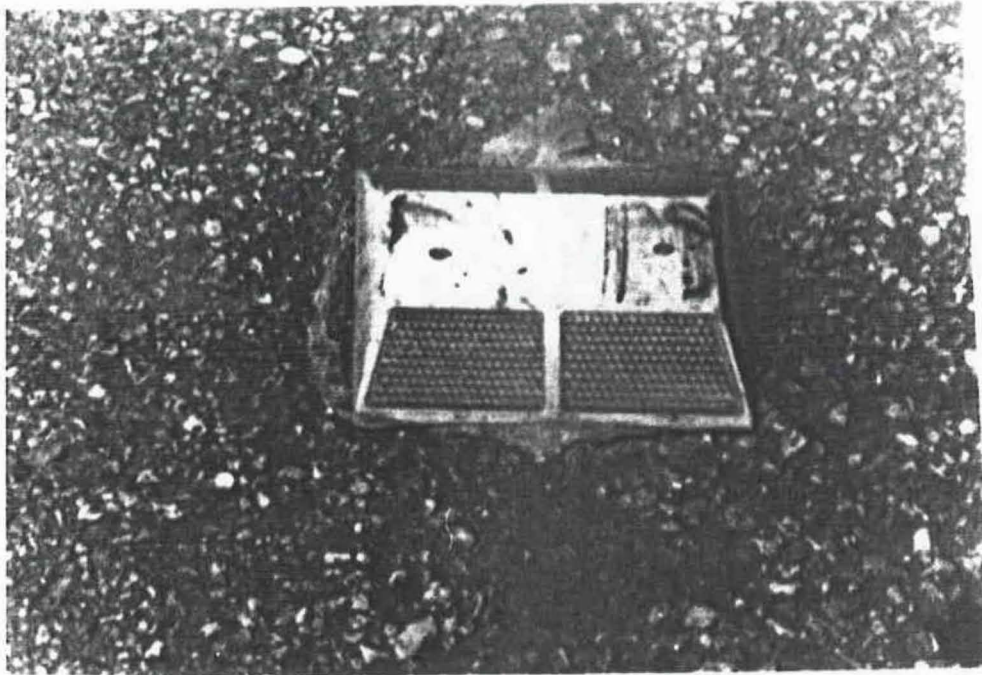


Figure 3. Two Views of a RPM, Type II-AA, Installed on the Seam Between Asphalt Lifts. Note the Poor Performance of the Paint Over the Seam.

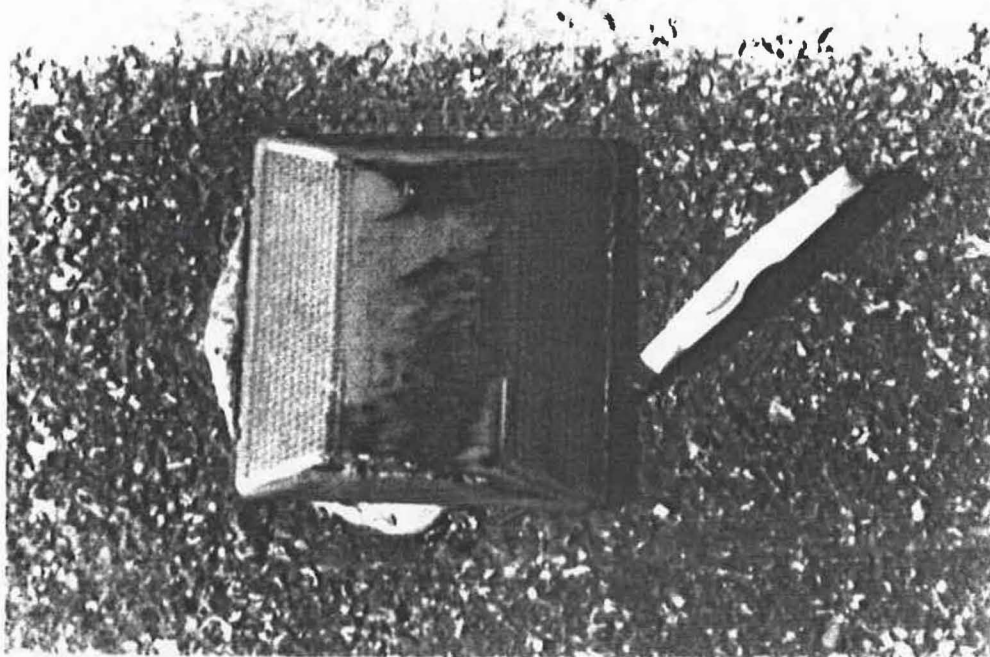


Figure 4. A Poorly Bonded RPM, Type II-AA. While Epoxy was Extruded from Two Sides it is not from the Other Two Leaving the Corners Unsupported.

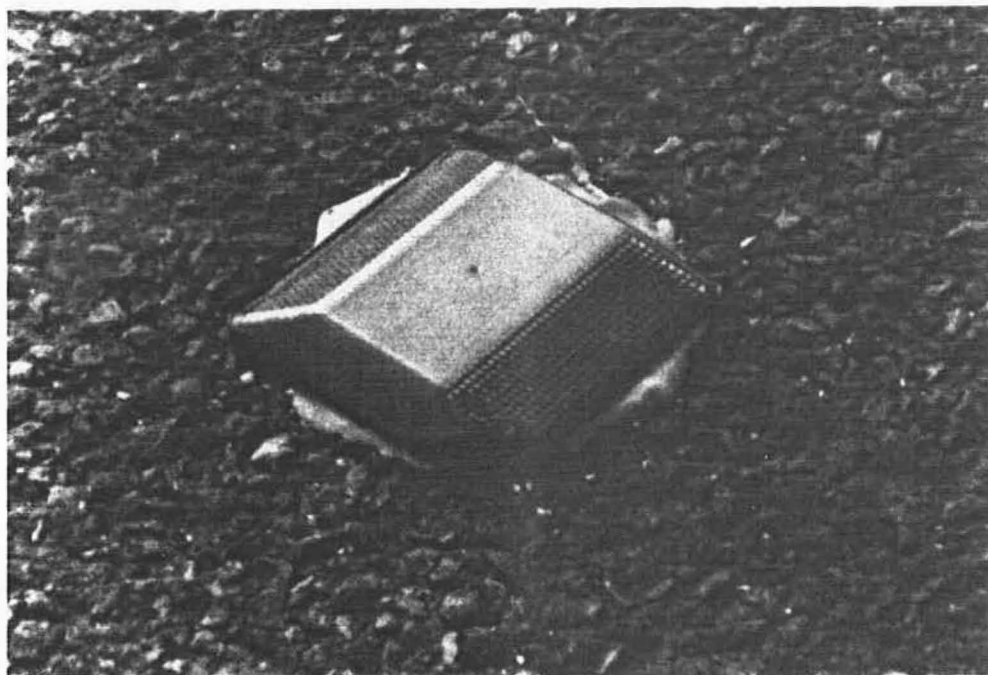


Figure 5. Improper Placement of the Epoxy Leaves the RPM Corners Unsupported and Susceptible to Failure as Shown.

of marker failure that results from incomplete coverage of the bonding surface.

Other installation errors included: sand blasting or grinding the bond surface too deeply before installing the RPM, installing markers in cold and/or wet weather, pushing the marker too firmly against the pavement surface, squeezing the epoxy out and away from the bond surfaces; installing RPMs on green concrete, P.C.C. and A.C.C.; and using inadequately mixed epoxy. All of these were determined to be common problems for both the SDHPT and RPM vendors.

The most severe of these factors was the loss of the RPM due to failure within the paving material itself. While this was a problem with Portland cement concrete and chip-seal coated pavements, it appeared to be more severe on asphaltic concrete pavements. The problem was complicated by erratic behavior between locations but it seemed to be primarily a function of the material properties of the asphaltic concrete. Reports from District 11 indicated that 20% of the RPMs placed on a L-M.C. Item type 290 asphalt surface in October 1981 were retained and that nearly 100% of those placed on asphaltic concrete L-M.C. Item Type 340 had been retained. Similar observations were made on IH-10 near San Antonio where the retention of RPMs on a chip-seal pavement northwest of the city was excellent, while the retention of those east of the city was poor. These markers were installed by the same contractor, at the same time. Figure 8, a photograph taken in District 17, shows an example of these types of failures and also gives evidence that wheel loadings are the primary factor in the dislodging failures.

Figure 6 and 7

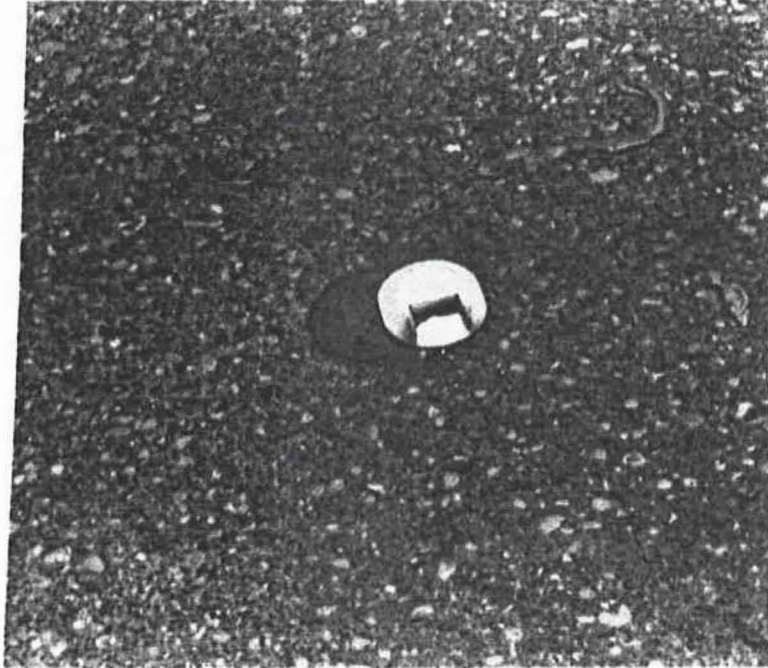


Figure 6. Photographs of a Sliding RTB Indicating the Epoxy did not Properly Cure.

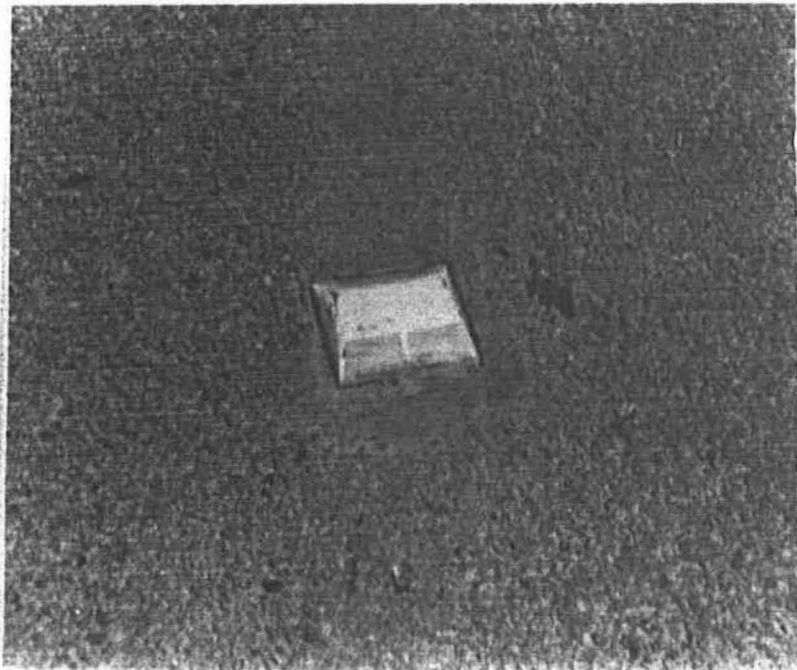


Figure 7. Photograph of a RPM Showing Excessive Flow of the Epoxy. Again Incomplete Cure is Suspected but the Cause Remains Unknown.

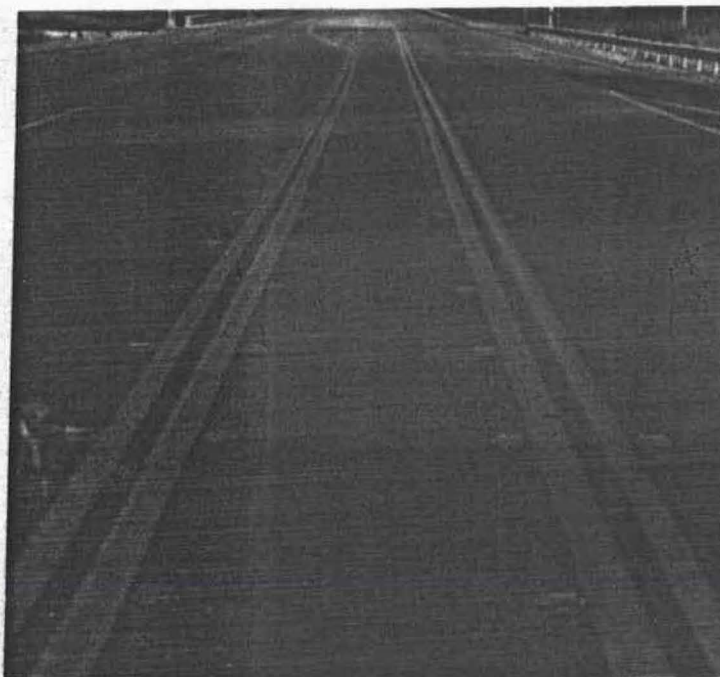


Figure 8. Photograph Showing the Influence of Traffic on Early RPM Loss. The RPMs Inside the Island and in the Turning Lane (on the left) Remain Intact While Those in the Traffic Lane (on the Right) are Missing. These RPMs have been in Place Three Months.

WEAR AND LOSS OF REFLECTIVITY

A related problem was a rapid loss in reflectivity which was observed between the newly installed markers and markers that had been in place for only a matter of months. This problem was observed to be true for both RPMs and RTBs and, was reversible during wet weather.

All RPMs showed a rapid deterioration with time and traffic. Structural deterioration accelerates the loss of reflectance therefore, wear and breakage are related to loss of reflectivity. This explains why lane line markers lose their effectiveness faster than centerline markers and island markers. It was judged that traffic--defined as the number of hits a RPM experienced--was a better indicator of deterioration than time alone.

Examples of diminished reflectivity due to wear and breakage were plentiful wherever RPMs had been in extended service. Worn lenses (Figure 9), missing lenses (Figure 10), cracked bodies (Figure 11), and dirt covered lenses (Figure 12) were frequent occurrences that were observed on Texas highways during the research study. Often the reflectivity was degraded when the marker was pounded vertically into the pavement, as shown in Figures 13 and 14. Large rolls of extruded epoxy in front of a marker similarly tended to degrade their reflectivity.

RPMs on asphaltic concrete pavements which had a retention problem had a higher breakage rate than on similar pavements without a retention problem. This was especially prevalent with the two-color RPMs, which frequently had cracking failures along the weld which induced a loss of reflectivity. Softening of the filler in RPMs during hot weather was reported as a rare mode of breakage in extreme South Texas.

RTBs were judged to be less reflective initially than the RPMs. The RTBs unequivocally were better retained which appears to be related to its shape.

COST

Both the initial installation and the maintenance costs of markers are extremely high, when compared to other types of pavement marking materials. Other states have made attempts to reduce the initial installation costs and are generally unsuccessful. While the initial costs are high, the maintenance and replacement costs are even higher. Once the retention problem has been solved the extended service life will offset both the initial and maintenance costs of the markers.

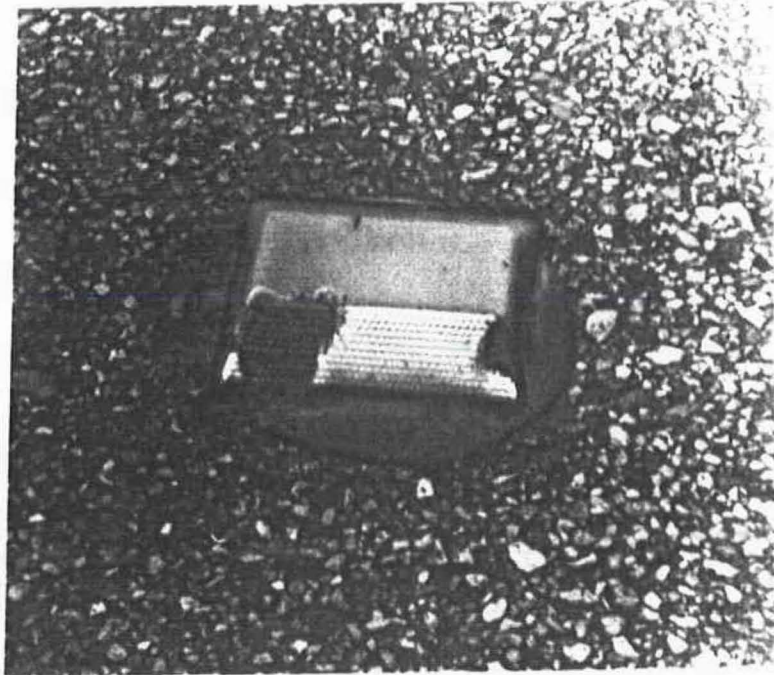


Figure 9. Badly Worn and Broken RPM, Type I-C.

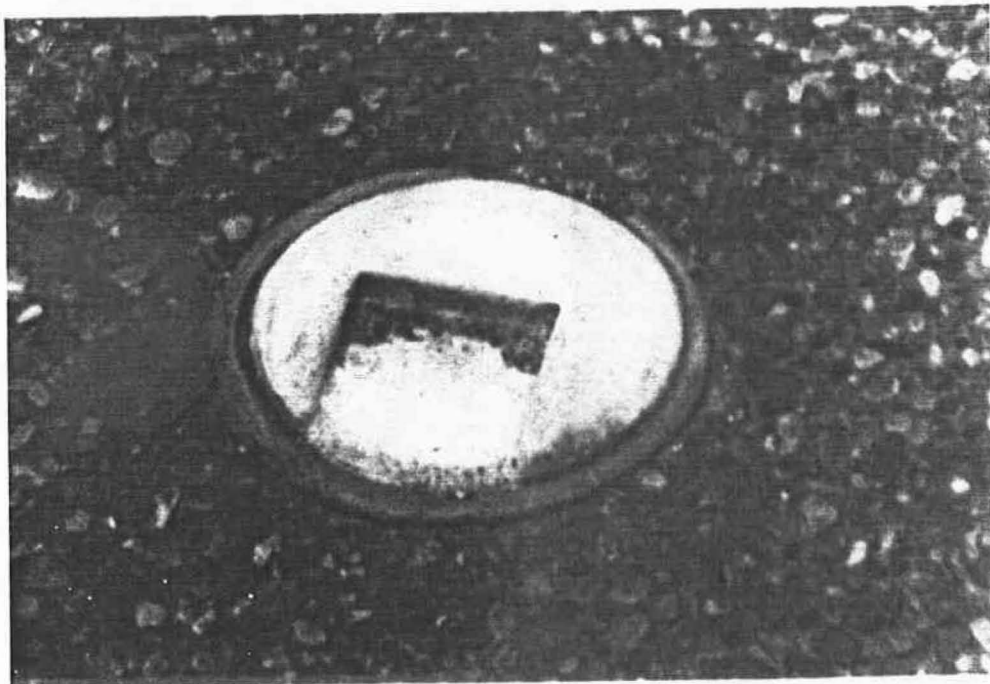


Figure 10. A RTB with the Reflective Lens Completely Missing.

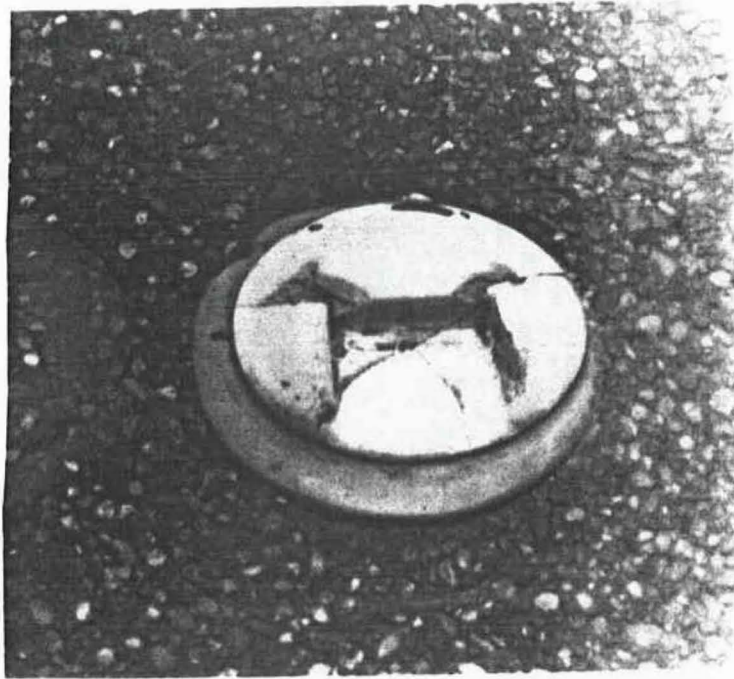


Figure 11. RTB, Type I-C, Badly Broken and Worn. Lens is Completely Missing.

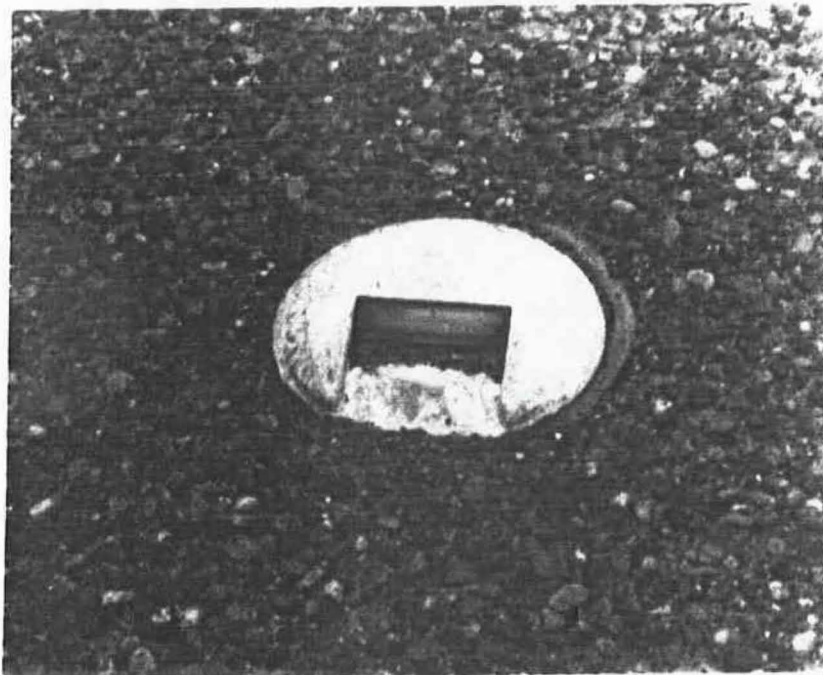


Figure 12. A RTB with the Lens Partially Obscured by Dirt.



Figure 13. A RTB Submerged Into the Asphalt Pavement.

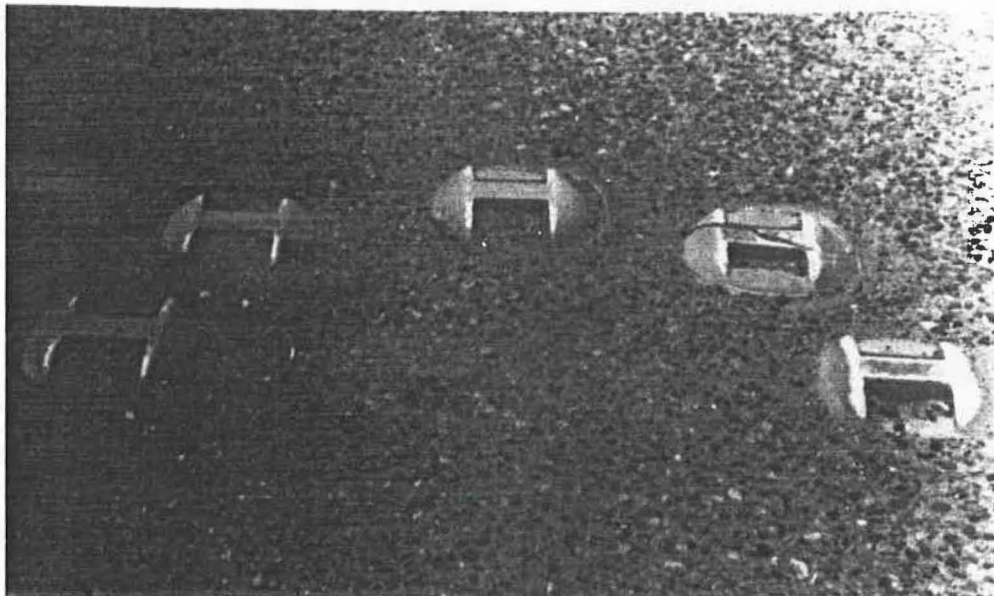


Figure 14. A Photograph of Five RTBs with Different Problems. Note the Amber Glaze Has Rapidly Worn Away, Probably Because of Lowered Lead Content. Also Note the Dirt Covered Lenses and the Tendency for the Markers to Sink Into the Asphalt.

OBJECTIVES

The objectives of this study were to seek out, quantify and document information available within the Department with respect to RPMs and RTBs. The specific objectives were:

1. Compile a list of the types and possible reasons for RPM and RTB failure.
2. Compile and publish known installation guidelines and procedures for RPMs and RTBs.
3. Relate retention of currently available RPMs to facility type, pavement, installation technique, traffic volumes, traffic content, and vehicle impact.
4. Perform feasibility usage analyses (including cost benefit analyses), using information collected for Objectives 1 and 3 found in the literature, to determine the effectiveness of RPMs as a function of the various parameters involved.
5. Subjectively evaluate and relate reflectivity by marker type, time, volumes, truck traffic, or other pertinent parameters.
6. Develop guidelines or warrants for use of RPMs and RTBs.
7. Secure from the Department and include in an Appendix to the Research Report, data and studies relating to the above objectives.
8. Relate retention to the type of epoxy being used in the RPMs and RTBs.

TYPES OF MARKERS BEING STUDIED

The scope of this research limits the types of reflective devices studied to RPMs and RTBs. The RPMs are square in shape, whereas the RTBs are round in shape, as shown in Figure 15. For purposes of this study, the RPMs used were those made by Amerace Corporation and ITL Corporation, and the RTBs were manufactured by Ferro Corporation. All of the RPMs and RTBs come in white and yellow. The RPM also comes in red. All of the marking devices come with mono and bidirectional reflectivity. The RPMs have an acrylic shell and a reflector filled with an epoxy potting compound. The RTBs are made with ceramic bases and plastic lenses with intensive sheeting reflectors. Table 1 presents the trade name, model number, width, length, height, and specific intensity at 0 and 20 incident angles. The specifications were obtained from the manufacturer representatives or SDHPT tests.

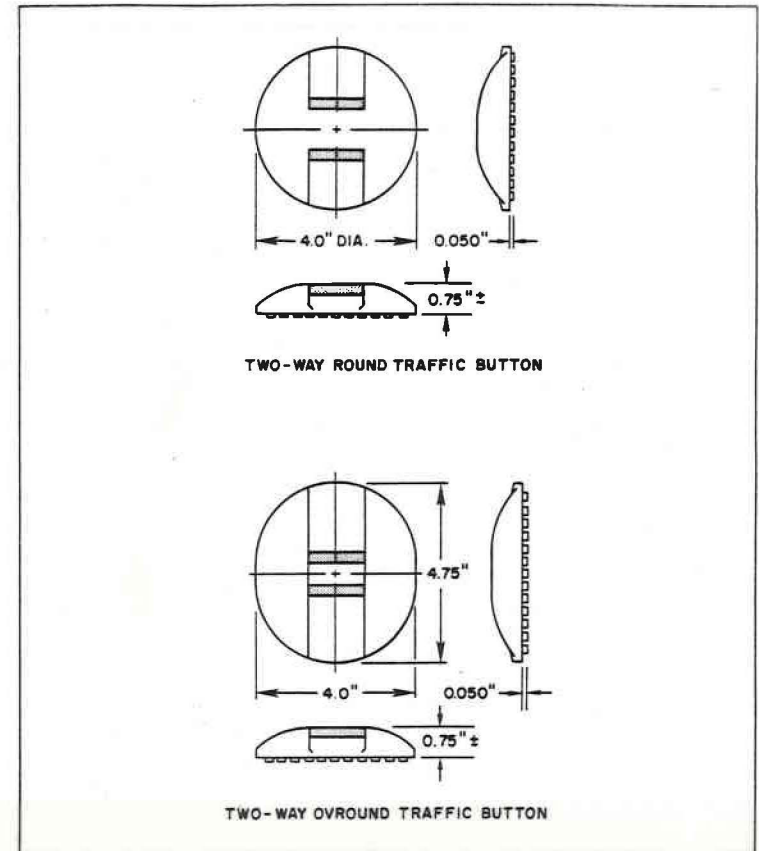
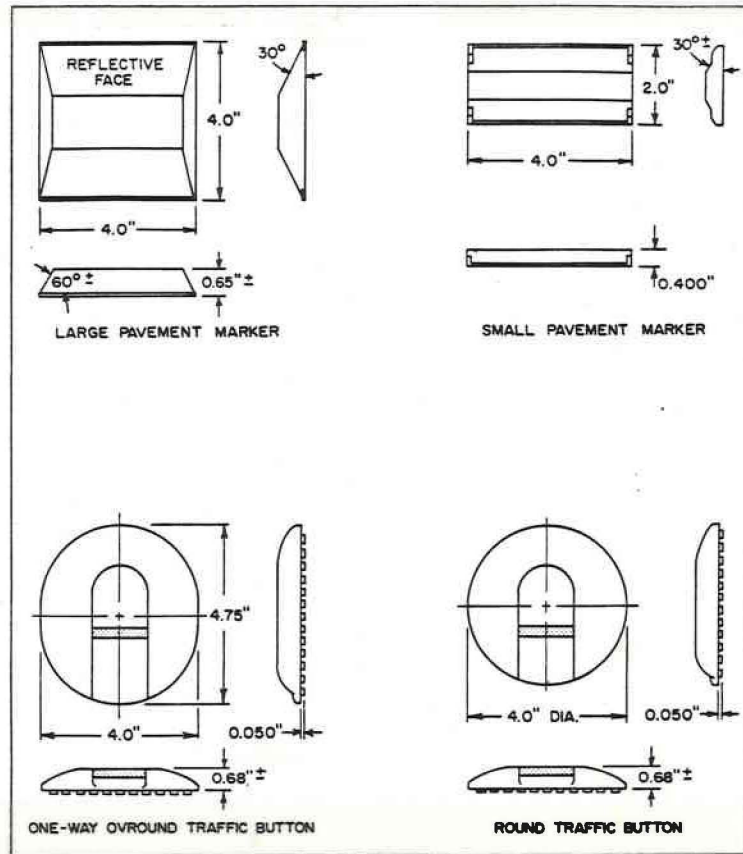


Figure 15. Types of RTBs and RPMs Under Investigation in This Study.

Table 1. Types and Specifications for RPMs and RTBs Used in This Study.

Tradename	Model	Width	Length	Height	Specific Intensity	
					0°	20°
<u>Plastic</u>						
Stimsonite	88	4"	4"	.65"	3.0	1.2
	911	4"	4"	.65"	3.0	1.2
	947	4"	2"	.40"	3.0	1.2
Ray-0-Lite	28	4"	4"	.69"	3.0	1.2
<u>Ceramic</u>						
Permark	P-15 (one-way)	4"		.68"	3.0	1.2
	P-15A (one-way)	4 3/4" (oval)		.68"	3.0	1.2
	P-117 (two-way)	4"		.75"	3.0	1.2
	P-17 (two-way)	4 3/4" (Oval)		.75"	3.0	1.2



PERFORMANCE STUDIES

To determine the magnitude of the problem and possible causes of the types of failures, field observations were performed. These observations were quantitative and the results were compared to a similar study the SDHPT performed in 1977.

Studies of this nature are simple to conduct but subjective. Missing RPMs are easy to see and count in daylight. Undamaged RPMs are not as easily detected, but upon close inspection, there would be little disagreement between reasonable observers as to which were damaged or not. Reflectivity damage could only be determined at night. Difficulties arise when it is necessary to evaluate RPMs during daylight inspections as "Effective", or at night to judge them as "Reflectivity Unimpaired".

DALLAS - SAN ANTONIO STUDY (1)

In March 1977 a systematic two year study of the retention and durability of pavement markers was initiated by the SDHPT at three select locations, one in Dallas and two in San Antonio. The Dallas location was on a six-lane divided highway (SH 183 from Mockingbird Lane to near International Place), and the markers were placed on both inside and outside lane lines. The two locations in San Antonio (IH 10 from Fredericksburg Road southeast to IH 35, and IH 35 from the Stockyards south to IH 10) are both four-lane divided highways, the markers were placed only as lane lines. While not always symmetrical in numbers, each type of RPM was placed exposed to traffic at each test site. Seven different Type II-CR markers were selected for evaluations. They were:

1. Stimsonite RPM, manufactured by Amerace Corporation
2. Stimsonite RPM with pressure sensitive adhesive backing.
3. New type Ray-O-Lite RPM with air-gap reflector, manufactured by Ray-O-Lite Division of ITL.
4. Old type Ray-O-Lite RPM with solid reflector.
5. Ray-O-Lite RPM with pressure sensitive adhesive backing. These markers have air-gap reflectors.
6. Old type Permark Low intensity reflectance RTB manufactured by Ferro Corp. (Model P-17).

7. New type Permark high intensity reflectance RTB manufactured by Ferro Corp. (Model P-117).

Six, twelve and 24 months after the test markers were placed, counts were made of those missing, nonreflective, 25% reflective, 50% reflective, and 75% reflective. It was assumed that all others were undamaged. Types numbered 2, 3, and 5 performed poorly and, except as temporary markers for construction areas, are not currently used by the Department. Markers numbered 1, 4, 6, and 7 are still being used.

The documents and data originally published by the SDHPT are included as Appendix A(TTI Research Report 322-3)

The performance of the RPMs (both Stimsonite and Ray-0-Lite) and of the RTBs (Permark P-17 and P-117) were plotted as a function of the number of vehicles passing in the adjacent two lanes (Figures 16 and 17, respectively). The ADT at each test site was different, therefore a weighted ADT was calculated. Table 2 illustrates how this calculation was made. The average traffic in the two adjacent lanes at all the test sites was found to be 33,000 vpd (or 12.15×10^6 vehicles/year).

The results were plotted as the average traffic in the adjacent two lanes. They included (1) the percent of RPMs remaining in place, (2) the percent of RPMs undamaged, and (3) the percent of RPMs effective. The definition of numbers (1) and (2) is straightforward, and it reflects actual numbers counted on the roadway. The percent of the original RPMs remaining in place is shown by the topmost heavy solid curve, and the percent of the markers still undamaged is shown by the lower (and lighter) solid curve. The number of RPMs effective, is a much more subjective term. The effective marker systems take into account (1) the number of missing markers and (2) the reduction in reflectivity of the remaining markers. The reflectivity is evaluated across all markers and not reduction in reflectivity for individual markers. These results are plotted on the graphs as a broken line. A review of Figures 16 and 17 indicates that the retention of RTBs is better than that of the RPMs, however, RPMs behaved much better in terms of reflective effectiveness and resistance to damage.

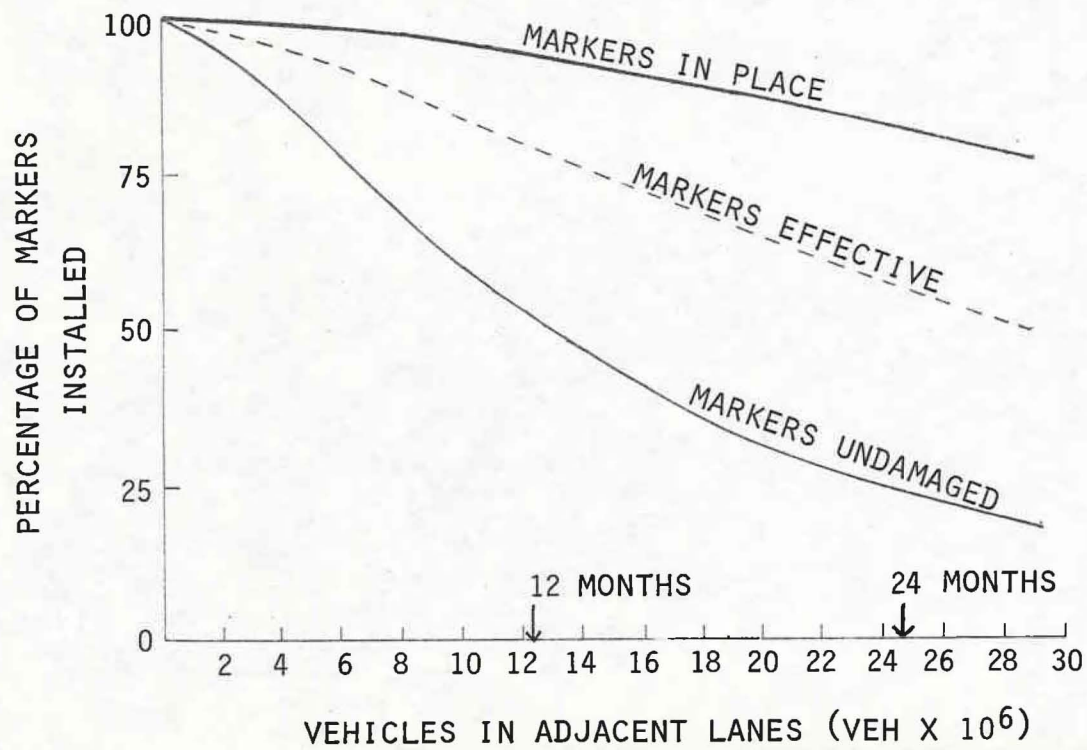


Figure 16. Curves Showing the Deterioration of RPMs Markers (Both Stimsonite and Ray-O-Lite) Observed in the 1977 Dallas - San Antonio Test. The Average Daily Traffic in the Two Lanes Adjacent to the Markers was 33,300 vpd.

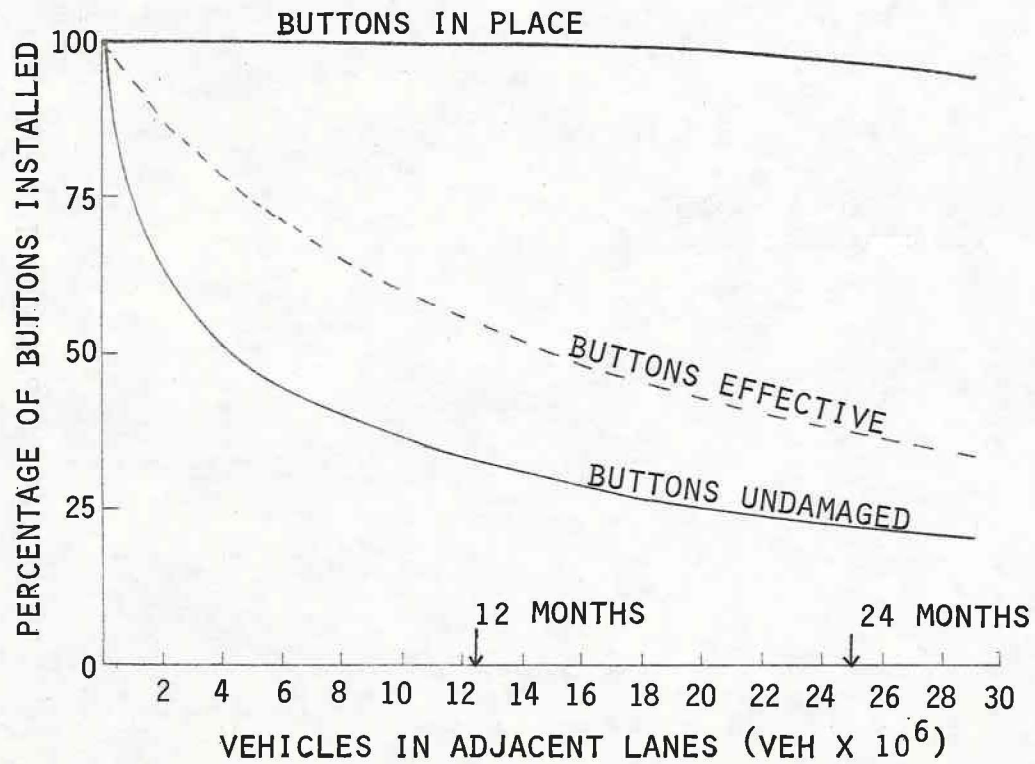


Figure 17. Curves Showing the Deterioration of RTBs (Permark P-17 and P-117) Observed in the 1977 Dallas - San Antonio Test. The Average Daily Traffic in the Two Lanes Adjacent to the Buttons was 33,300 vpd.

Table 2. Calculation of Average Daily Traffic for Dallas and San Antonio Test Markers.

Location	Type Pavement	Number of Lanes	ADT (Both Ways) (vpd)	Number of Test Markers	Two Lane ADT (vpd)	Markers x Two Lane ADT
<u>San Antonio</u>						
I-10	Asphaltic Concrete	4-lane	90,000	78	45,000	3.51×10^6
I-35	Asphaltic Concrete	4-lane	80,000	41	40,000	1.64×10^6
<u>Dallas</u>						
SH-183	Portland Cement Concrete	6-lane	70,000			
			Outside laneline	60	23,333	1.40×10^6
			Inside laneline	60	23,333	1.40×10^6
			TOTALS	239		7.95×10^6

Weighted Average Daily Traffic = $\frac{7.95 \times 10^6}{239} = 33,300$ vpd
 overall average in adjacent two lanes divided by the number of markers.

RELATIVE PERFORMANCE OF MARKER TYPES

It is relatively rare that different types and makes of markers are installed at the same time and location for comparison. Because of the technical interest of a few SDHPT engineers, it has occurred in a few places. The following two sections describe the observed results.

Comparison of 947s, 88s, and P-117s

In April, 1981, District 15 installed three types of markers, over a three mile segment of IH 10 east of San Antonio (asphaltic concrete). Each of the markers were TY II-CR and were used to supplement the lane lines in both directions of the four-lane highway. Center and edge lines were not involved in the test.

The three types of markers compared were:

Stimsonite No. 947

Stimsonite No. 88

Permark No. P-117

The ADT in 1980 indicated the traffic volume was approximately 18,500 vpd both directions. The observations were made in July, 1982. Approximately 4.22×10^6 vehicles had traveled the two lanes on each side of the markers since they were installed. The data were taken from a moving automobile both day and night. The data collected are included in Appendix B.

The results of these observations are shown plotted against the summary curves from the Dallas - San Antonio study in Figure 18 for the 947s, Figure 19 for the 88s, and Figure 20 for the P-117s. It is apparent that this section of highway does not have good retention properties. While only 2% of the P-117s were gone (all epoxy failures), 13% of the 88s and 79% of the 947s had disappeared! This confirmed by other observations, that the RTBs are retained better than the RPMs.

These data indicate the rather poor performance of all RPMs found on many of the asphaltic concrete pavements in Texas. The magnitude of this problem is extensive and will be expensive to rectify. The next section presents data from IH 10 northwest of San Antonio, where the markers are on an asphaltic pavement; and there was no marker retention problem.

Installation Date: April, 1981
 Pavement: Hot mix asphalt concrete
 Tradename: Stimsonite 947 (Type II-CR)
 ADT (two adjacent lanes only): 9,250
 Total Markers: 392

Note: Open symbols represent daytime data
 Solid symbols represent nighttime data

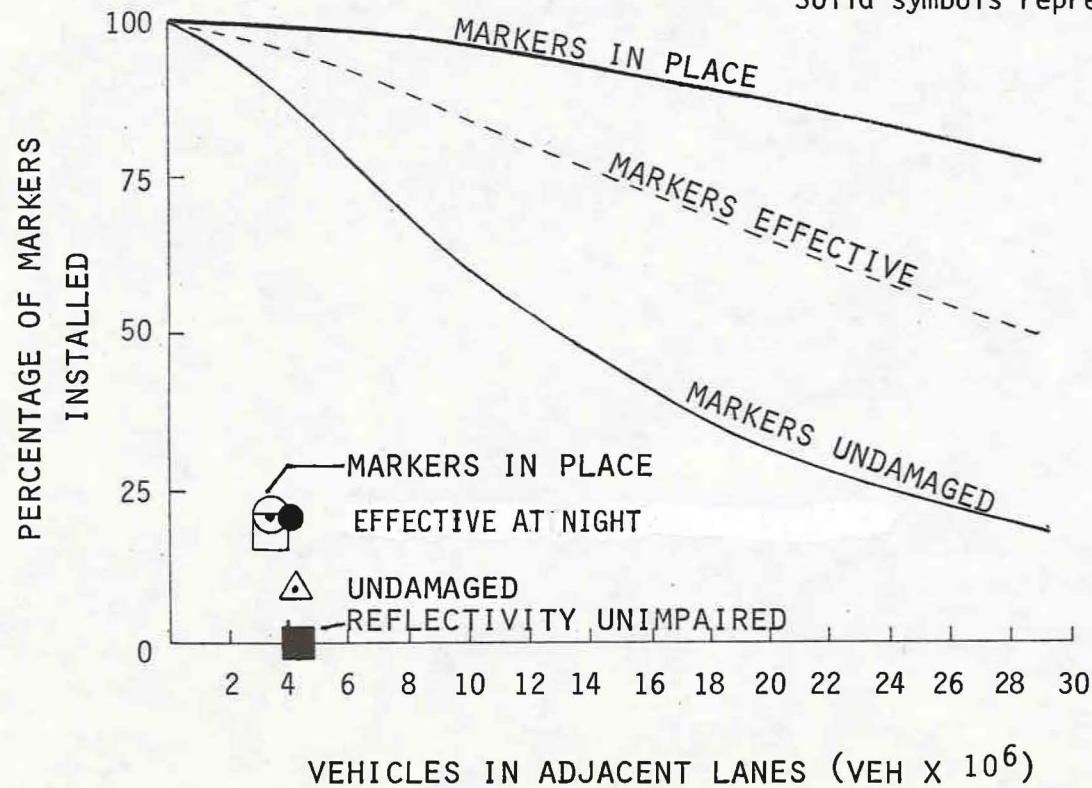


Figure 18. Observed Condition of RPMs on IH 10 East of San Antonio (Both Directions) Compared to RPM Performance Reported in the 1977 Dallas - San Antonio Study.

Installation Date: April, 1981
 Pavement: Hot mix asphalt concrete
 Tradename: Stimsonite 88 (Type II-CR)
 ADT (two adjacent lanes only): 9,250
 Total Markers: 392
 Note: Open symbols represent daytime data
 Solid symbols represent nighttime data

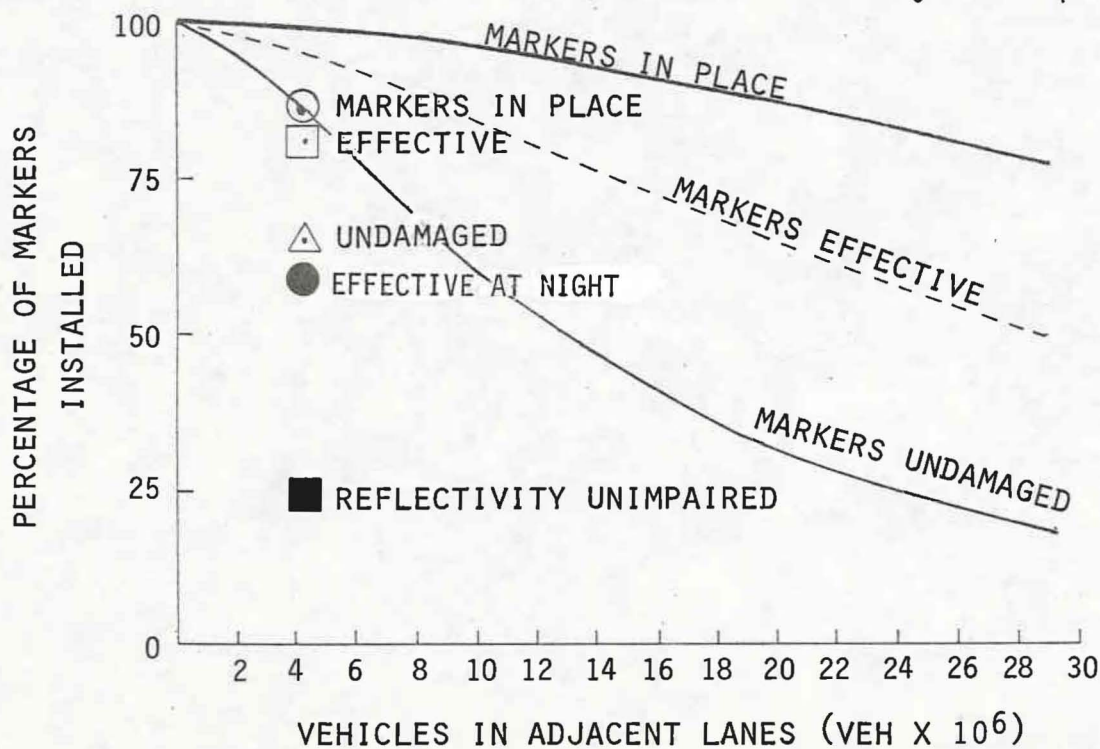


Figure 19. Observed Condition of ROMs on IH 10 East of San Antonio (Both Directions) Compared to ^{RPM's} RPM Performance Reported in the 1977 Dallas - San Antonio Study.

Installation Date: April, 1981
 Pavement: Hot mix asphalt concrete
 Tradename: Permark P117
 ADT (two adjacent lanes only): 9,250
 Total Buttons: 392
 Note: Open symbols represent daytime data
 Solid symbols represent nighttime data

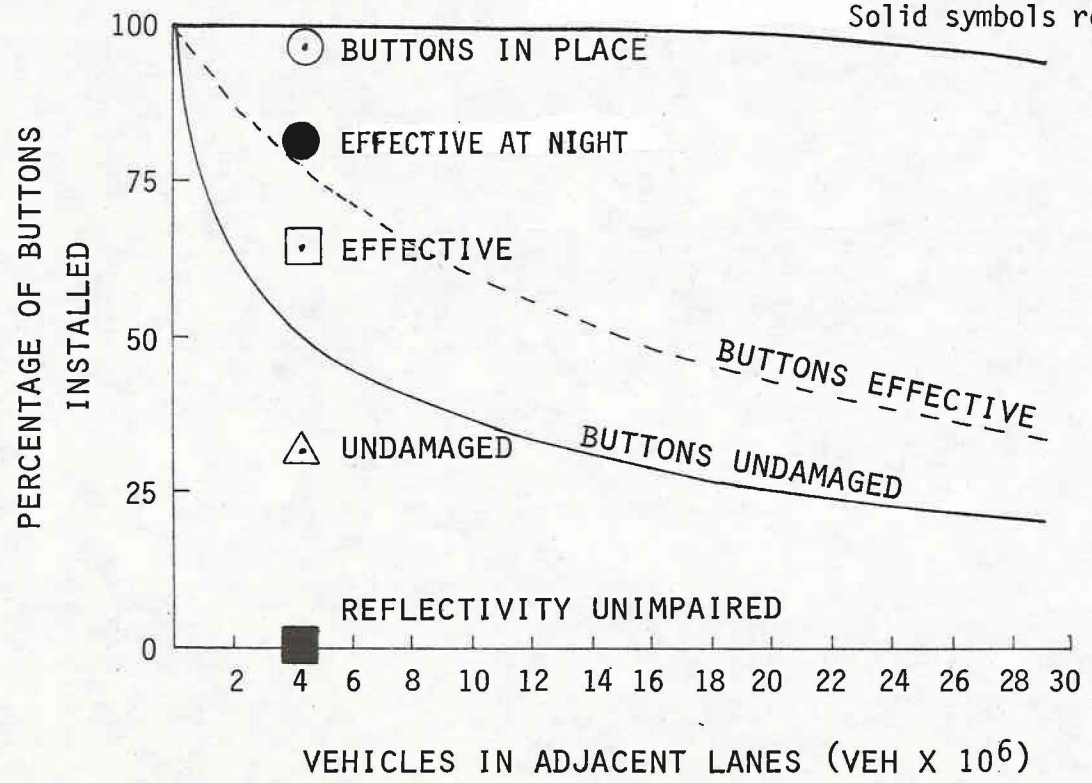


Figure 20. Observed Condition of RTBs on IH 10 East of San Antonio (Both Directions) Compared to RTB Performance Reported in the 1977 Dallas - San Antonio Study.

Comparison of 88s With P-117s

At about the same time that the test markers were placed on IH 10 east of San Antonio, a much longer test section of RPMs were placed on IH 10 northwest of San Antonio. The test section continues from south of Boerne to Kerrville, Texas a distance of more than 30 miles. RTBs (P-117s) were used to supplement the laneline northwest bound and RPMs (88s) to supplement the laneline southeast bound. The ADT by lane distribution of 12,000 vpd in each direction is unknown, as is the proportion of trucks. These RPMs were placed by the same contractor that installed the RPMs east of San Antonio.

The results of the performance of these markers is shown in Figures 21 and 22 for the RPMs and RTBs, respectively. The count was for the test section near Boerne, and it involved more than 700 markers in each direction; it represents the largest single sample that was taken. It is readily apparent that the performance of these RPMs is superior to the other test section previously described.

Both types of markers were retained, so the superiority of the RTB retention properties over the RPMs is not obvious. The susceptibility of the reflecting element of the RTB to early damage is obvious.

But the most striking conclusion that can be drawn from these data is that when good retention is observed, there is a parallel improvement in the resistance to breakage and wear. This conclusion was found to be valid, at least, when comparing RPM performance on asphaltic pavements.

RPM PERFORMANCE ON ASPHALTIC CONCRETE

District 14's count of RPMs on SH 71 near Bergstrom Airforce Base reflects the poor ability of some asphaltic concrete pavements to retain markers. These results, first for the eastbound four lanes west of Bergstrom Main Gate and second for the eastbound two lanes east of the Main Gate, are shown in Figures 23 and 24, respectively. The RPMs were installed at the same time.

Not only is the poor retention obvious, (39% of those to the west and 81% of those to the east are missing), but also a higher than usual percentage of those remaining were judged ineffective. This observation is typical of all types of asphaltic concrete.

Installation Date: April, 1981
 Pavement: Hot mix asphalt concrete
 Tradename: Stimsonite 88 (Type II-CR)
 ADT (two adjacent lanes only): 6,000
 Total Markers: 700
 Note: Open symbols represent daytime data

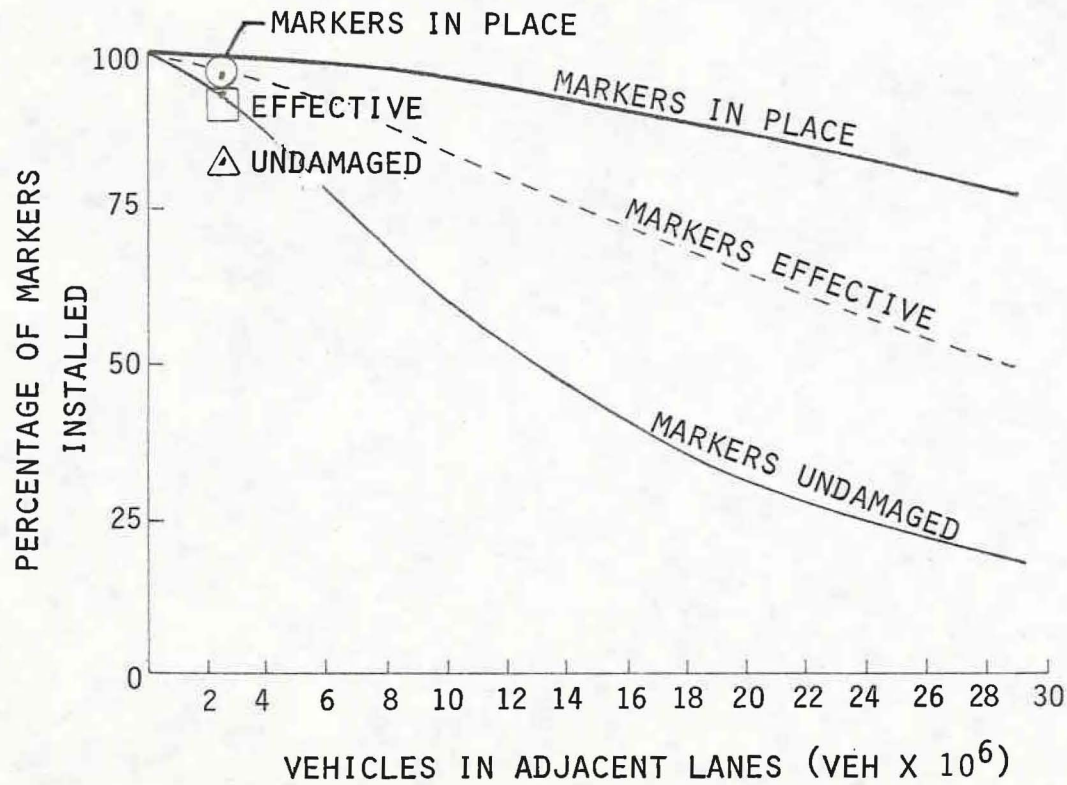


Figure 21. Observed Condition of RPMs on IH 10 Northwest of San Antonio (Eastbound) Compared to RPM Performance Reported in Dallas - San Antonio Study.

Installation Date: April, 1981
 Pavement: Hot mix asphalt concrete
 Tradename: Permark P117 (Type II-CR)
 ADT (two adjacent lanes only): 6,000
 Total Buttons: 736
 Note: Open symbols represent daytime data

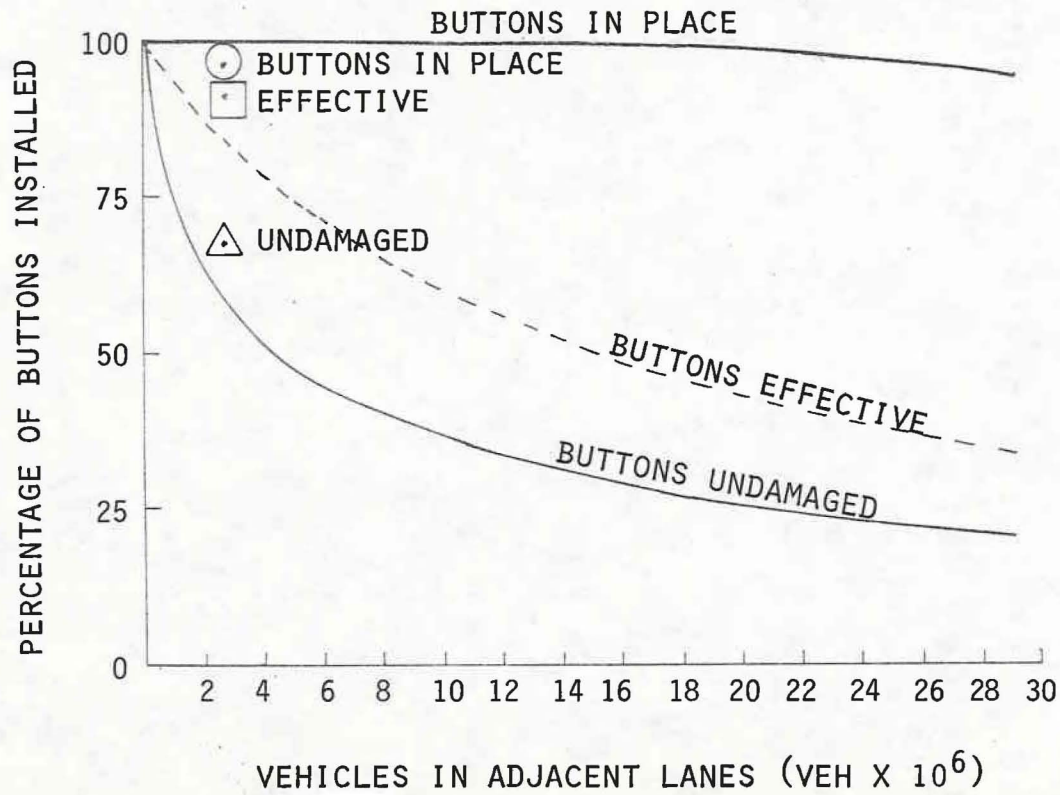


Figure 22. Observed Condition of RTBs on IH 10 Northwest of San Antonio (Westbound) Compared to RTB Performance Reported in Dallas - San Antonio Study.

Installation Date: September, 1979
 Pavement: Asphalt concrete
 Tradename: Stimsonite 88 (Type II-CR)
 ADT (two adjacent lanes only): 14,750
 Total Markers: 213
 Note: Open symbols represent daytime data

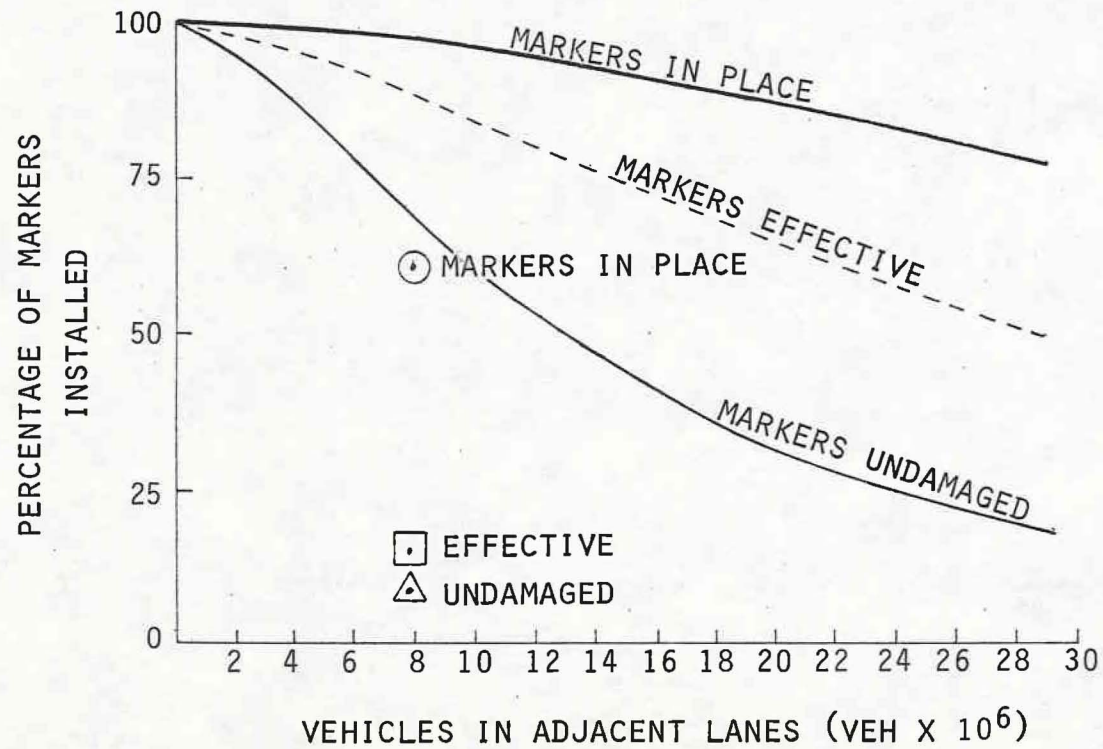


Figure 23. Observed Condition of RPMs on SH 71 West of the Bergstrom Main Gate (Eastbound) Compared to RPM Performance Reported in 1977 Dallas - San Antonio Study.

Installation Date: September, 1979
 Pavement: Asphalt concrete
 Tradename: Stimsonite 88 (Type II-CR)
 ADT (two adjacent lanes only): 8,900
 Total Markers: 38
 Note: Open symbols represent daytime data

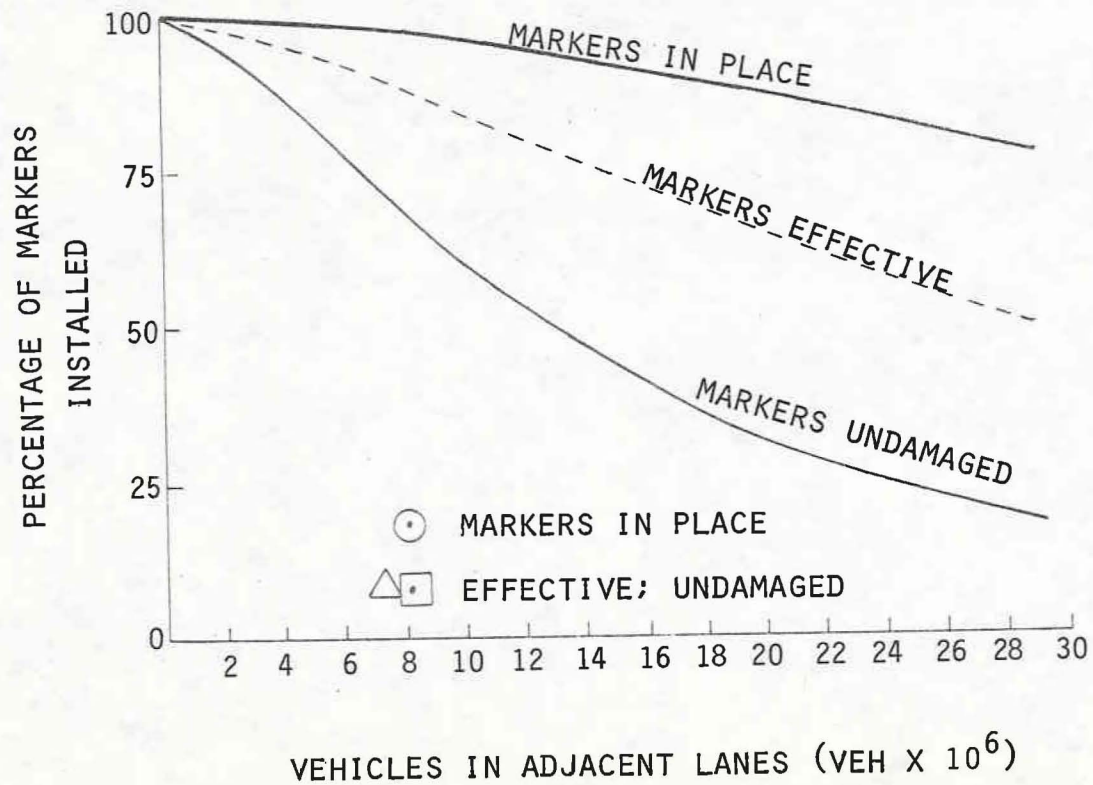


Figure 24. Observed Condition of RPMs on SH 71 East of The Bergstrom Main Gate (Eastbound) Compared to RPM Performance Reported in 1977 Dallas - San Antonio Study.

The behavior of RPMs on asphaltic concrete is demonstrated by the points plotted in Figures 25 and 26. These data show the performance of RPMs on the eastbound and westbound lane lines of US 290 east of Austin. The traffic counts and percentage of truck traffic in both directions are identical. The surface courses of both lanes were placed in August, 1978, and both lines of markers were placed in June, 1979.

In the eastbound direction more than three times the RPMs are missing than in the westbound direction. This is due to the trucks being either loaded in the eastbound direction and empty in the westbound direction. While a comparable number of RPMs were judged effective in both directions, the number rated as damaged in the eastbound direction was double that of the westbound direction. This type of erratic and unexplained behavior is more characteristic of asphaltic pavements than those of Portland cement concrete pavement.

PERFORMANCE ON PORTLAND CEMENT CONCRETE

To provide an indication of the overall performance of RPMs on Portland cement concrete, the section of IH 10 west of Houston between SH 6 and Exit 750 where there are three lanes each way was surveyed. These RPMs were installed in July 1977. Assuming the traffic is evenly divided between all six lanes, each have seen about 42 million vehicles pass in the adjacent two lanes. The data were originally collected by laneline and, as would be expected, the outside lane showed slightly more distress than the inside lane. In Figure 27 the combined results for all lanelines in both directions are shown.

After five years and 42 million vehicles the results are nearly the same as those predicted by extrapolating the curves found from the Dallas - San Antonio Study. It is more informative to note that 35% are missing, and only 2% were attributed to pavement failures. Refer to the data in Appendix A. The remaining 33% were judged to be equally divided between RPM-to-epoxy failures and epoxy-to-pavement failures.

Installation Date: June, 1979
Pavement: Asphalt concrete
ADT (two adjacent lanes only): 5,000
Total Markers: 297

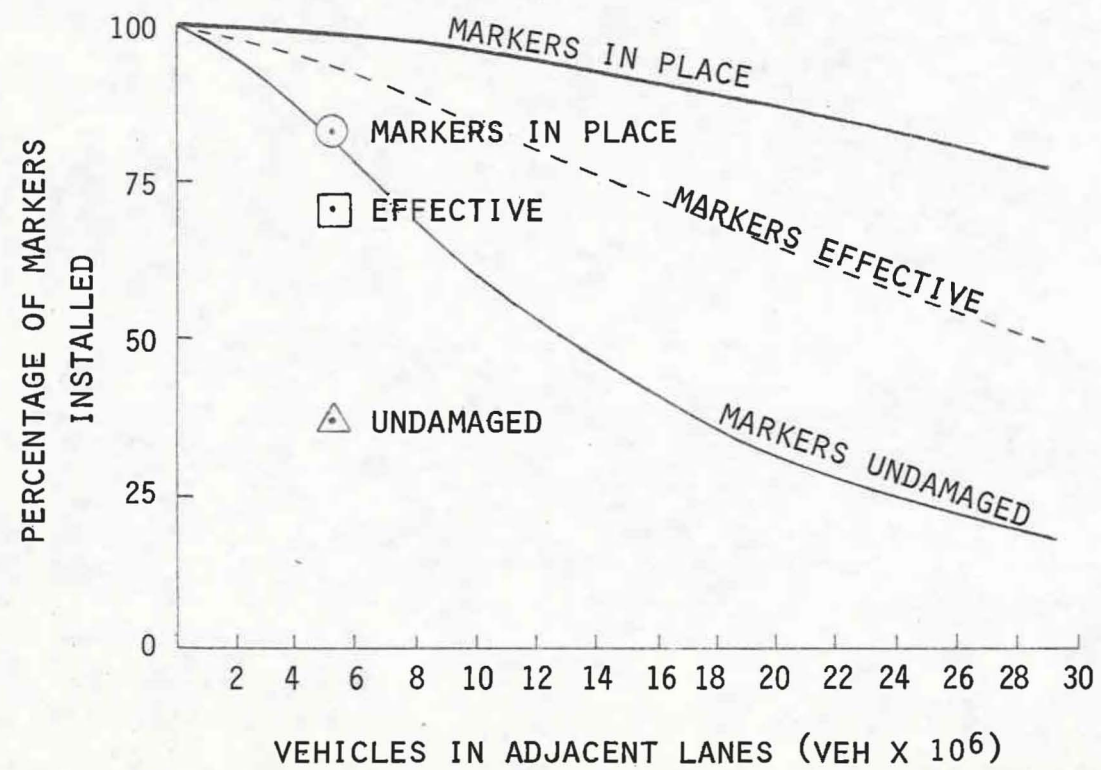


Figure 25. Observed Condition of RPMs on U.S. 290 East of Austin (Eastbound) Compared to RPM Performance Reported in the 1977 Dallas - San Antonio Study.

Installation Date: June, 1979
Pavement: Asphalt concrete
ADT (two adjacent lanes only): 5,000
Total Markers: 297

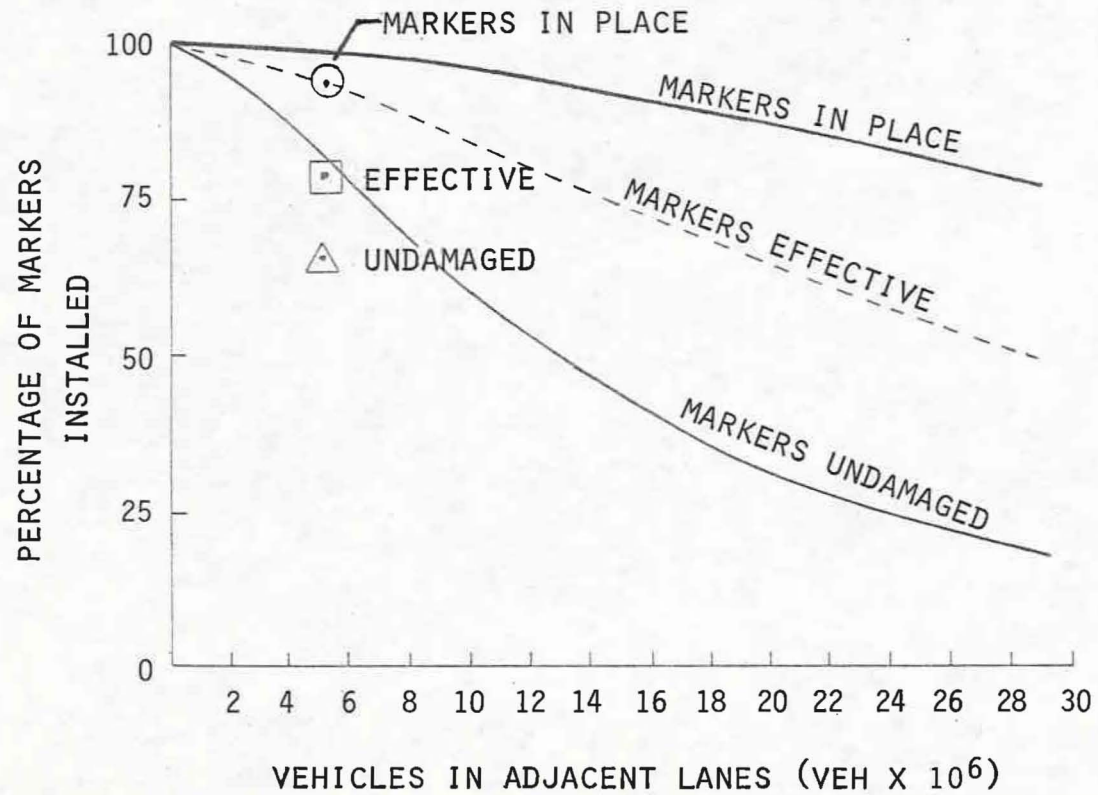


Figure 26. Observed Condition of RPMs on U.S. 290 East of Austin (Westbound) Compared to RPM Performance Reported in the 1977 Dallas - San San Antonio Study.

Installation Date: July, 1977
 Pavement: Portland Cement Concrete
 Tradename: Stimsonite 88 (Type II-CR)
 ADT (both directions): 69,000
 Total Markers: 403
 Note: Open symbols represent daytime data

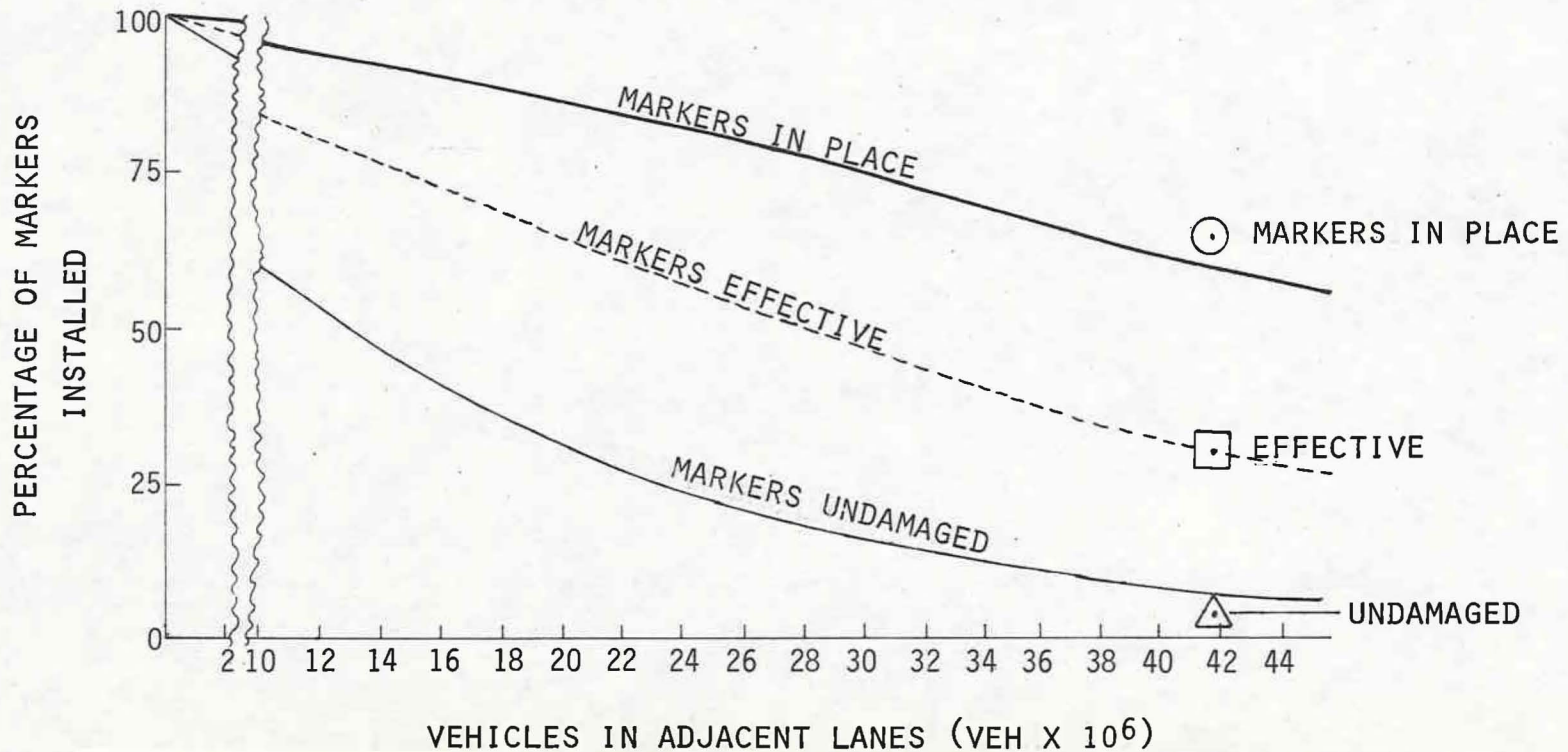


Figure 27. Observed Condition of RPMs on IH 10 West of Houston (Both Directions) Compared to RPM Performance Reported in the 1977 Dallas - San Antonio Study.

SUPERIOR RTB PERFORMANCE

District 14 has an example of superior RTB performance on the lower and upper levels of IH 35 in Austin. RTBs were used to form the laneline stripes. At this location Type II-CRs were used for the lead RTB and three Type I-C were equally spaced to form the 10 foot stripe. Figure 28 shows the results for the Type IIs on a concrete pavement, Figure 29 for Type I's on concrete, Figure 30 for Type IIs on asphaltic pavement, and Figure 31 for Type Is on asphaltic pavement.

The performance was superior to the RPMs though the Type II's did not perform as well as the Type I's. This may be due to the inherent fragility of the two-way RTB's compared to those reflecting in only one direction. It is suspected that the Type II-CR, especially the round ones (P-117), are more susceptible to fracturing than the Type I-C. On the other hand, it may be that the lead RTB in a stripe receives more impacts than the others.

The performance of the Type I-C was exceptional especially on PCC. After passage of 8 years and 80 million vehicles, over 87% were judged effective, 74% undamaged, and less than 1% were missing. The low percentage of truck traffic (5.4%) is a contributing factor. Nonetheless this was by far the most impressive RTB performance.

This is an example showing that it is possible to make markers, especially RTBs, provide long and satisfactory service.

RPMs In Urban Areas

The urban performance of the RPM is especially critical because of the high cost and, more importantly, the safety risks associated with their maintenance. The urban markers are outperforming those on more lightly traveled roads of the state in terms of surviving traffic counts.

Data were taken on the performance of RPM's on IH 45 in downtown Houston between Allen Parkway and IH 10. On the four southbound lanes, both Stimsonite 88s and Ray-0-Lites were installed in June, 1980. The four northbound lanes have Stimsonite 88s which were installed in June, 1981. Figures 32 and 33 reflect these findings. The RPM's are performing better than those from the earlier Dallas - San Antonio Study.

Installation Date: February, 1974
 Pavement: Portland Cement Concrete
 Tradename: Permark P117 (Type II-CR)
 ADT (two adjacent lanes only): 27,450
 Total Markers: 132
 Note: Open symbols represent daytime data

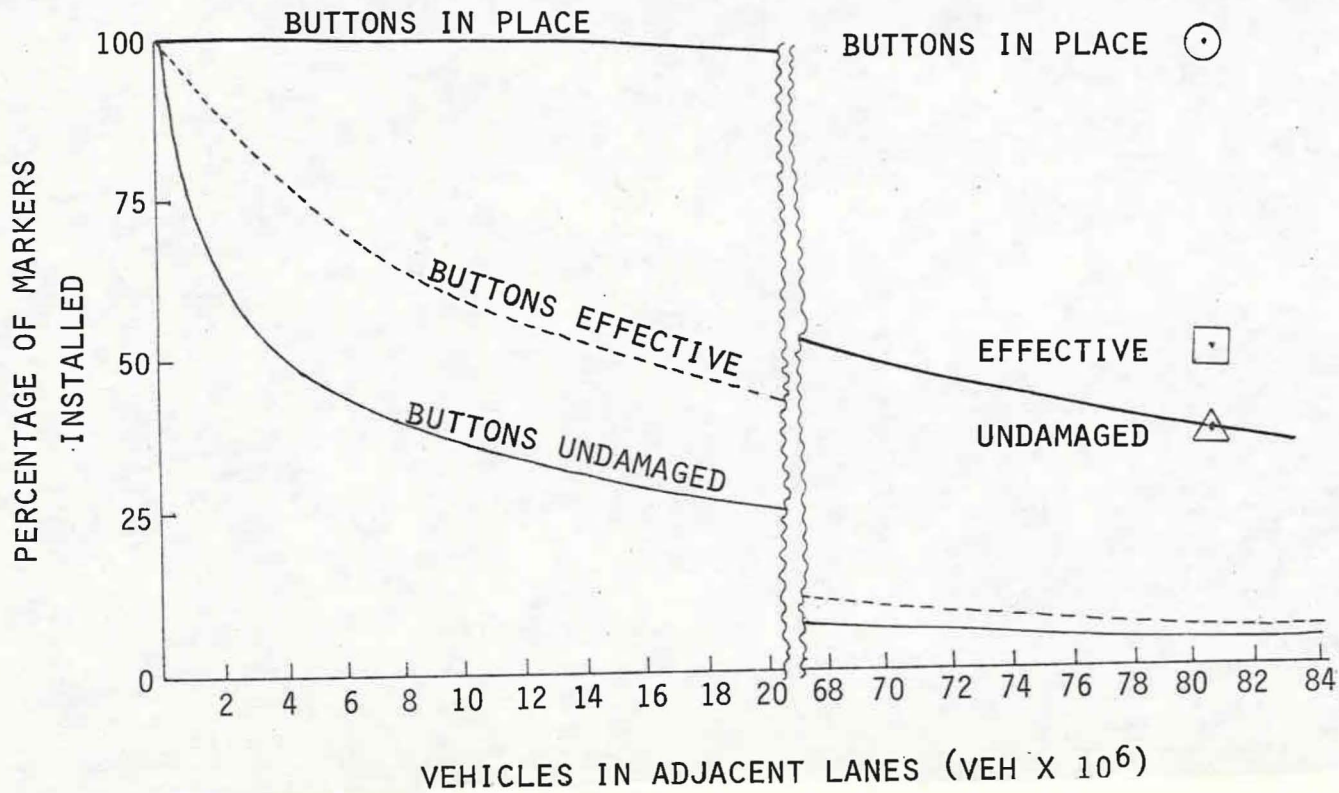


Figure 28. Observed Condition of RTBs on IH 35 Upper Level in Austin (Northbound) Compared to RTB Performance Reported in the 1977 Dallas - San Antonio Study.

Installation Date: February, 1974
 Pavement: Portland Cement Concrete
 Tradename: Permark P117 (Type I-C)
 ADT (two adjacent lanes only): 27,450
 Total Buttons: 396
 Note: Open symbols represent daytime data

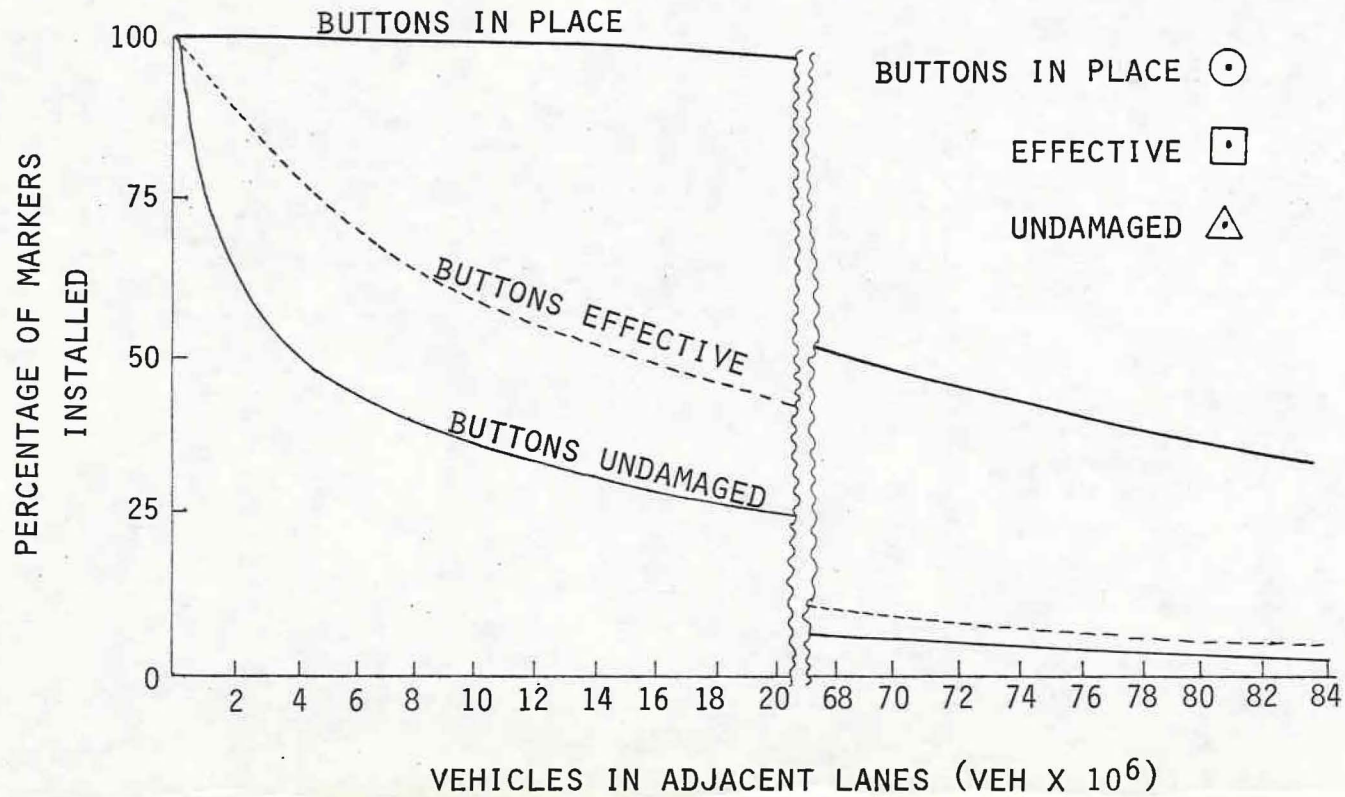


Figure 29. Observed Conditions of RTBs on IH 35 Upper Level, in Austin (Northbound) Compared to RTB Performance Reported in the 1977 Dallas - San Antonio Study.

Installation Date: May, 1976
 Pavement: Asphalt Concrete
 Tradename: Permark P-117 (Type II-CR)
 ADT (two adjacent lanes only): 22,500
 Total Buttons: 70
 Note: Open symbols represent daytime data

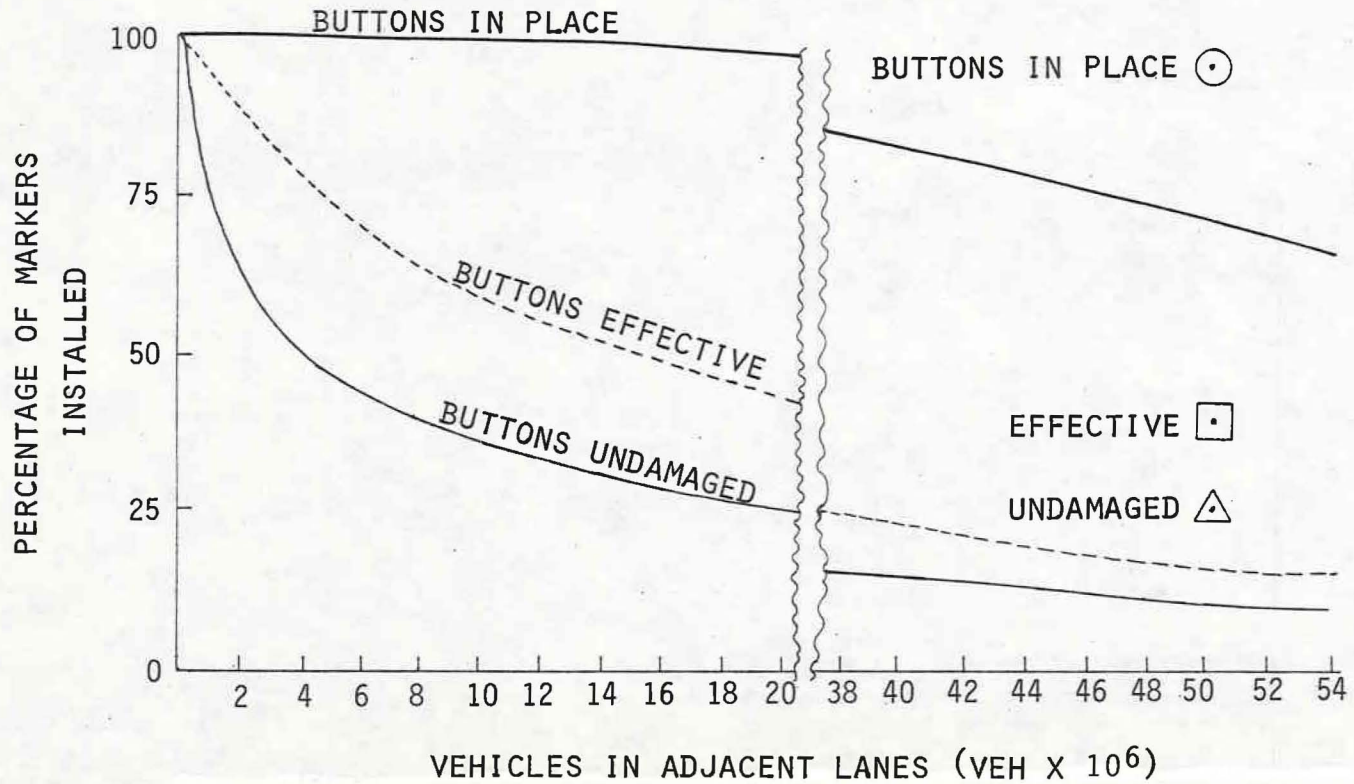


Figure 30. Observed Conditions of RTBs on IH 35 Lower Level, in Austin, (Southbound) Compared to RTB Performance Reported in the 1977 Dallas - San Antonio Study.

Installation Date: May, 1976
 Pavement: Asphalt concrete
 Tradename: Permark P-15 (Type I-C)
 ADT (two adjacent lanes only): 22,500
 Total Buttons: 396
 Note: Open symbols represent daytime data

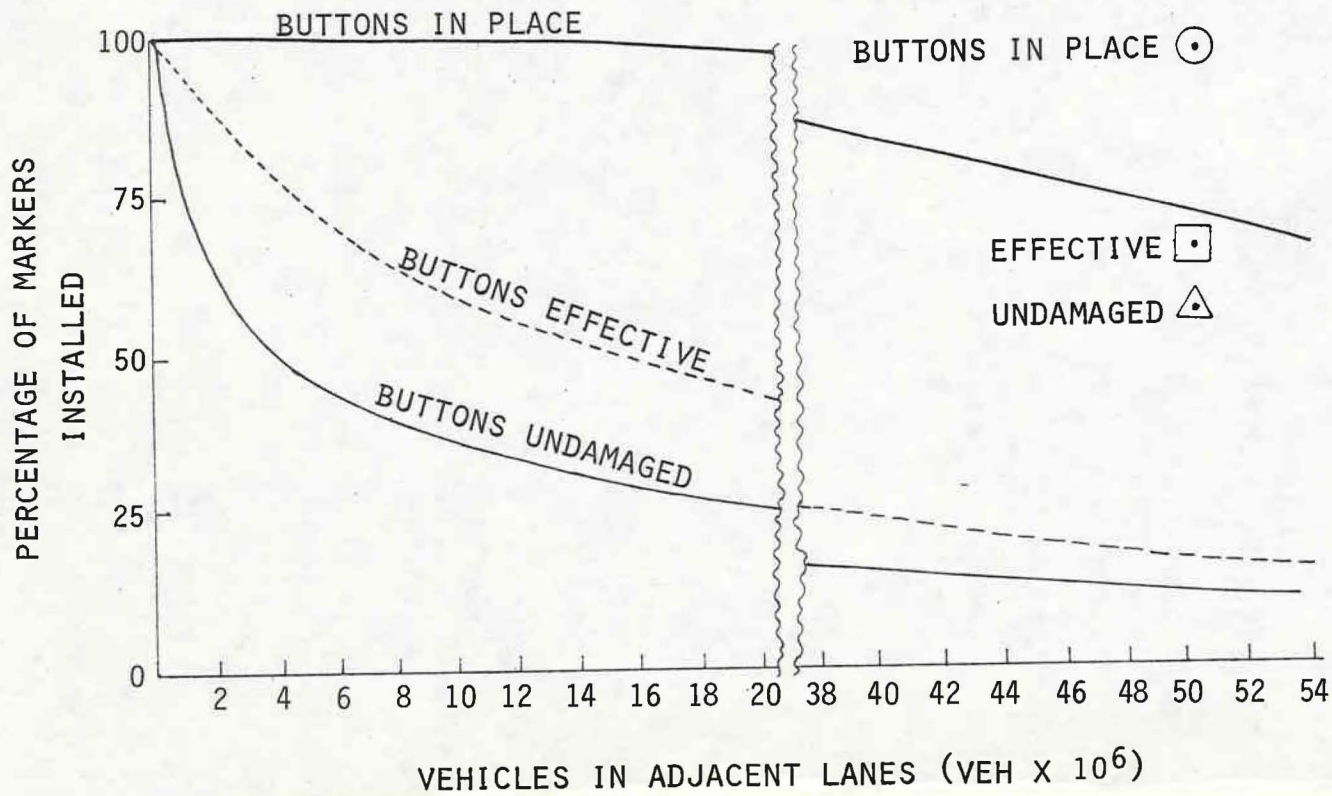


Figure 31. Observed Condition of RTBs on IH 35 Lower Level, in Austin (Southbound) Compared to RTB Performance Reported in the 1977 Dallas - San Antonio Study.

Installation Date: June, 1980
 Pavement: Portland cement concrete
 Tradename: Ray-O-Lite and Stimsonite 88
 (Type II-CR)
 ADT (two adjacent lanes only): 63,000
 Note: Open symbols represent daytime data

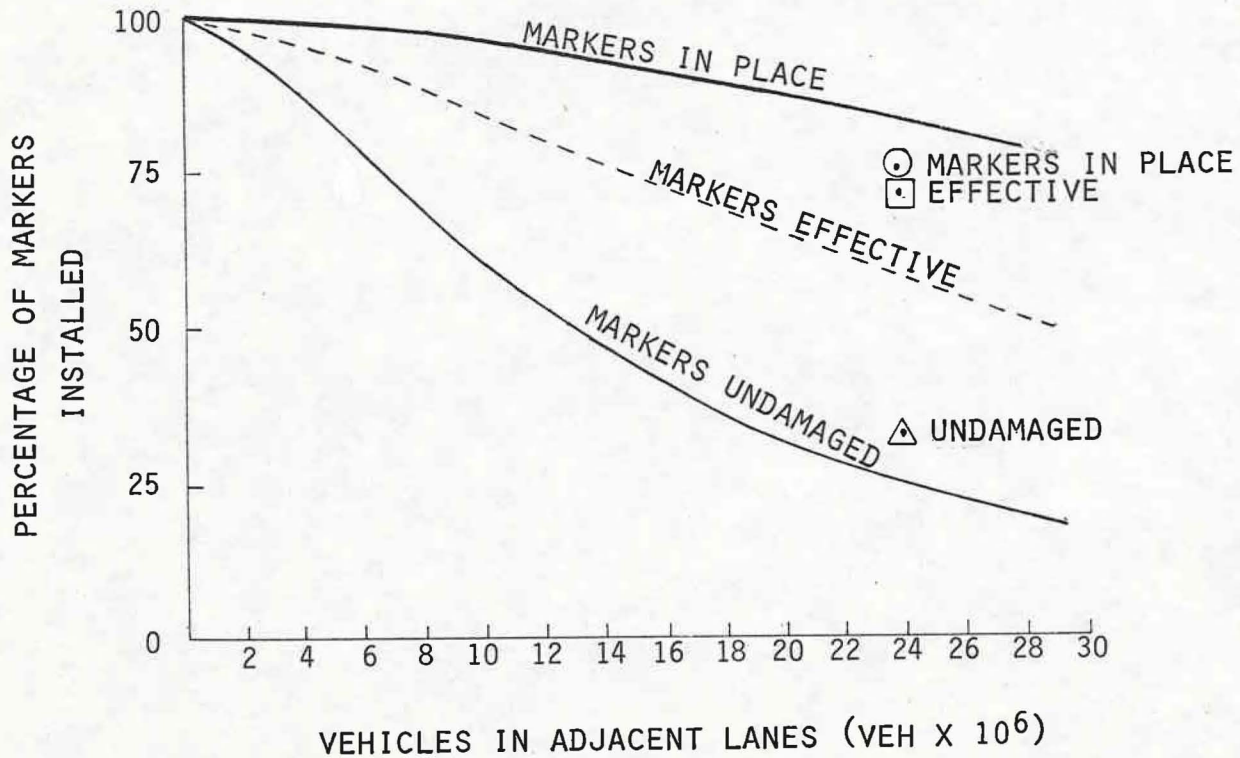


Figure 32. Observed Condition of RPMs on IH 45 in Downtown Houston (Southbound) Compared to RPM Performance Reported in 1977 Dallas - San Antonio Study.

Installation Date: June, 1981
 Pavement: Portland cement concrete
 Tradename: Stimsonite 88 (Type II-CR)
 ADT (two adjacent lanes only): 36,900
 Total Markers: 385
 Note: Open symbols represent daytime data

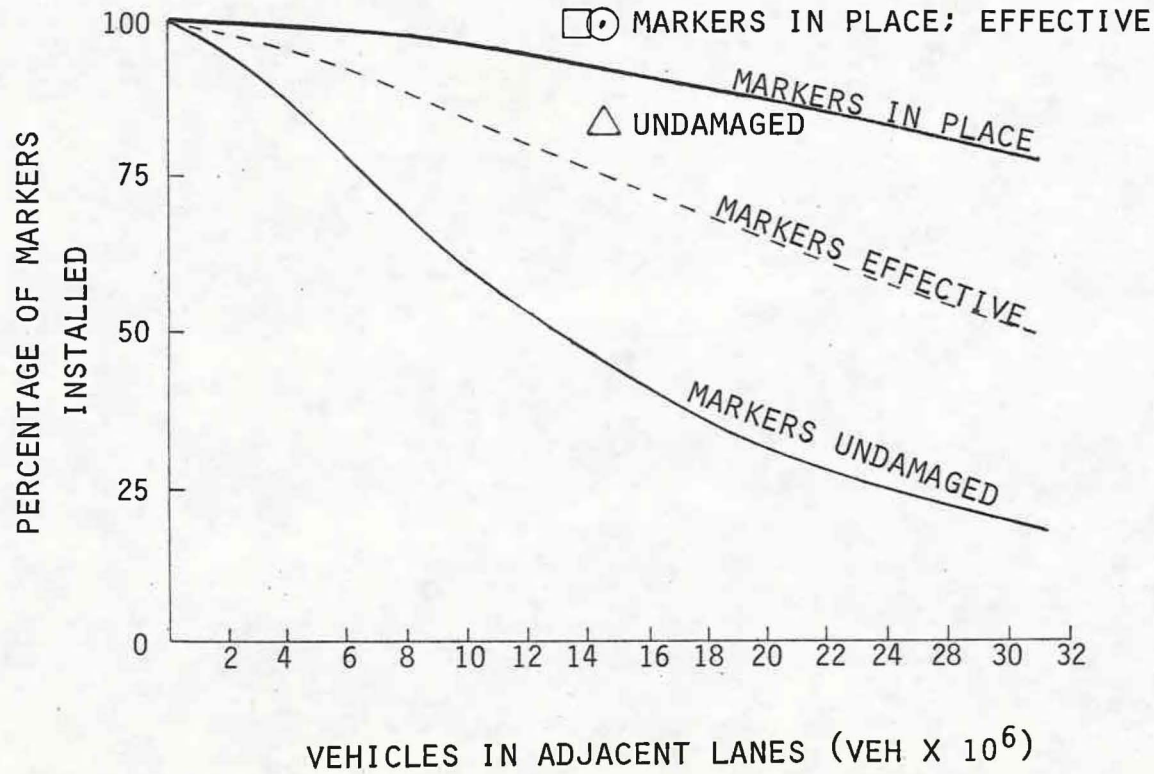


Figure 33. Observed Condition of RPMs on IH 45 in Downtown Houston (Northbound) Compared to RPM Performance in 1977 Dallas - San Antonio Study.

TRAFFIC CHARACTERISTICS

The reflectivity and retention of raised pavement markers is more dependent on the volume of traffic than on the length of time the markers have been installed. It is very difficult to separate the two since both are closely related. Total traffic passing through a pattern of raised pavement markers is increased as a function of time. Retention of the markers is dependent on the number of vehicular impacts with the markers.

Traffic volume is a good indicator of whether or not to expect a large loss of effectiveness in the first few months. The second dominate parameter is the location of the markers. In high weave areas, a higher loss rate is to be expected and more markers will be lost earlier than in an area with low weaves but a high ADT.

USES AND GEOMETRICS OF RAISED REFLECTIVE PAVEMENT MARKERS

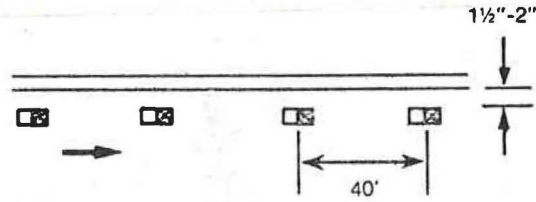
The traditional role of markers has been an effective wet weather information source. In adverse weather conditions, other forms of delineation become useless after a sheet of water covers the road surface. The markers are presently being evaluated by the Texas Transportation Institute to determine the effects the markers have on reducing nighttime and wet weather accidents. An additional safety benefit is the rumble effect of the markers. The rumble will have an effect on reducing the number of vehicles drifting across lanes or across the centerline into the path of oncoming vehicles.

In 1976, seven (7) states used RPMs as centerline and laneline markers. Table 3 summarizes the spacing and additional uses by these seven states. From these data, it becomes evident that most states sampled adopted a spacing of 80 feet with optional spacings of 40 feet to be used in severe geometric cases. Only California and Arizona adopted spacings less than 80 feet as standard spacings. Arizona uses 40 feet in all situations, and California uses 48 feet as their normal spacing and 24 feet for severe geometrics. No state sampled used spacings greater than 80 feet.

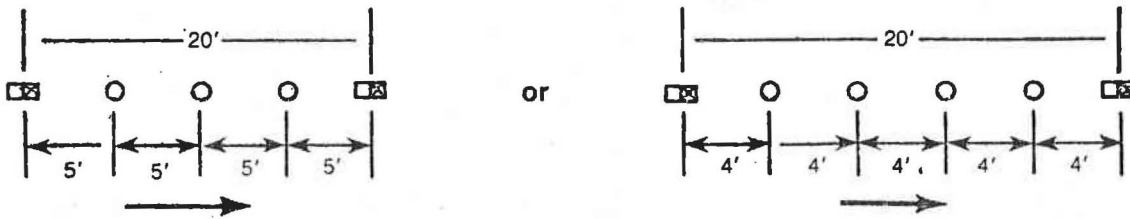
The Federal Highway Administration recently released an implementation package for Roadway Delineation (2). This handbook contains recommended practices for the installation of various types of patterns of reflective and nonreflective raised pavement markers. The release of this handbook resulted in the deletion of any study involving marker spacing. Figures 34 through 47 contain the illustrations for the most generally accepted patterns throughout the country. In situations where the spacing is left to the user, the generalized "N" concept is referred to in the illustration. In Texas, N is 80 feet, two sets of stripes 10 feet long and spaces of 30 feet separate RPM's.

Table 3. Reflective Raised Pavement Marker Delineation Practices (2).

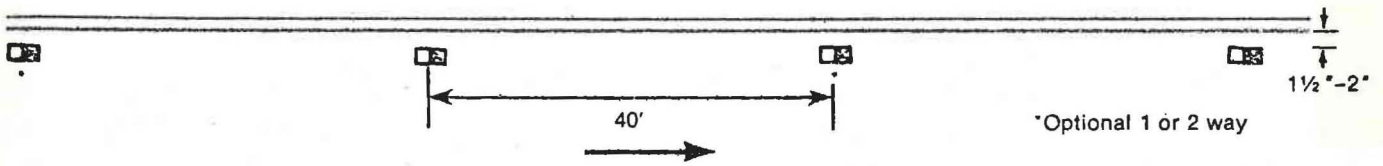
State	Centerline and Lane Line Marker Spacing	Additional Uses
Arizona	40'	Outline Islands
California	48' standard 24' optional	Channelization Exit Gore Median Edgeline Ramp Edgeline Two-Way Left Turn Lanes
Georgia	80' standard 40' optional	Channelization Exit Gore Intersecting Roads Pavement Arrow - Wrong Way Reversible Lane Shoulder Approach to Narrow Bridge Shoulder Encroachment Two-Way Left Turn Lanes
Louisiana	80'	None
Texas	N = 80' standard $\frac{1}{2}$ N = 40' optional	Outline Islands Wrong-Way Arrows Exit Gore Two-Way Left Turn Lanes
Washington	80' 40' on curves	None None
Wyoming	80'	None



a) Combination RPM/Stripe for Left Edge Line (RPMs not recommended for right edge line)



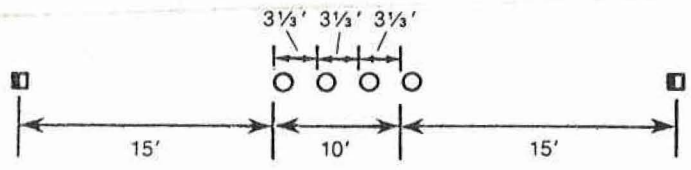
b) RPM System for No Passing Barrier



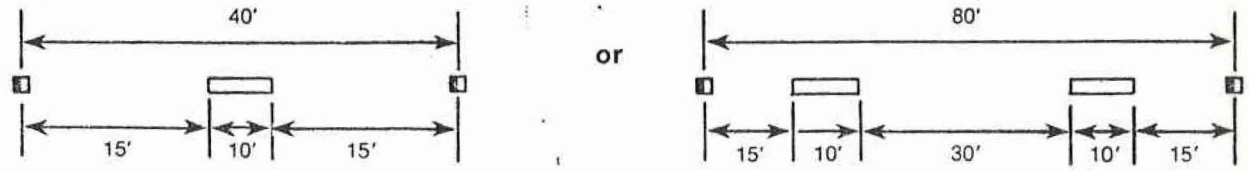
c) Combination RPM/Stripe System for No Passing Barrier

- Non-Ref. Yellow
- ◻ Single Yellow
- ▬ White Stripe
- ▬ Yellow Stripe
- ➔ Direction of Traffic

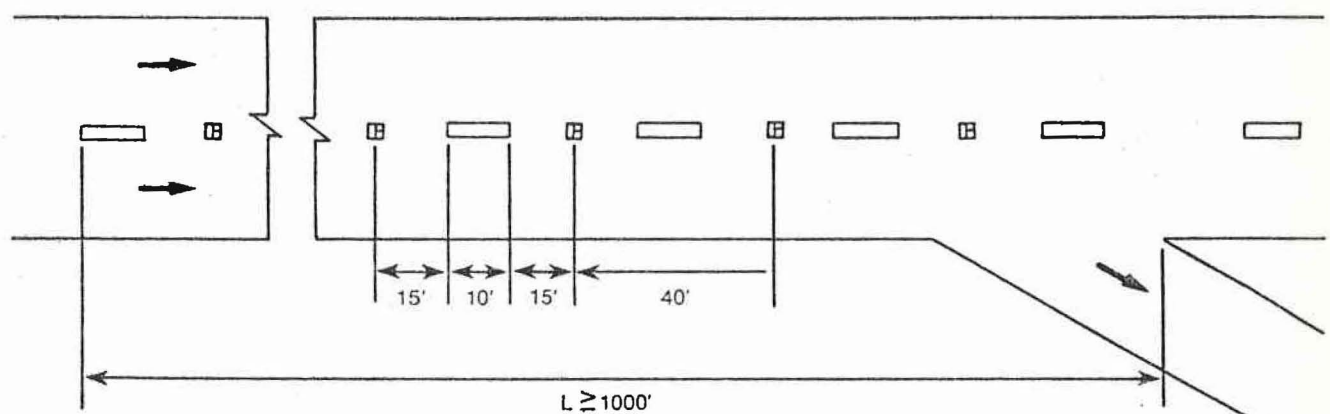
Figure 34. Marking Patterns for Solid Lines.



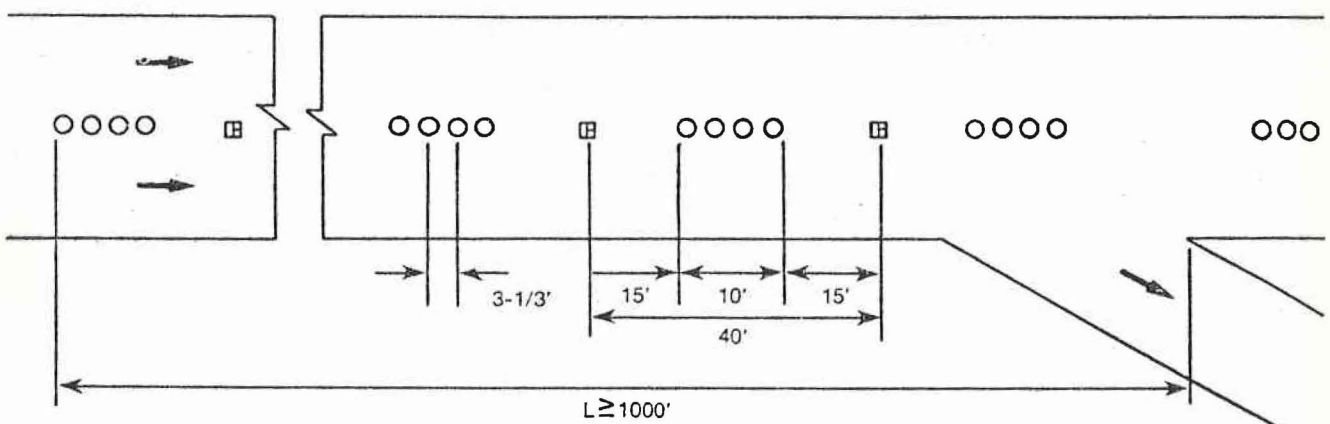
a) RPM System



b) Combination RPM/Stripe System



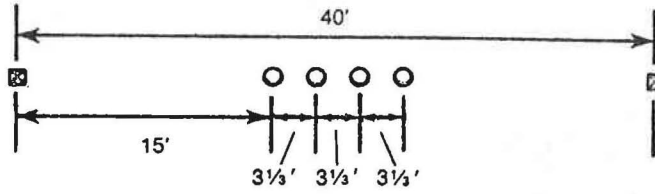
c) Combination RPM/Stripe System in Advance of Exit Ramp



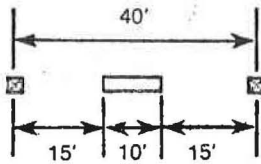
d) RPM System in Advance of Exit Ramp

- Non-Ref. White
- Single White
- ▣ White and Red
- ▭ White Stripe
- ➔ Direction of Traffic

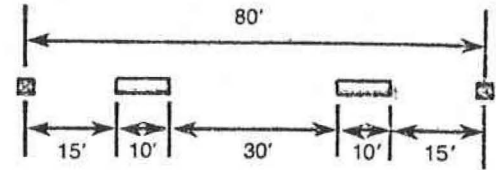
Figure 35. Lane Line Patterns.



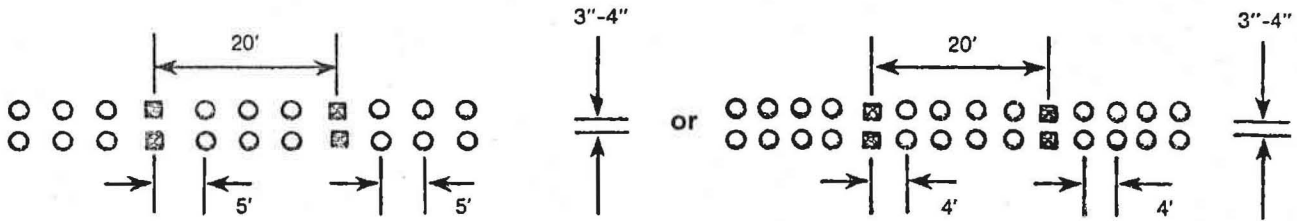
a) RPM System for Two-Lane Two-Way Roadway



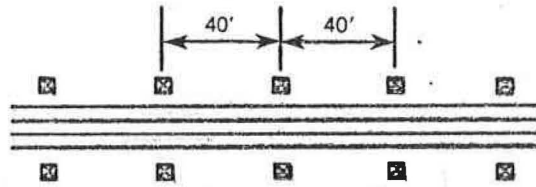
or



b) Combination RPM/Stripe System for Two-Lane, Two Way Roadway



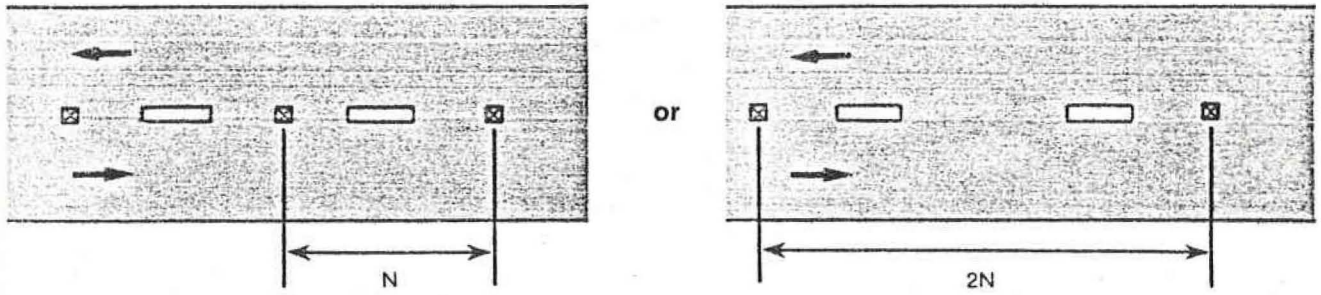
c) RPM System for Multilane, Two-Way Roadway



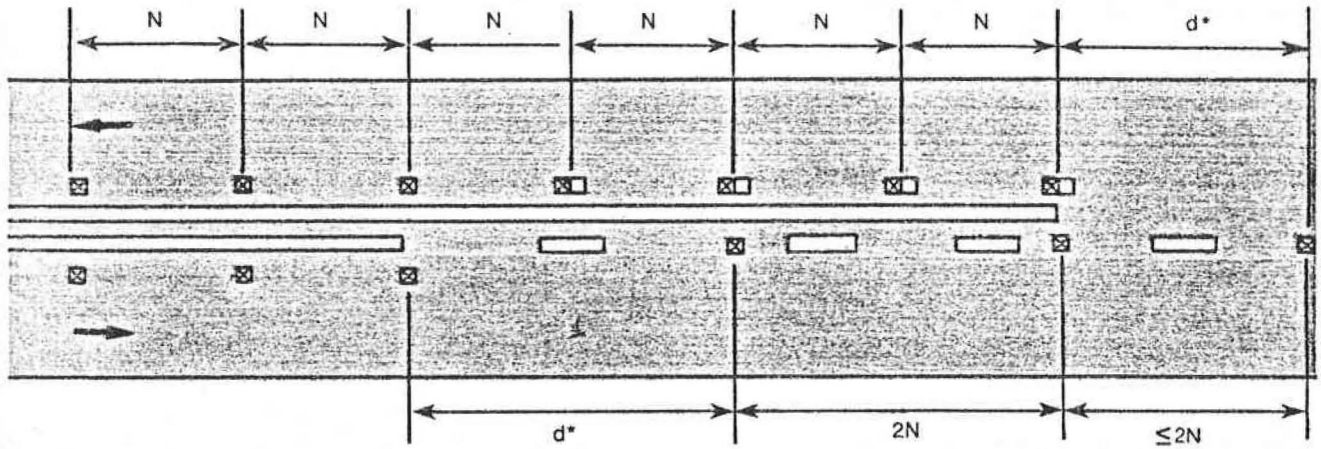
d) Combination RPM/Stripe System for Multilane, Two-Way Roadway

- Non-Ref. Yellow
- ⊠ Double Yellow
- ▬ Yellow Stripe

Figure 36. Centerline Patterns.



a) Two-Lanes

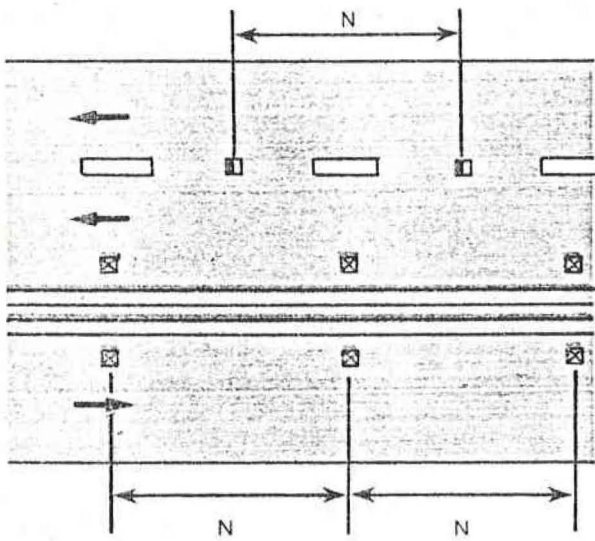


b) No Passing Zone

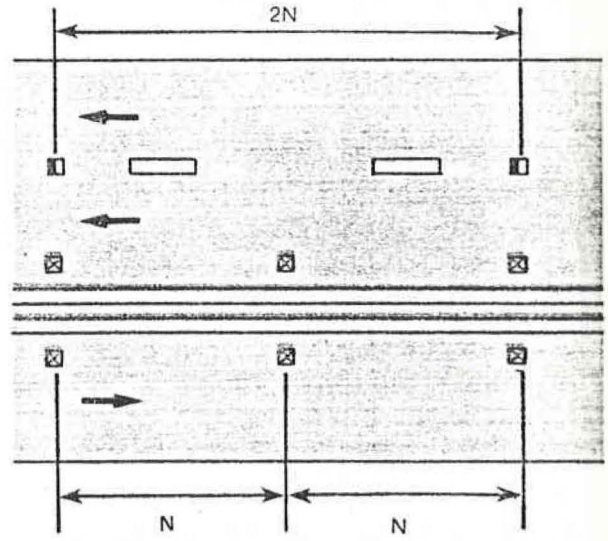
* $d \leq 2N$

- N Normal Spacing
- ☒ Double Yellow
- ☐ Single Yellow
- ▭ Yellow Stripe
- Direction of Traffic

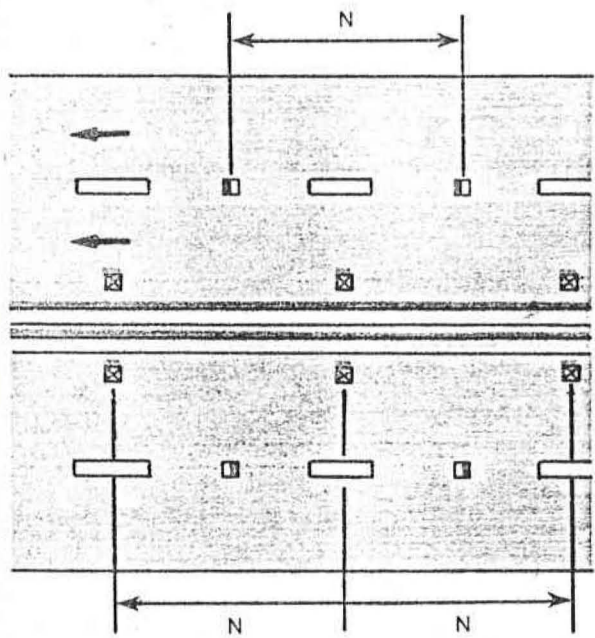
Figure 37. Marking Patterns for Two-Way Roads.



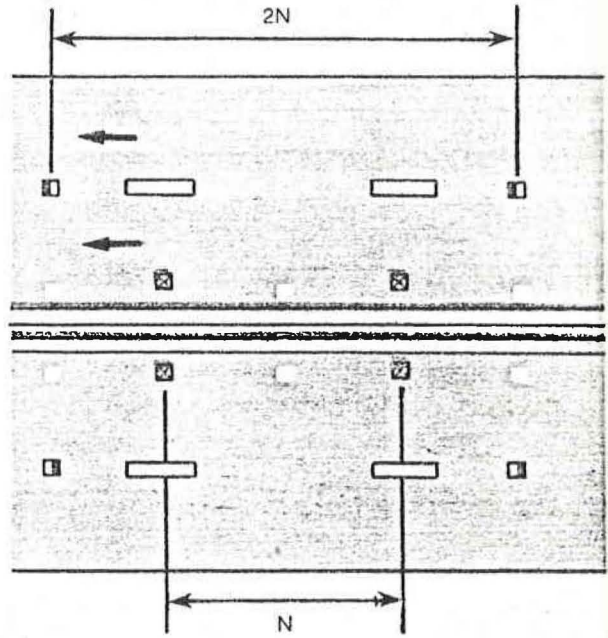
or



c) Three-Lanes



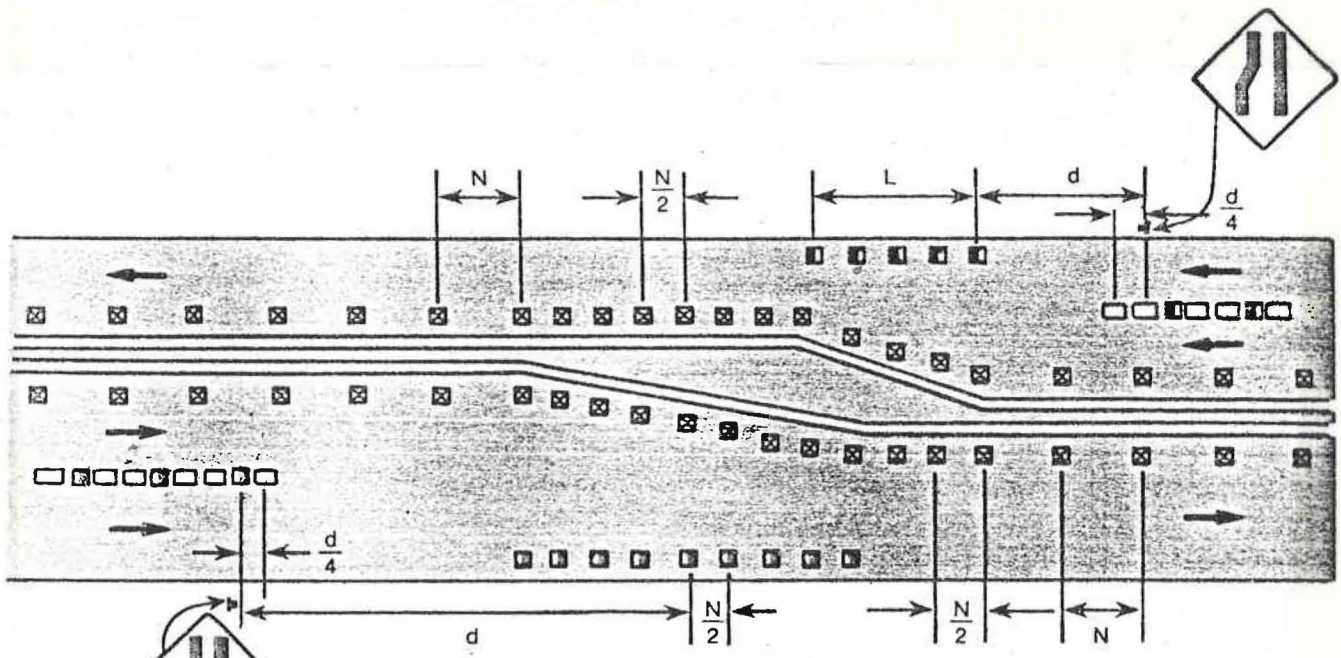
or



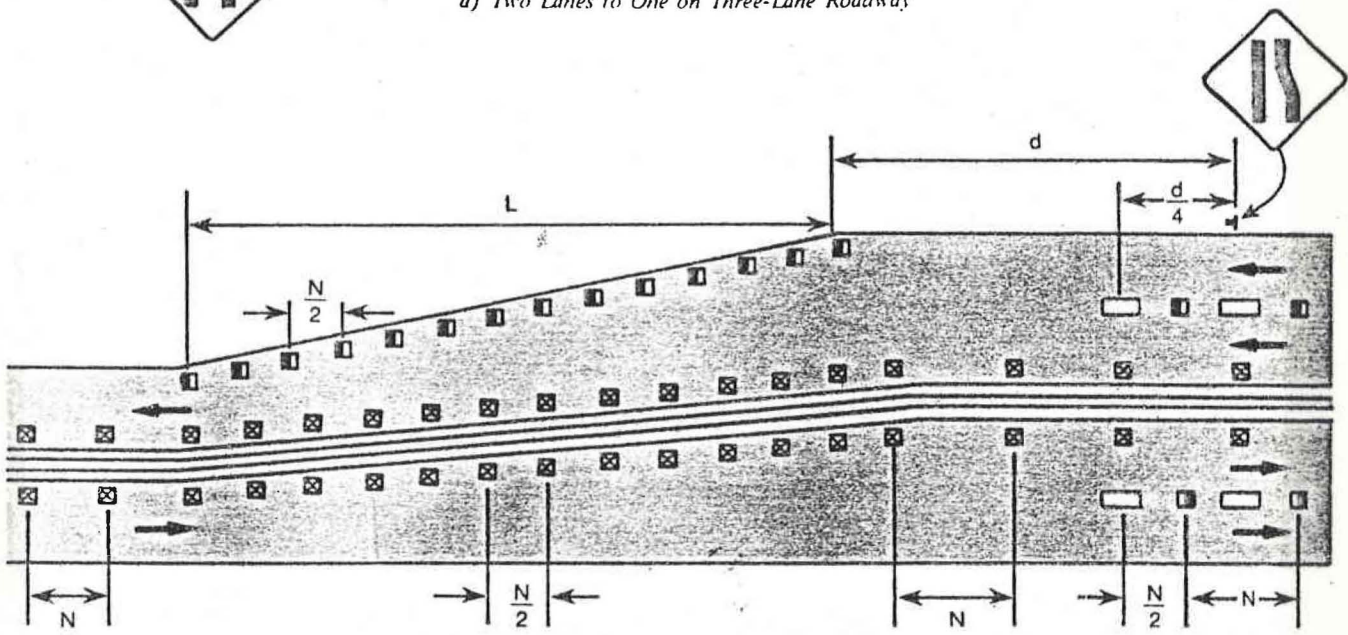
d) Four Lanes

- N Normal Spacing
- Single White
- ▣ Double Yellow
- ▭ White Stripe
- ▭ Yellow Stripe
- ➔ Direction of Traffic

Figure 38. Marking Patterns for Two-Way Roads (Continued).



a) Two Lanes to One on Three-Lane Roadway



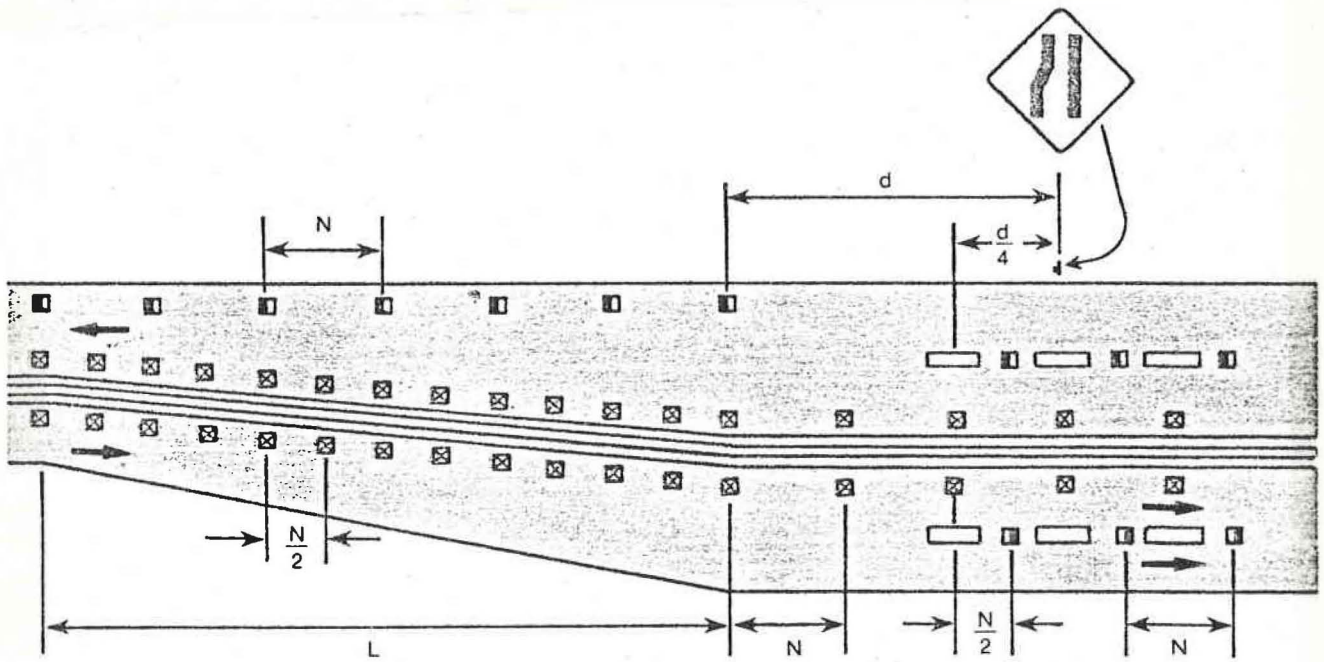
b) Four Lanes to Two-Lane Roadway - Left

- Single White
- ▣ Double Yellow
- N Normal Spacing
- ▭ White Stripe
- ▭ Yellow Stripe
- Direction of Traffic

d = Advance Warning Distance
 For $S \geq 45$ $L = WS$
 For $S < 45$ $L = WS^2/60$

L = Length of Taper in Feet
 S = 85th Percentile Speed
 W = Offset in Feet

Figure 39. Marking Patterns for Transition Situations.



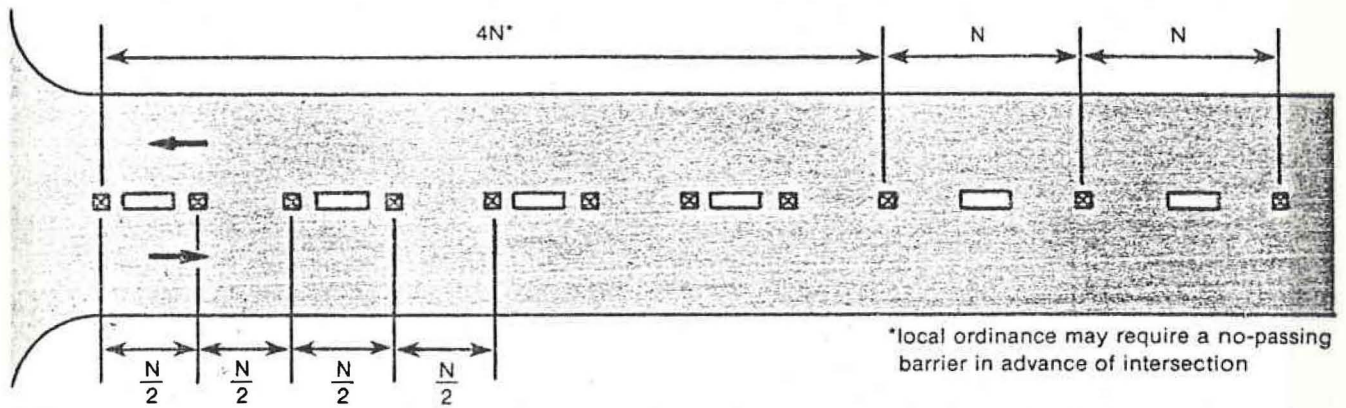
c) Four Lanes to Two-Lane Roadway - Right

- Single White
- ⊠ Double Yellow
- N Normal Spacing
- ▭ White Stripe
- ▭ Yellow Stripe
- Direction of Traffic

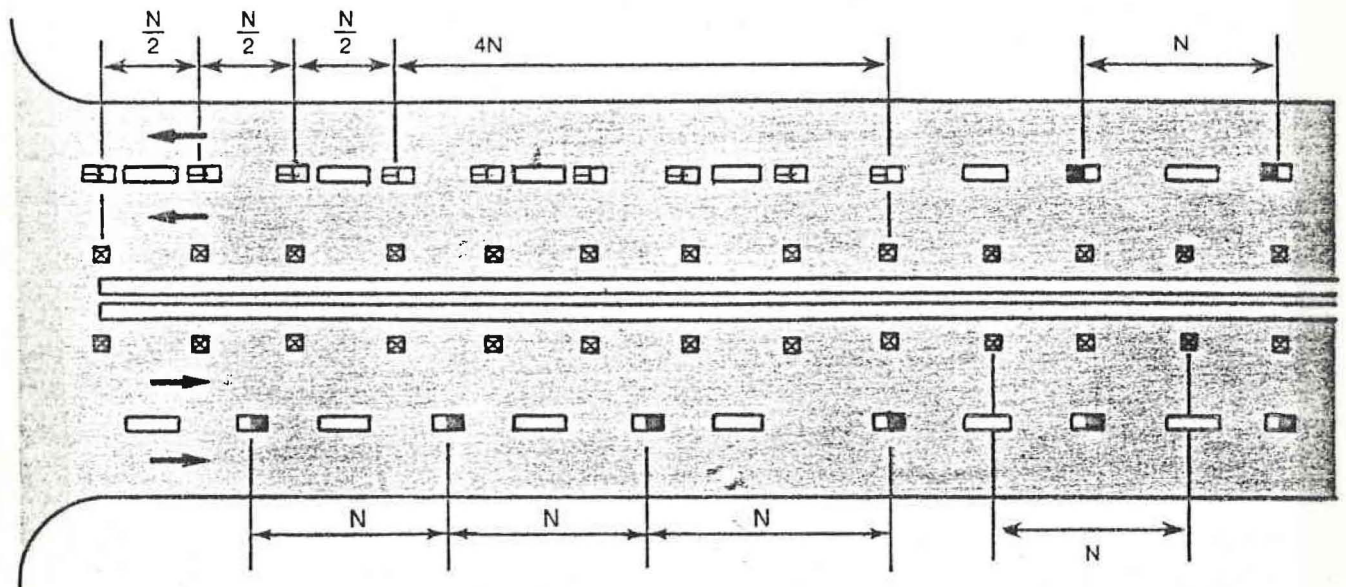
d = Advance Warning Distance
 For $S \geq 45$ $L = WS$
 $S < 45$ $L = WS^2/60$

L = Length of Taper in Feet
 S = 85th Percentile Speed
 W = Offset in Feet

Figure 40. Marking Patterns for Transition Situations (Continued).



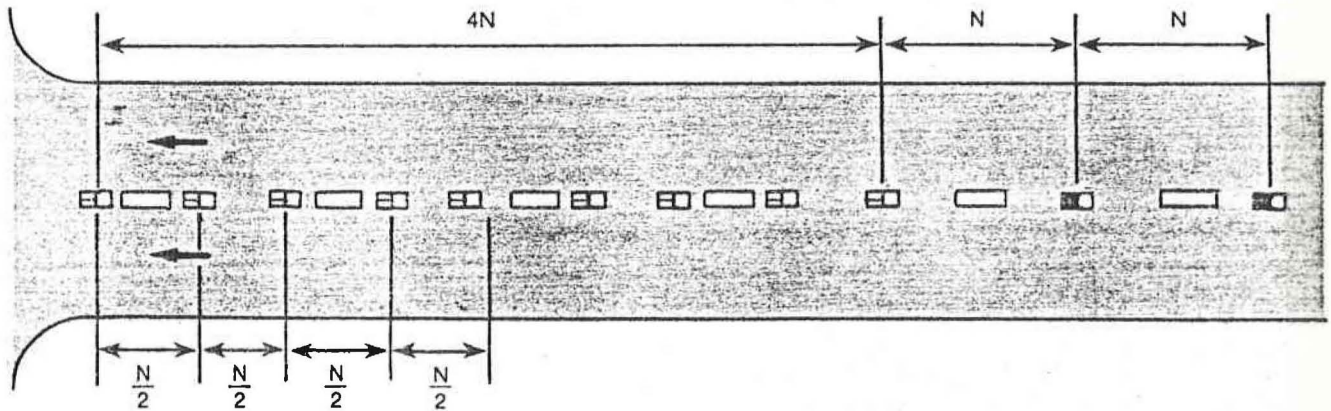
a) Two-Lane, Two-Way Roadway



b) Four Lanes, Two-Way Roadway

- ☒ Double Yellow
- ☐ Single White
- ☒ Red and White
- ☐ White Stripe
- ☐ Yellow Stripe
- ➔ Direction of Traffic

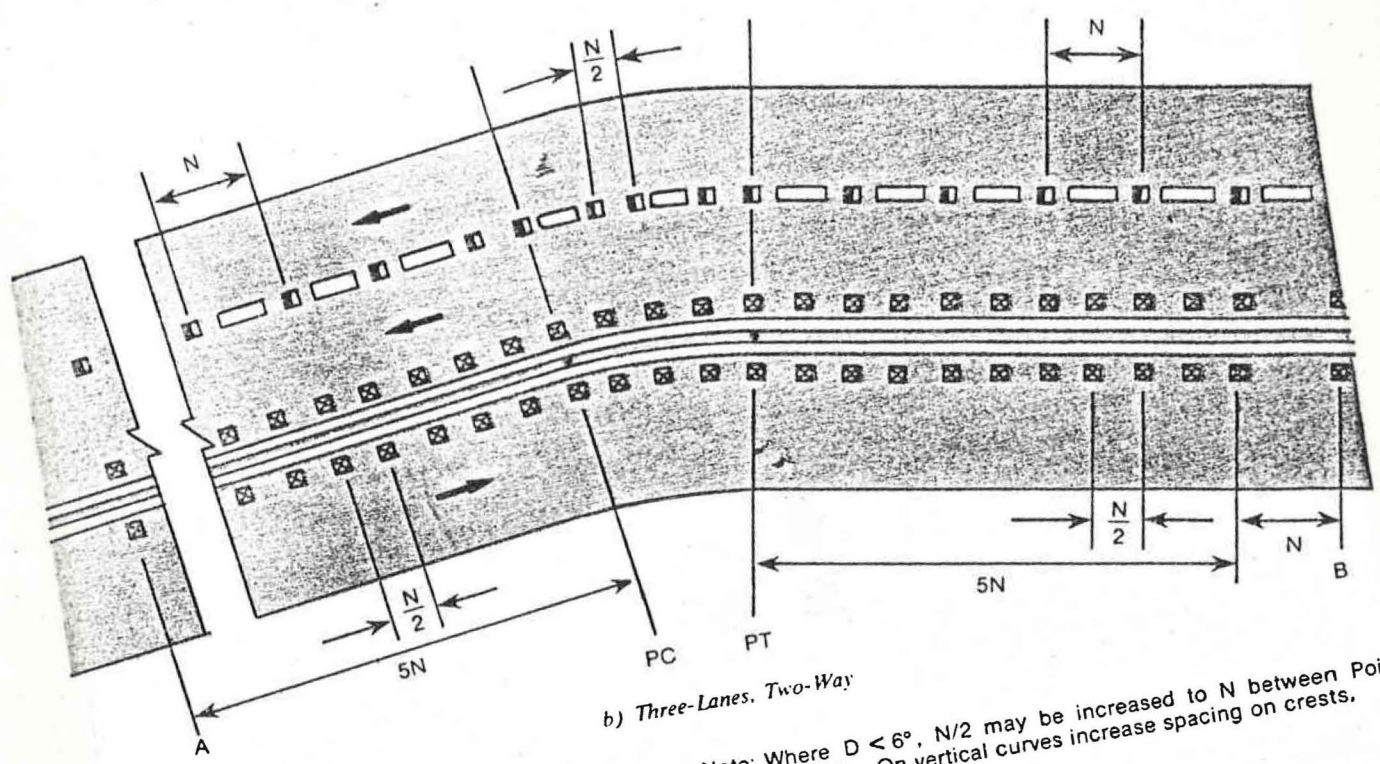
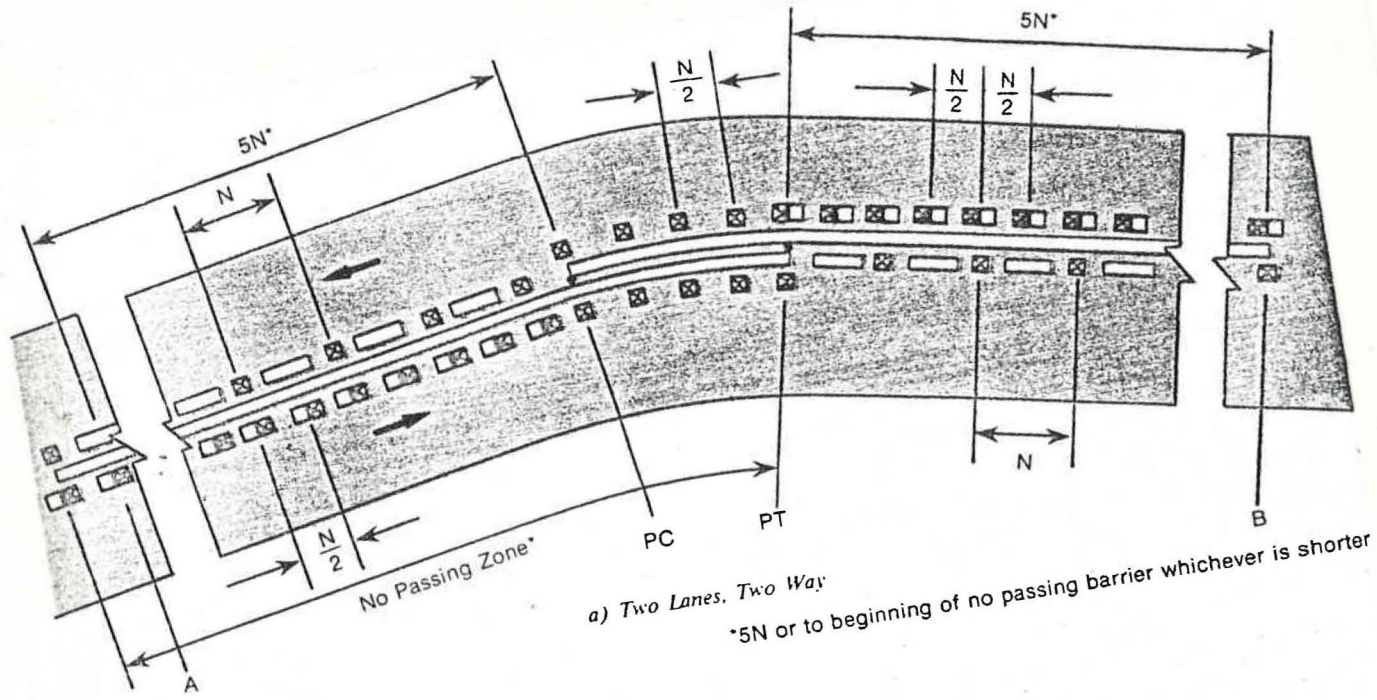
Figure 41. Marking Patterns for Intersection Approaches.



c) Two Lane, One-Way Roadway

- Single White
- ▨ Red and White
- ▭ White Stripe
- ➔ Direction of Traffic

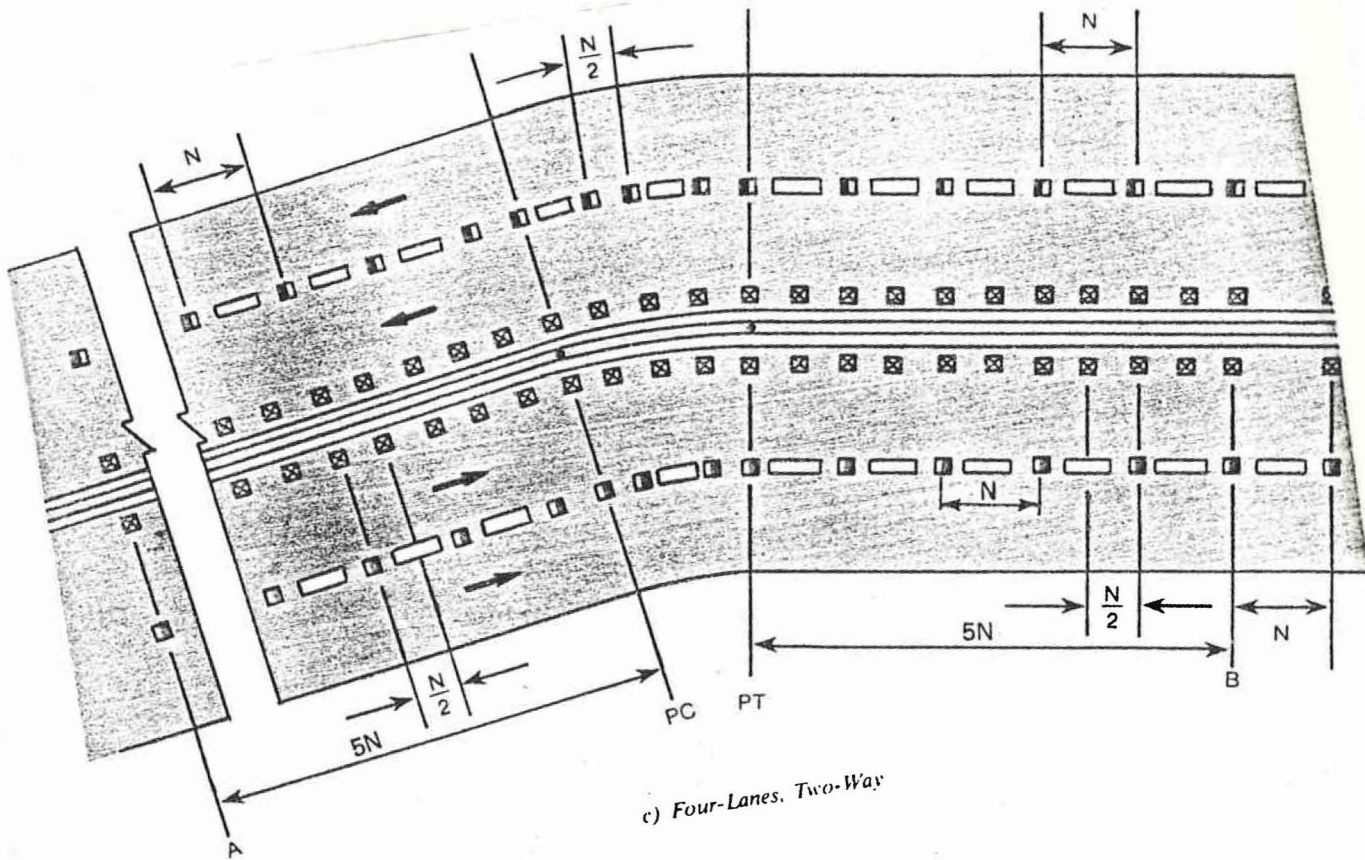
Figure 42. Marking Patterns for Intersection Approaches (Continued).



Note: Where $D < 6^\circ$, $N/2$ may be increased to N between Points A and B. On vertical curves increase spacing on crests.

- N Normal Spacing
- ▣ Single White
- ▣ Double Yellow
- ▣ Single Yellow
- ▭ White Stripe
- ▭ Yellow Stripe
- Direction of Traffic

Figure 43. Marking Patterns for Horizontal Curves Having 6° or Greater Curvature.

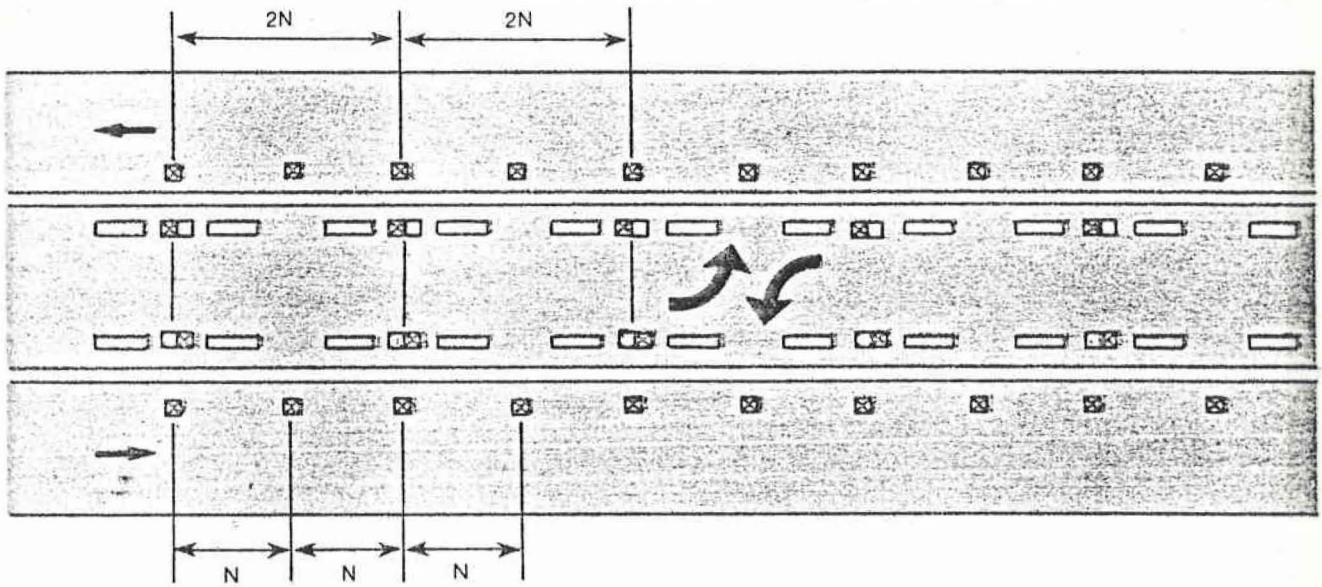


c) Four-Lanes, Two-Way

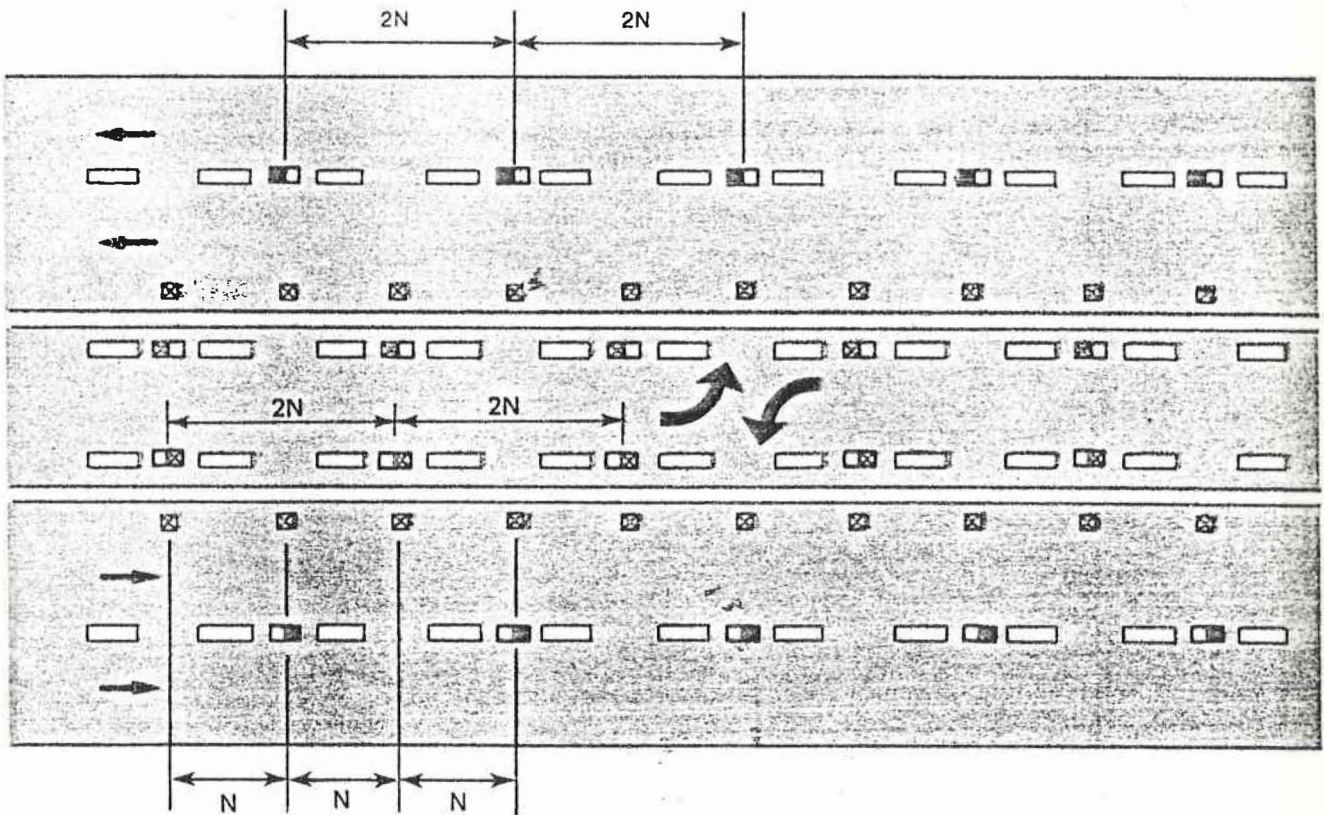
Note: Where $D < 6^\circ$, $N/2$ may be increased to N between Points A and B. On vertical curves increase spacing on crests.

- N Normal Spacing
- Double Yellow
- Single White
- ▭ White Stripe
- ▭ Yellow Stripe
- Direction of Traffic

Figure 44. Marking Patterns for Horizontal Curves Having 6° or Greater Curvature (Continued).

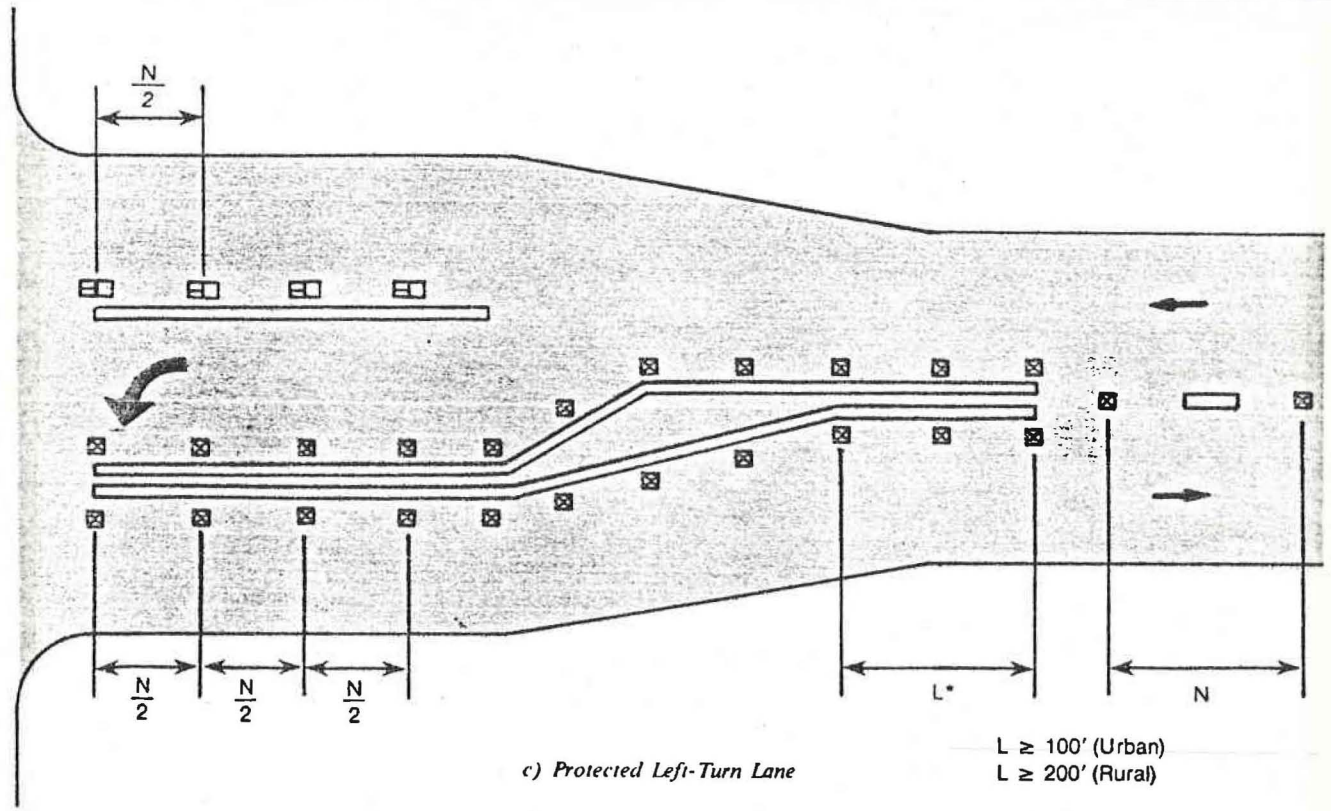


a) Center Lane of Three-Lane Roadway



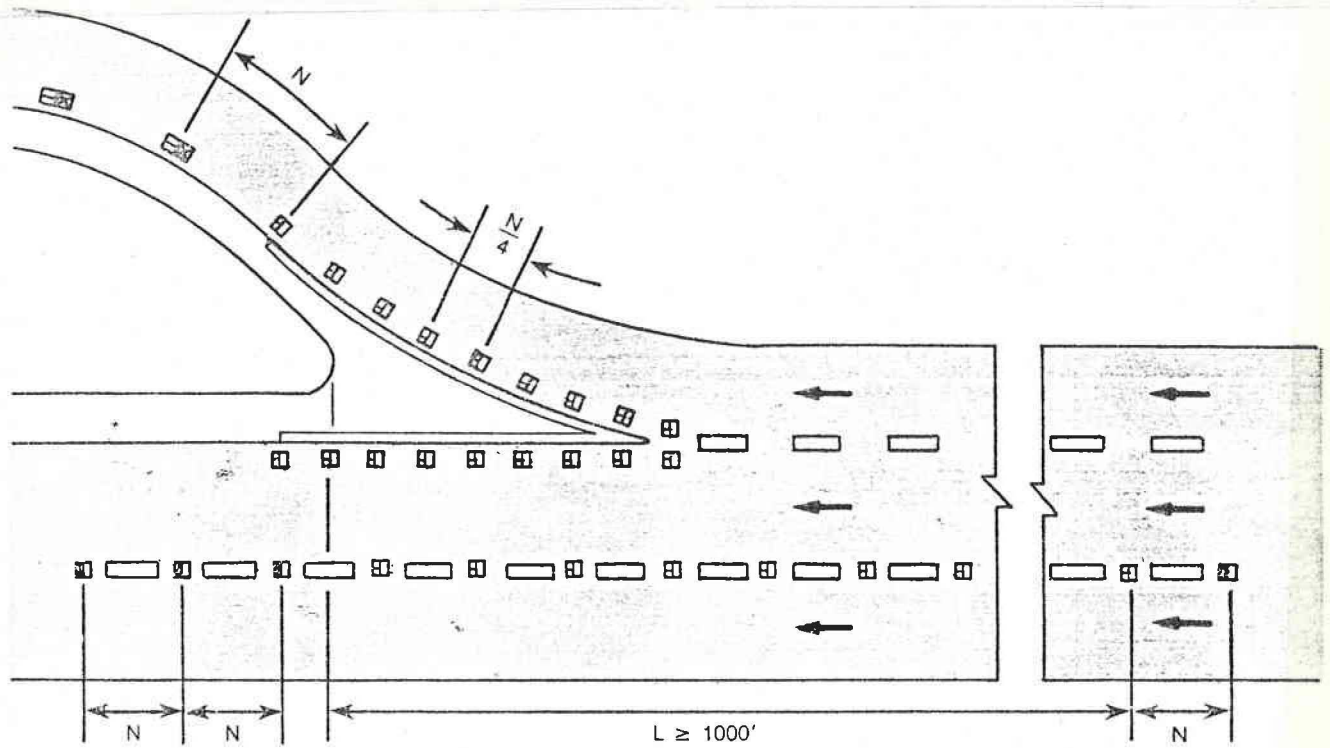
b) Center Lane of Five-Lane Roadway

Figure 45. Marking Patterns for Left-Turn Lanes.

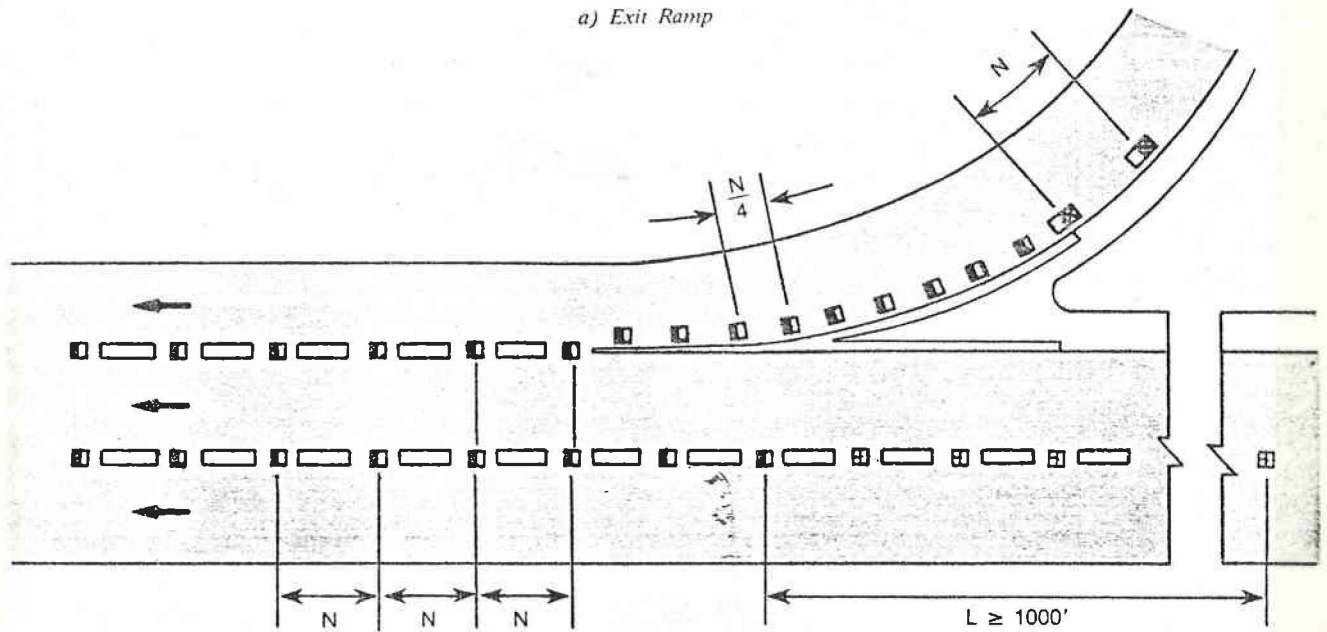


- ☒ Double Yellow
- ☒ White and Red
- ▭ White Stripe
- ▭ Yellow Stripe
- ➔ Direction of Traffic

Figure 46. Marking Patterns for Left-Turn Lanes (continued).



a) Exit Ramp



b) Entrance Ramp








-  Yellow and Red
-  Single White
-  Red and White
-  N Normal Spacing
-  White Stripe
-  Direction of Travel
-  Single Yellow

Figure 47. Marking Patterns for Freeway Ramps.

REFLECTIVITY OF RAISED PAVEMENT MARKERS

Currently, the state of Texas has an "Initial Brightness" criteria used in the acceptance of lot shipments of markers sent to the Department. This initial brightness level was set at a minimum specific intensity of 3.0 candle power per foot-candle (CP/FT-C) for crystal markers. The specific intensity is a measure of the efficiency of the raised pavement markers reflector. Yellow markers shall have a specific intensity of 2.0 CP/FT-C and red markers shall have a specific intensity of .4 CP/FT-C. These values apply to an incidence angle of 4. For an incidence angle of 20, the specific intensity drops off significantly. The specific intensity for white is 1.5 (CP/FT-C); for yellow, 1.00 (CP/FT-C); and for red, 0.20 (CP/FT-C).

Studies conducted by the SDHPT in Dallas and San Antonio determined the specific intensity levels of the markers after several months in the field. Figures 48 and 49 show the specific intensity degradation curves for both Dallas and San Antonio, respectively. This curve shows that after only three months, the specific intensity level was a fraction of the initial brightness. Over 99 percent of the markers initial reflectivity level has been lost.

The Signal Products Division of the Amerace Corporation presents the results of an accelerated wear test (3) in Figure 50. The validity of the data at this time is not known. These data indicate that Stimsonite markers lose 75% of its initial reflectivity after 200,000 impacts. In wet conditions, the markers lose one-third of their initial brightness. The reduction in intensity is non-linear, and the greatest loss of brightness occurs in the first few months after installation. Dry markers lose over 50% of their initial brightness in the first 25,000 impacts and an additional 20% loss in the next 175,000 impacts.

IMPACTS

While the number of impacts have an effect on the brightness levels of the markers, other factors also affect brightness. Impact affects brightness in two ways. First, the number of impacts determine the degree to which the lense is scratched. This scratching has a significant impact on the brightness level of the marker. Second, the number of impacts significantly determines the number of markers missing at any location. The number of

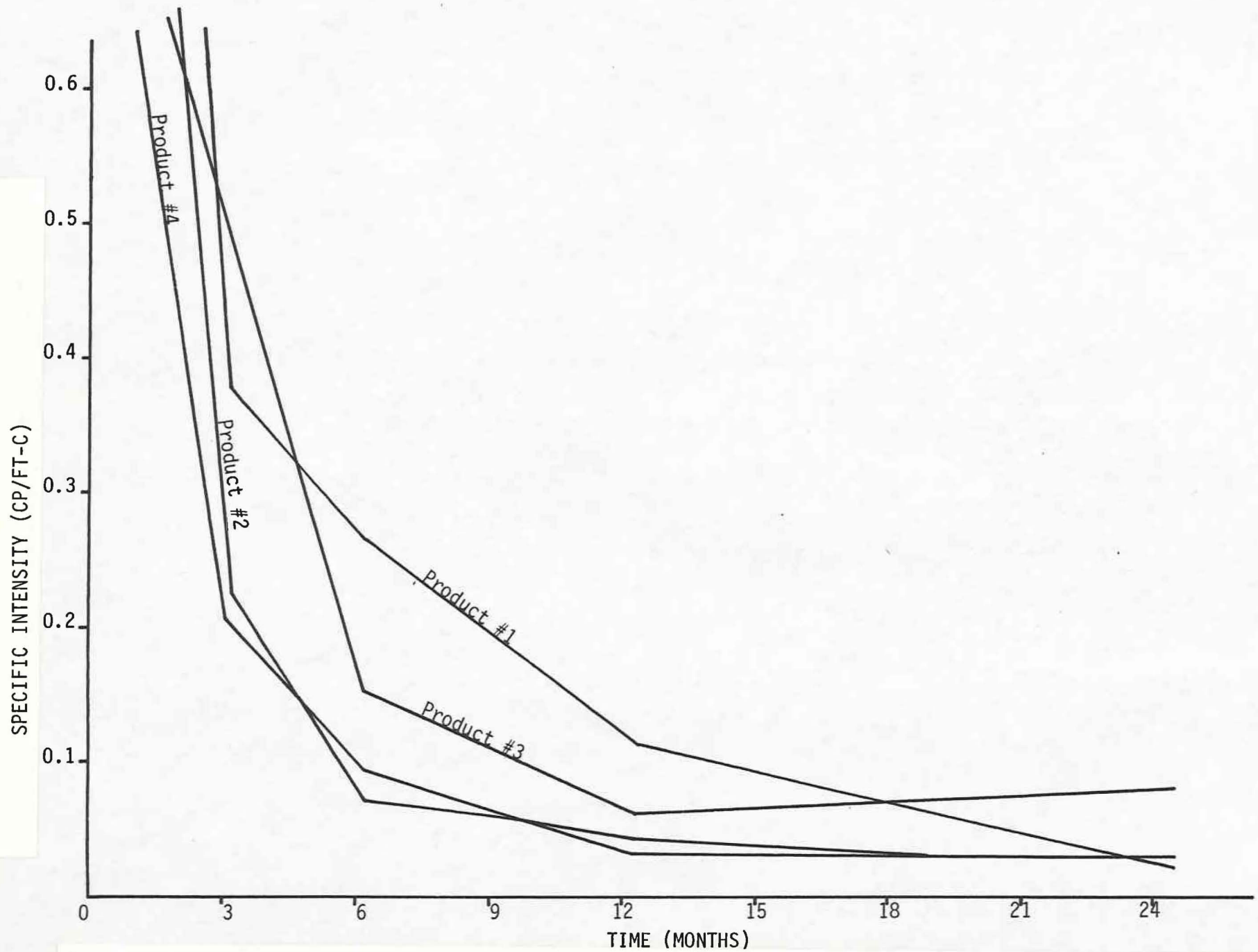


Figure 48. Specific Intensity Levels, Less Than 1.0 CP/FT-C, for the Four Major Types of Rural Pavement Markers by Length of Time From Dallas Test Sites.

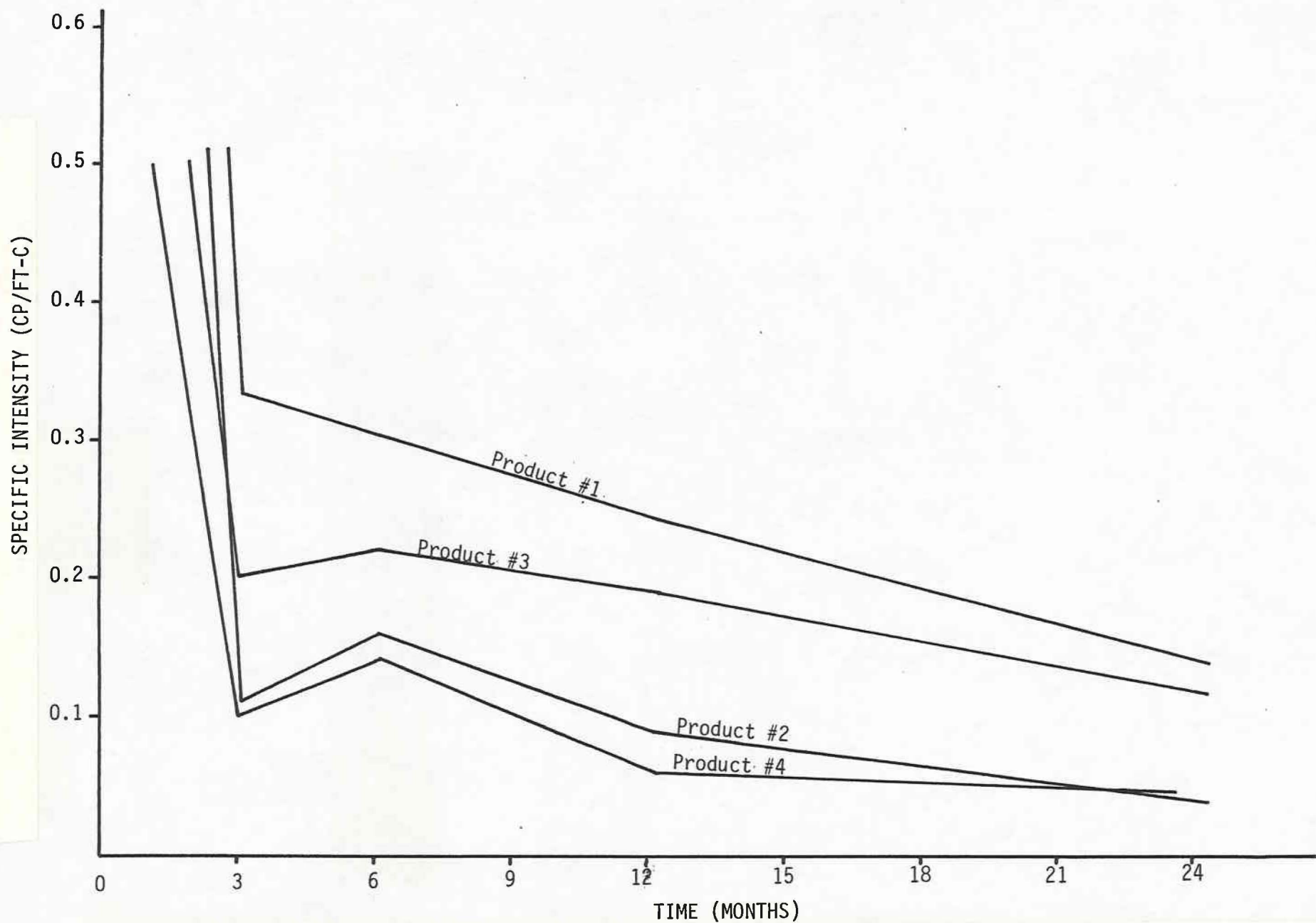


Figure 49. Specific Intensity Levels, Less Than 1.0 CP/FT-C, For the Four Major Types of Raised Pavement Markers by Length of Time on Roadway From San Antonio Test Sites.

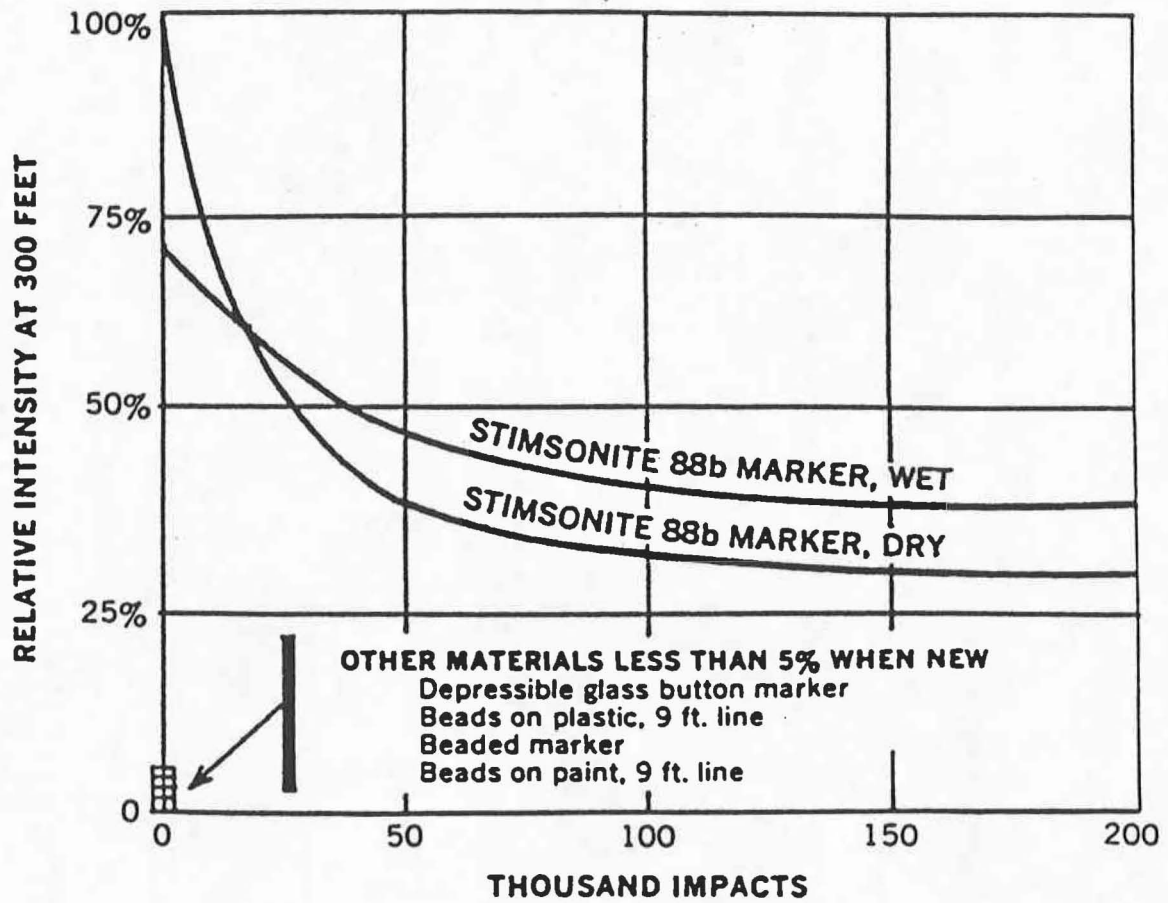


Figure 50. Accelerated Wear Test Results.

missing markers will greatly reduce the amount of information the driver receives concerning the geometrics of the roadway. If the marker is missing, the brightness level is an absolute zero at that location. Other factors which affect brightness levels of the RPMs are (1) ambient light, (2) poor drainage, (3) high humidity, and (4) dirt accumulation. Each of these factors either directly or indirectly affect the brightness of the RPMs.

AMBIENT LIGHT

A high level of ambient light will reduce the visual cue to the driver because the contrast ratio between the background light level and the RPM is decreased. This will reduce the effect the markers have on the driver as an information source.

DRAINAGE

A roadway with poor drainage will allow a build-up of water on the road surface. If more than three-fourths of an inch of water accumulates, the marker will be submerged and its reflectance will drop significantly. It is highly important that the roadway surface be properly drained for the markers to have value during wet conditions. This should be one prerequisite for the installation of any marker system.

HUMIDITY

In areas of high humidity, markers to be installed are inspected for damage to the casing and bad ones discarded and good ones should be attached properly to the roadway to insure a good seal. It is a fact that if any marker has a cracked or damaged case, moisture will seep in, and reduce the reflectivity of the marker or cause the marker to separate from the pavement. In any event, after a short period of time, the marker will be useless.

DIRT ACCUMULATION

Dirt accumulation reduces the reflectivity of the markers. The dirt builds up on the face of the marker, and if cars and trucks do not hit the markers, after a short period of time their reflectivity is diminished. At this point a dichotomy exists. If cars and trucks do not impact the markers, an accumulation of dirt will diminish their brightness. However, any marker can take only a finite number of impacts before it either disintegrates on Portland cement or pulls out on all other types of pavements.

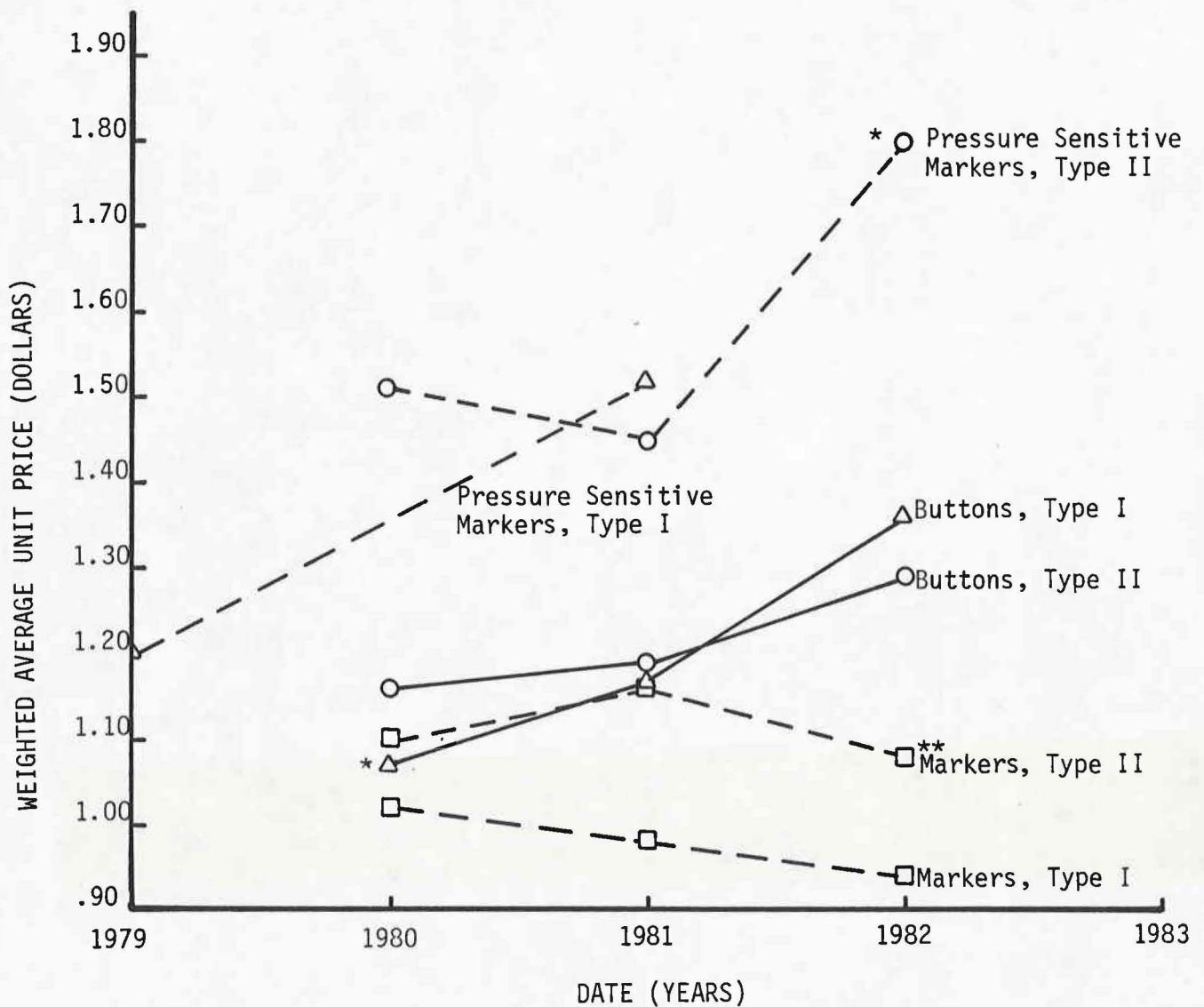
COST ANALYSIS

MARKER INSTALLATION COST ANALYSIS

In analyzing the initial installation cost of both RPM's and RTB's, the weighted average unit price (WAUP) will be used rather than the average unit price. Appendix C contains cost information supplied by D-4. The weighted average unit price is more sensitive to quantity discounts. It represents the weighted average unit price (in 1981 dollars) for the years 1979, 1980, 1981, and 1982 for markers purchased by the SDHPT for replacement purposes.

The standard RPM (4X4) is consistently cheaper than either the RTB or the pressure sensitive RPM for both Type I and Type II. The 1981 WAUP for the Type II marker is the highest of the three years. This may tend to deflate the price differential between the other RPMs and RTBs, making them appear to be more cost competitive than they actually are. In all situations, the pressure sensitive RPMs are considerably higher than the plain RTBs. The cost differentials range from 3% higher (Type I) in 1970 to 55% higher (Type II) in 1982. The reflective raised traffic buttons ranged from 8% lower (Type I) in 1980 to 17% higher (Type I) in 1982. In all years, Figure 51, except 1982, the Type I RTB is lower priced than the Type II RTB.

Figure 52, adapted from a Caltrans Report (4), reflects bid prices for the installation of RPMs in California between 1966 and 1975. The increase in cost is due entirely to the cost of installation. The cost of RPM's remained practically unchanged.



Note: No purchases of Type I, pressure sensitive markers were made in 1980.

* : Based on one purchase for the year.

** : Based on two purchases for the year.

Figure 51. Weighted Average Unit Price.

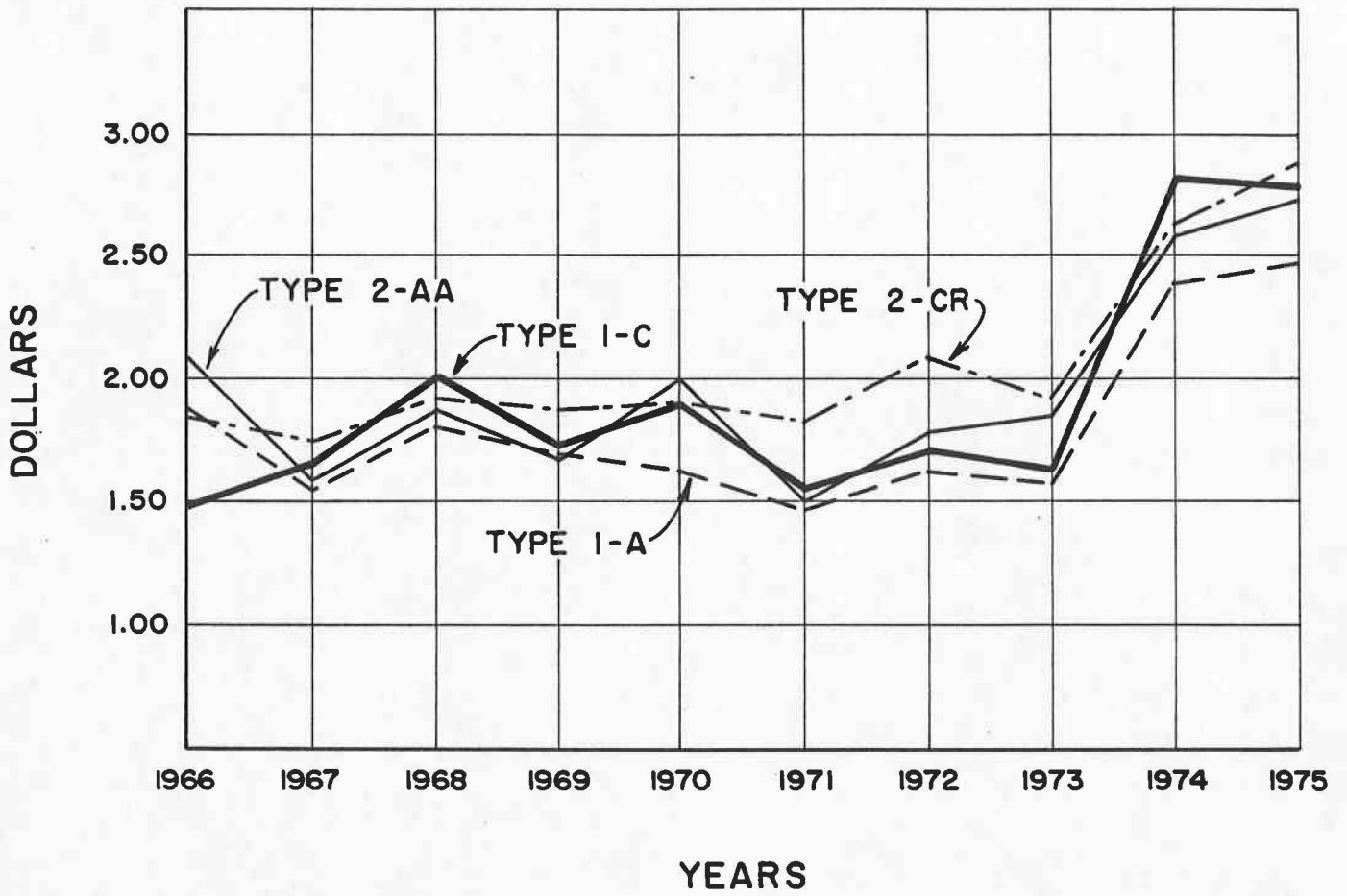


Figure 52. California Experience with Pavement Marker Costs - Installed.



RESEARCH METHODOLOGY

REFLECTIVITY OF MARKERS

The research methodology employed in the reflectivity part of this research project was developed so that the markers were evaluated in the environment in which they operate. To evaluate markers based solely on laboratory analysis of specific intensity would not suffice to determine the effectiveness of the markers. Additional factors within the operating environment, which laboratory analyses cannot measure or take into consideration include, ambient illumination, type of pattern, number of missing markers and roadway geometrics.

A 35mm slide study was conducted to accomplish the objectives of this study. Sites around the state were photographed both day and night. Additional information to include, date of initial installation, percent of trucks in the traffic stream, the average daily traffic (ADT), the number of missing markers and the type of road materials and road geometrics were obtained at each site. At the time the photographs are taken, a representative sample (5-6 markers) at each site were removed to determine the average specific intensity (S.I.).

A panel of experts reviewed the slides and evaluated them with respect to their ability to transmit positive route guidance information to the driver. The panel of experts were composed of members of the Texas SDHPT and the FHWA field office. During the final year of the project, a group of individuals would go to several sites to validate (1) the quality of the slides and (2) the evaluations of the panel of experts. The results of these studies and any other studies relating to the reflectivity of the RPMs and RTBs are reported in research report 322-2.

RETENTION OF MARKERS

The retention of markers on any road surface is dependent mainly on the number of hits a marker sustains. The number of hits is a function of (1) time after installation and (2) the average daily traffic (ADT) on the road or in adjacent lanes. Many variables with respect to the epoxy and the road material will affect the service life. To determine those factors which affect the loss of markers on asphalt, field tests and controlled field tests

were conducted. Sites which were visited and inventoried with respect to retention were cored to determine tensile strength of the material, and the markers were pulled from the road to determine the total force required to remove the markers and the type of failure the old markers experienced.

An additional test was evaluated at D-9's suggestion. It was a simple "Polyethelene" test to determine excessive moisture on or in the road surface prior to installation. This test was evaluated from a controlled field study conducted at the Texas A&M University Research Center.

A study was conducted to evaluate different types of epoxies to use on road surfaces with poor retention properties. The study is currently being conducted near the Bryan/College Station area for access to the researchers and to hold down travel costs. The results and documentation of these studies and any additional studies are reported in research report 322-3, and 322-4.

RESULTS

The results from this state-of-the-art review indicates that:

1. Retention of RPMs (88s and 947s) is a major problem on A.C.C. pavements.
2. Ceramic markers major problem is related to reflectivity. Lenses are dirty or missing.
3. Improper installation procedures cause RPMs and RTBs to dislodge from the pavement.
4. RPMs and RTBs lose reflectivity within six months regardless of initial reflectivity levels.
5. The initial cost and subsequent maintenance costs appear to make both RPMs and RTBs a cost-ineffective system.
6. Shape appears to be the largest factor contributing to increased service life.



REFERENCES

1. Texas State Department of Highways and Public Transportation, "Durability of Reflective Markers Under Traffic", Research Project 3-03-76-079, 1978.
2. Fullerton, I.J., "Roadway Delineation Practices Handbook", JHK & Associates, Department of Transportation, Federal Highway Administration, FHWA Report Number, FHWA-IP-81-S.
3. Amerace Corporation, "Results of Accelerated Wear Testing", PM-2-3/76.
4. California Department of Transportation, "Optimization of Traffic Lane Delineation", Department of Transportation, Federal Highway Administration, FHWA Report Number FHWA-TS-77-200, December 1976.

APPENDIX A
Reflective Markers - Wear and Retention Data





RAISED REFLECTIVE PAVEMENT MARKER
WEAR AND RETENTION DATA

District 15, Data Collected by R. W. McNeas: July 1, 1982
J. S. Noel

Daylight

- 1) Highway: IH 10
- 2) Location: East of San Antonio
Eastbound
from Milepost 581 to 584
- 3) Traffic: ADT: 18,500 (1980) (both ways)
Truck Traffic:
- 4) Surface: Type: Hot mix asphalt concrete
Date Finished:
Width: 2 - 12' lanes, shoulders paved
- 5) Pavement Markers Studied: Type II-CR, Reflective Pavement Marker @
80 o/c
Stimsonite 947
Date Placed: April 1981
Test Period: 1 year 3 months
(4.22×10^6 vehicles in adjacent lanes)

<u>Pavement Marker, Type II-CR - Stimsonite 947</u>	<u>Total Number of Markers</u>	<u>Percent</u>
Unbroken, Effective	12	6
Broken, Effective	25	13
Submerged:	1	0.5
Broken, Ineffective (includes worn surface):	1	0.5
Missing, Epoxy Failure:	0	0
Missing, Pavement Failure:	157	80

RAISED REFLECTIVE PAVEMENT MARKER
WEAR AND RETENTION DATA

District 15, Data Collected by R. W. McNees: July 1, 1982
J. S. Noel

Daylight

- 1) Highway: IH 10
- 2) Location: East of San Antonio
Westbound
from Milepost 584 to 581
- 3) Traffic: ADT: 18,500 (1980) (both ways)
Truck Traffic:
- 4) Surface: Type: Hot mix asphalt concrete
Date Finished:
Width: 2 - 12' lanes, shoulders paved
- 5) Pavement Markers Studied: Type II-CR, Reflective Pavement Marker @
80 o/c
Stimsonite 947
Date Placed: April 1981
Test Period: 1 year 3 months
(4.22×10^6 vehicles in adjacent lanes)

<u>Pavement Marker, Type II-CR - Stimsonite 947</u>	<u>Total Number of Markers</u>	<u>Percent</u>
Unbroken, Effective	23+	12
Broken, Effective	16	8
Submerged:	3	1
Broken, Ineffective (includes worn surface):	0	0
Missing, Epoxy Failure:	1	1
Missing, Pavement Failure:	153	78

SUMMARY, both East and Westbound

Unbroken, Effective	35	9
Broken, Effective	41	11
Submerged:	4	1
Broken, Ineffective (includes worn surface):	1	0
Missing, Epoxy Failure:	1	0
Missing, Pavement Failure:	310	79

76 77

RAISED REFLECTIVE PAVEMENT MARKER
WEAR AND RETENTION DATA

District 15, Data Collected by R. W. McNees: July 1, 1982
J. S. Noel

Nighttime
(dry)

- 1) Highway: IH 10
- 2) Location: East of San Antonio
Eastbound
from Milepost 581 to 584
- 3) Traffic: ADT: 18,500 (1980) (both ways)
Truck Traffic:
- 4) Surface: Type: Hot mix asphalt concrete
Date Finished:
Width: 2 - 12' lanes, shoulders paved
- 5) Pavement Markers Studied: Type II-CR, Reflective Pavement Marker @
80 o/c
Stimsonite 947
Date Placed: April 1981
Test Period: 1 year 3 months
(4.22×10^6 vehicles in adjacent lanes)

<u>Pavement Marker, Type II-CR - Stimsonite 947</u>	<u>Total Number of Markers</u>	<u>Percent</u>
Reflectivity Unimpaired:	0	0
Reflectivity Impaired:	34	17
Unseen:	162	83

RAISED REFLECTIVE PAVEMENT MARKER
WEAR AND RETENTION DATA

District 15, Data Collected by R. W. McNees: July 1, 1982
J. S. Noel

Nighttime
(dry)

- 1) Highway: IH 10
- 2) Location: East of San Antonio
Westbound
from Milepost 584 to 581
- 3) Traffic: ADT: 18,500 (1980) (both ways)
Truck Traffic:
- 4) Surface: Type: Hot mix asphalt concrete
Date Finished:
Width: 2 - 12' lanes, shoulders paved
- 5) Pavement Markers Studied: Type II-CR, Reflective Pavement Marker @
80 o/c
Stimsonite 947
Date Placed: April 1981
Test Period: 1 year 3 months
(4.22×10^6 vehicles in adjacent lanes)

<u>Pavement Marker, Type II-CR - Stimsonite 947</u>	<u>Total Number of Markers</u>	<u>Percent</u>
Reflectivity Unimpaired:	0	0
Reflectivity Impaired:	43	22
Unseen:	153	78

SUMMARY, both East and Westbound

Reflectivity Unimpaired:	0	0
Reflectivity Impaired:	77	20
Unseen:	315	80

RAISED REFLECTIVE PAVEMENT MARKER
WEAR AND RETENTION DATA

District 15, Data Collected by R. W. McNeese: July 1, 1982
J. S. Noel

Daylight

- 1) Highway: IH 10
- 2) Location: East of San Antonio
Eastbound
from Milepost 584 to 587
- 3) Traffic: ADT: 18,500 (1980) (both ways)
Truck Traffic:
- 4) Surface: Type: Hot mix asphalt concrete
Date Finished:
Width: 2 - 12' lanes, shoulders paved
- 5) Pavement Markers Studied: Type II-CR, Reflective Pavement Marker @
80 o/c
Stimsonite 88
Date Placed: April 1981
Test Period: 1 year 3 months
(4.22×10^6 vehicles in adjacent lanes)

<u>Pavement Marker</u>	<u>Total Number of Markers</u>	<u>Percent</u>
Unbroken, Effective:	137	70
Broken, Effective:	43	22
Submerged:	0	0
Broken, Ineffective (includes worn surface):	6	3
Missing, Epoxy Failure:	0	0
Missing, Pavement Failure:	10	5

79 30

RAISED REFLECTIVE PAVEMENT MARKER
WEAR AND RETENTION DATA

District 15, Data Collected by R. W. McNees: July 1, 1982
J. S. Noel

Daylight

- 1) Highway: IH 10
- 2) Location: East of San Antonio
Westbound
from Milepost 587 to 584
- 3) Traffic: ADT: 18,500 (1980) (both ways)
Truck Traffic:
- 4) Surface: Type: Hot mix asphalt concrete
Date Finished:
Width: 2 - 12' lanes, shoulders paved
- 5) Pavement Markers Studied: Type II-CR, Reflective Pavement Marker @
80 o/c
Stimsonite 88
Date Placed: April 1981
Test Period: 1 year 3 months
(4.22×10^6 vehicles in adjacent lanes)

<u>Pavement Marker</u>	<u>Total Number of Markers</u>	<u>Percent</u>
Unbroken, Effective:	123	63
Broken, Effective:	21	10
Submerged:	1	1
Broken, Ineffective (includes worn surface):	9	5
Missing, Epoxy Failure:	4	2
Missing, Pavement Failure:	38	19

SUMMARY: both East and Westbound

Unbroken, Effective:	260	66
Broken, Effective:	64	16
Submerged:	1	1
Broken, Ineffective (includes worn surface):	15	4
Missing, Epoxy Failure:	4	1
Missing, Pavement Failure:	48	12

RAISED REFLECTIVE PAVEMENT MARKER
WEAR AND RETENTION DATA

District 15, Data Collected by R. W. McNeese: July 1, 1982
J. S. Noel

Nighttime
(dry)

- 1) Highway: IH 10
- 2) Location: East of San Antonio
Eastbound
from Milepost 584 to 587
- 3) Traffic: ADT: 18,500 (1980) (both ways)
Truck Traffic:
- 4) Surface: Type: Hot mix asphalt concrete
Date Finished:
Width: 2 - 12' lanes, shoulders paved
- 5) Pavement Markers Studied: Type II-CR, Reflective Pavement Marker @
80 o/c
Stimsonite 88
Date Placed: April 1981
Test Period: 1 year 3 months
(4.22×10^6 vehicles in adjacent lanes)

<u>Pavement Marker</u>	<u>Total Number of Markers</u>	<u>Percent</u>
Reflectivity Unimpaired	28	14
Reflectivity Impaired:	84	43
Unseen:	84	43

RAISED REFLECTIVE PAVEMENT MARKER
WEAR AND RETENTION DATA

District 15, Data Collected by R. W. McNees: July 1, 1982
J. S. Noel

Nighttime

- 1) Highway: IH 10
- 2) Location: East of San Antonio
Westbound
from Milepost 587 to 584
- 3) Traffic: ADT: 18,500 (1980) (both ways)
Truck Traffic:
- 4) Surface: Type: Hot mix asphalt concrete
Date Finished:
Width: Two lanes, shoulders paved
- 5) Pavement Markers Studied: Type II-CR, Reflective Pavement Marker @
80 o/c
Stimsonite 88
Date Placed: April 1981
Test Period: 1 year 3 months
(4.22×10^6 vehicles in adjacent lanes)

<u>Pavement Marker</u>	<u>Total Number of Markers</u>	<u>Percent</u>
Effective:	64	33
Reflectivity Impaired:	59	30
Unseen:	73	37

SUMMARY, both East and Westbound

Reflectivity Unimpaired:	92	24
Reflectivity Impaired:	143	36
Unseen:	157	40

RAISED REFLECTIVE TRAFFIC BUTTON
WEAR AND RETENTION DATA

District 15, Data Collected by R. W. McNees: July 1, 1982
J. S. Noel

Daytime

- 1) Highway: IH 10
- 2) Location: East of San Antonio
Eastbound
from Milepost 587 to 590
- 3) Traffic: ADT: 18,500 (1980) (both ways)
Truck Traffic:
- 4) Surface: Type: Hot mix asphalt concrete
Date Finished:
Width: 2 - 12' lanes, shoulders paved
- 5) Pavement Markers Studied: Type II-CR, Reflective Pavement Marker @
80 o/c
Permark Rounds
Date Placed: April 1981
(4.22 x 10⁶ vehicles in adjacent lanes)

<u>Traffic Buttons</u>	<u>Total Number of Buttons</u>	<u>Percent</u>
Unbroken, Effective:	63	32
Broken, Effective:	57	29
Unbroken, Missing Rod:	6	3
Broken, Ineffective:	65	33
Missing, Epoxy Failure:	4	2
Missing, Pavement Failure:	1	1

RAISED REFLECTIVE TRAFFIC BUTTON
WEAR AND RETENTION DATA

District 15, Data Collected by R. W. McNees: July 1, 1982
J. S. Noel

Daytime

- 1) Highway: IH 10
- 2) Location: East of San Antonio
Westbound
from Milepost 590 to 587
- 3) Traffic: ADT: 18,500 (1980) (both ways)
Truck Traffic:
- 4) Surface: Type: Hot mix asphalt concrete
Date Finished:
Width: 2 - 12' lanes, shoulders paved
- 5) Pavement Markers Studied: Type II-CR, Reflective Pavement Marker @
80 o/c
Permark Rounds
Date Placed: April 1981
(4.22×10^6 vehicles in adjacent lanes)

<u>Traffic Buttons</u>	<u>Total Number of Buttons</u>	<u>Percent</u>
Unbroken, Effective:	63	32
Broken, Effective:	72	37
Unbroken, Missing Rod:	14	7
Broken, Ineffective:	45	23
Missing, Epoxy Failure:	2	1
Missing, Pavement Failure:	0	0

SUMMARY, both East and Westbound

Unbroken, Effective:	126	32
Broken, Effective:	129	33
Unbroken, Missing Rod:	20	5
Broken, Ineffective:	110	28
Missing, Epoxy Failure:	8	2
Missing, Pavement Failure:	1	0

85
84

RAISED REFLECTIVE TRAFFIC BUTTON
WEAR AND RETENTION DATA

District 15, Data Collected by R. W. McNees: July 1, 1982
J. S. Noel

Nighttime
(dry)

- 1) Highway: IH 10
- 2) Location: East of San Antonio
Eastbound
from Milepost 587 to 590
- 3) Traffic: ADT: 18,500 (1980) (both ways)
Truck Traffic:
- 4) Surface: Type: Hot mix asphalt concrete
Date Finished:
Width: 2 - 12' lanes, shoulders paved
- 5) Pavement Markers Studied: Type II-CR, Reflective Pavement Marker @
80 o/c
Permark Rounds
Date Placed: April 1981
(4.22 x 10⁶ vehicles in adjacent lanes)

<u>Traffic Buttons</u>	<u>Total Number of Buttons</u>	<u>Percent</u>
Reflectivity Unimpaired:	0	0
Reflectivity Impaired:	166	85
Unseen:	30	15

RAISED REFLECTIVE TRAFFIC BUTTON
WEAR AND RETENTION DATA

District 15, Data Collected by R. W. McNees: July 1, 1982
J. S. Noel

Nighttime
(dry)

- 1) Highway: IH 10
- 2) Location: East of San Antonio
Westbound
from Milepost 590 to 587
- 3) Traffic: ADT: 18,500 (1980) (both ways)
Truck Traffic:
- 4) Surface: Type: Hot mix asphalt concrete
Date Finished:
Width: 2 - 12' lanes, shoulders paved
- 5) Pavement Markers Studied: Type II-CR, Reflective Pavement Marker @
80 o/c
Permark Rounds
Date Placed: April 1981
(4.22×10^6 vehicles in adjacent lanes)

<u>Traffic Buttons</u>	<u>Total Number of Buttons</u>	<u>Percent</u>
Reflectivity Unimpaired:	0	0
Reflectivity Impaired:	155	79
Unseen:	41	21

SUMMARY, both East and Westbound

Reflectivity Unimpaired:	0	0
Reflectivity Impaired:	321	82
Unseen:	71	18

RAISED REFLECTIVE PAVEMENT MARKER
WEAR AND RETENTION DATA

District 15, Data Collected by S. Pennartz: July 1, 1982
 R. W. McNees
 J. S. Noel Daytime

- 1) Highway: IH 10
- 2) Location: Northwest of San Antonio
 Eastbound
 from Milepost 534 to 545
- 3) Traffic: ADT: 12,000 vpd (1980) (both ways)
 Percent Trucks:
- 4) Surface: Type: Hot mix asphalt concrete
 Date Finished:
 Width: 2 - 12' lanes, both shoulders paved
- 5) Pavement Markers Studied: Type II-CR, Reflective Pavement Marker @
 80 o/c
 Stimsonite 88
 Date Placed: April 1981
 Test Duration: 1 year 3 months

<u>Pavement Markers, TY II-CR, Stimsonite</u>	<u>Total Number of Markers</u>	<u>Percent</u>
Unbroken, Effective:	588	84
Broken, Effective:	77	11
Submerged:	0	0
Broken, Ineffective (includes worn surface):	20	3
Missing, Epoxy Failure:	6	1
Missing, Pavement Failure:	9	1

RAISED REFLECTIVE TRAFFIC BUTTON
WEAR AND RETENTION DATA

District 15, Data Collected by S. Pennartz: July 1, 1982
 R. W. McNees
 J. S. Noel Daytime

- 1) Highway: IH 10
- 2) Location: Northwest of San Antonio
 Westbound
 from Milepost 545 to 534
- 3) Traffic: ADT: 12,000 vpd (1980) (both ways)
 Percent Trucks:
- 4) Surface: Type: Hot mix asphalt concrete
 Date Finished:
 Width: 2 - 12' lanes, both shoulders paved
- 5) Pavement Markers Studied: Type II-CR, Reflective Pavement Marker @
 80 o/c
 Date Placed: April 1981
 Test Duration: 1 year 3 months

<u>Traffic Buttons, TY II-CR, Round Buttons</u>	<u>Total Number of Buttons</u>	<u>Percent</u>
Unbroken, Effective:	507	69
Broken, Effective:	179	24
Unbroken, Missing Rod:	6	1
Broken, Ineffective:	29	4
Missing, Epoxy Failure:	15	2
Missing, Pavement Failure:	0	0

88
89

RAISED REFLECTIVE PAVEMENT MARKER
WEAR AND RETENTION DATA

District 14, Data Collected by Mathew Barton

March 24, 1982

Daytime

- 1) Highway: S. H. 71
- 2) Location: Eastbound
From Beginning 4 lanes at Bergstrom Interchange
To end 4 lanes near Bergstrom Main Gate
Approximately a 1-mile long segment
- 3) Traffic: ADT: 17,450 vpd (1980) (one-way)
Truck Traffic: 6.3%
- 4) Surface: Type: Hot mix asphalt concrete
Date Finished: May, 1978
Width: 4 - 12' lanes, no shoulder
- 5) Pavement Markers Studied: Type II-CR, Reflective Pavement Marker @
80 o/c
Stimsonite 88
Date Placed: September, 1979
Test Duration: 2 year 6 months
Total Vehicle (adjacent lanes) = 7.96×10^6

<u>Pavement Markers, TY II-CR</u>	<u>Total Number of Markers</u>	<u>Percent</u>
Unbroken, Effective:	19	8.9
Broken, Effective:	12	5.6
Submerged:	--	--
Broken, Ineffective (includes worn surface):	99	46.5
Missing, Epoxy Failure:	--	--
Missing, Pavement Failure:	83	39.0

70
87

RAISED REFLECTIVE PAVEMENT MARKER
WEAR AND RETENTION DATA

District 14, Data Collected by Mathew Barton March 24, 1982

Daytime

- 1) Highway: S. H. 71
- 2) Location: Eastbound
From Beginning 2 lanes at Bergstrom Main Gate
To 1/2 mile east
Approximately a 1-mile long segment
- 3) Traffic: ADT: 8,900 (1980) (one-way)
Truck Traffic: 7.1%
- 4) Surface: Type: Hot mix asphalt concrete
Date Finished: June, 1979
Width: 2 - 12' lanes, 10' Rt and 6' Lt paved shoulder
- 5) Pavement Markers Studied: Type II-CR, Reflective Pavement Marker @
80 o/c
Stimsonite 88
Date Placed: September, 1979
Test Duration: 2 year 6 months
Total Vehicle (adjacent lanes) = 8.1×10^6

<u>Pavement Markers, TY II-CR</u>	<u>Total Number of Markers</u>	<u>Percent</u>
Unbroken, Effective:	3	7.9
Broken, Effective:	0	0.0
Submerged:	--	--
Broken, Ineffective (includes worn surface):	4	10.5
Missing, Epoxy Failure:	--	--
Missing, Pavement Failure:	31	81.5

RAISED REFLECTIVE PAVEMENT MARKER
WEAR AND RETENTION DATA

District Houston Urban, Data Collected by R. McNees: July 8, 1982
J. Noel Daytime

- 1) Highway: IH 45
- 2) Location: Downtown Houston
Northbound
Between Allen Parkway and IH 10
- 3) Traffic: ADT: 74,000 vpd (one-way) (1980)
Truck Traffic: 5.0%
- 4) Surface: Type: Portland Cement Concrete
Width: 4 lanes each way
- 5) Pavement Markers Studied: TY II-CR, Three Lane Lines Spaced @
40 feet o/c
Stimsonite 88
Date Placed: June 15, 1981
Test Duration: 13 months
Total Vehicles (adjacent lanes) = 14.6×10^6

<u>Pavement Markers, TY II-CR, Stimsonite 88</u>	<u>Total Number of Markers</u>	<u>Percent</u>
Unbroken, Effective	322	84
Broken, Effective	62	16
Broken, Ineffective	1	0
Missing, Epoxy to RRPM Failure	0	0
Missing, Epoxy to Pavement Failure	0	0
Missing, Pavement Failure	0	0

RAISED REFLECTIVE PAVEMENT MARKER
WEAR AND RETENTION DATA

District Houston Urban, Data Collected by R. McNees: July 8, 1982
J. Noel Daytime

- 1) Highway: IH 45
- 2) Location: Downtown Houston
Southbound
Between IH 10 and Allen Parkway
- 3) Traffic: ADT: 63,000 vpd (one-way) (1980)
Truck Traffic: 5.0%
- 4) Surface: Type: Portland Cement Concrete
Width: 4 lanes each way
- 5) Pavement Markers Studied: TY II-CR, Three Lane Lines Spaced @
40 feet o/c
Both Ray-O-Lite and Stimsonite 88
Date Placed: June 15, 1981
Test Duration: 25 months
Total Vehicles (adjacent lanes) = 24.0×10^6

<u>Pavement Markers, TY II-CR,</u>	<u>Total Number of Markers</u>	<u>Percent</u>
Unbroken, Effective	106	33
Broken, Effective	126	39
Broken, Ineffective	13	4
Missing, Epoxy to RRPM Failure	10	3
Missing, Epoxy to Pavement Failure	21	6
Missing, Pavement Failure	48	15

10

93
96

RAISED REFLECTIVE PAVEMENT MARKER
WEAR AND RETENTION DATA

District 12, Data Collected by R. McNees: July 8, 1982
J. Noel Daytime

- 1) Highway: IH 10
- 2) Location: West of Houston
Eastbound
from Exit 750 to SH 6
- 3) Traffic: ADT: 34,000 (1981) near SH 6 (one-way)
Truck Traffic: 12.8%
- 4) Surface: Type: Portland Cement Concrete
Width: 3 lanes each way
- 5) Pavement Markers Studied: Type II-CR, Both Lane Lines Spaced @
40 feet o/c
Stimsonite 88
Date Placed: July 1977
Test Duration: 5 years

Pavement Marker	<u>Inside Lane</u>		<u>Outside Lane</u>		<u>Combined</u>
	Total Number of Markers	Percent	Total Number of Markers	Percent	Percent
Unbroken, Effective	0	0	0	0	0
Broken, Effective	38	35	26	24	30
Broken, Ineffective (worn)	42	38	27	25	32
Missing, Epoxy to RRPM Failure	9	8	23	21	14
Missing, Epoxy to Pavement Failure	20	18	30	28	23
Missing, Pavement Failure	1	1	2	2	1

<u>Summary, Both Ways, Both Lanes</u>	<u>Total Number of Markers</u>	<u>Percent</u>
Unbroken, Effective	16	4
Broken, Effective	105	26
Broken, Ineffective (worn)	140	35
Missing, Epoxy to RRPM Failure	60	15
Missing, Epoxy to Pavement Failure	75	18
Missing, Pavement Failure	7	2

REFLECTIVE PAVEMENT MARKER
WEAR AND RETENTION DATA

District 12, Data Collected by R. McNees: July 8, 1982
J. Noel Daytime

- 1) Highway: IH 10
- 2) Location: West of Houston
Westbound
from SH 6 to Exit 750
- 3) Traffic: ADT: 35,000 vpd (one-way)
Truck Traffic: 12.8%
- 4) Surface: Type: Portland Cement Concrete
Width: 3 lanes each way
- 5) Pavement Markers Studied: Type II-CR, Both Lane Lines Spaced @
40 feet o/c
Stimsonite 88
Date Placed: July 1977
Test Duration: 5 years

Pavement Marker	<u>Inside Lane</u>		<u>Outside Lane</u>		<u>Combined</u>
	Total Number of Markers	Percent	Total Number of Markers	Percent	Percent
Unbroken, Effective	7	7	9	10	9
Broken, Effective	28	29	13	15	22
Broken, Ineffective (worn)	38	39	33	38	38
Missing, Epoxy to RRPM Failure	11	11	17	20	15
Missing, Epoxy to Pavement Failure	11	11	14	16	14
Missing, Pavement Failure	3	3	1	1	2

RAISED REFLECTIVE TRAFFIC BUTTON
WEAR AND RETENTION DATA

District 14, Data Collected by Mathew Barton - March 24, 1982 Daytime

- 1) Highway: IH 35 Upper Level
- 2) Location: Northbound Upper Level (in Austin)
From beginning of 10' Rt shoulder
To 1-mile north at Sign Bridge
A segment just over 1 mile long*
- 3) Traffic: ADT: 27,450 (one-way) (1980)
Truck Traffic: 5.4%
- 4) Surface: Type: Concrete
Date Finished: February, 1974
Width: 2 -12' lanes with 6' Lt and 10' Rt shoulders
- 5) Pavement Markers Studied: TY I-C Buttons, 3 buttons per 10' stripe
at 5' o/c
TY II-CR Buttons, lead buttons per 10' stripe
Date Placed: February, 1974

<u>Traffic Button, TY I-C</u>	<u>Total Number of Buttons</u>	<u>Percent</u>
Unbroken, Effective	293	74.0
Broken, Effective	53	13.4
Broken, Ineffective	32	8.1
Missing, Epoxy to RRPM Failure	17	4.3
Missing, Epoxy to Pavement Failure	1	0.3
Missing, Pavement Failure	0	0

<u>Traffic Button, TY II-CR</u>	<u>Total Number of Buttons</u>	<u>Percent</u>
Unbroken, Effective	49	37.1
Broken, Effective	18	13.6
Unbroken, Missing Rod		
Clear	4	3.0
Red	36	27.2
Red and Clear	13	9.8
Broken, Ineffective	12	9.1
Missing, Epoxy Failure	0	0
Missing, Pavement Failure	0	0

* Section beginning at the end of acceleration lane and end 1/4 mile in advance of Exit Ramp, with no ramps between these two points.

RAISED REFLECTIVE TRAFFIC BUTTON
WEAR AND RETENTION DATA

District 14, Data Collected by Mathew Barton - March 24, 1982

Daytime

- 1) Highway: IH 35 Lower Level
- 2) Location: Southbound Lower Level (in Austin)
from 38½ Street
to just south of Manor Road
a segment about 1 mile long*
- 3) Traffic: ADT: 22,500 (one-way) (1980)
Truck Traffic: 5.4%
- 4) Surface: Type: Asphalt Concrete Pavement
Date Finished: May 1976
Width: 2'- 12' lanes with 10' shoulder outside,
concrete median barrier
- 5) Pavement Markers Studied: TY I-C Buttons, 3 buttons per 10' stripe
TY II-CR Buttons, 1 lead button per 10' stripe
Date Placed: May 1976

<u>Traffic Button, TY I-C</u>	<u>Total Number of Buttons</u>	<u>Percent</u>
Unbroken, Effective	227	57.3
Broken, Effective	40	10.1
Broken, Ineffective	24	6.1
Missing, Epoxy to RRPM Failure	100	25.3
Missing, Epoxy to Pavement Failure	1	0.2
Missing, Pavement Failure	4	1.0
 <u>Traffic Button, TY II-CR</u>		
Unbroken, Effective	35	50.0
Broken, Effective	19	27.1
Unbroken, Missing Rod		
Clear	0	0
Red	0	0
Red and Clear	1	1.4
Broken, Ineffective	13	18.6
Missing, Epoxy Failure	0	0
Missing, Pavement Failure	2	2.9

* There are 2 Exit and 2 Entrance ramps in this section.

RAISED REFLECTIVE TRAFFIC BUTTON
WEAR AND RETENTION DATA

District 14, Data Collected by Mathew Barton - April 7, 1982

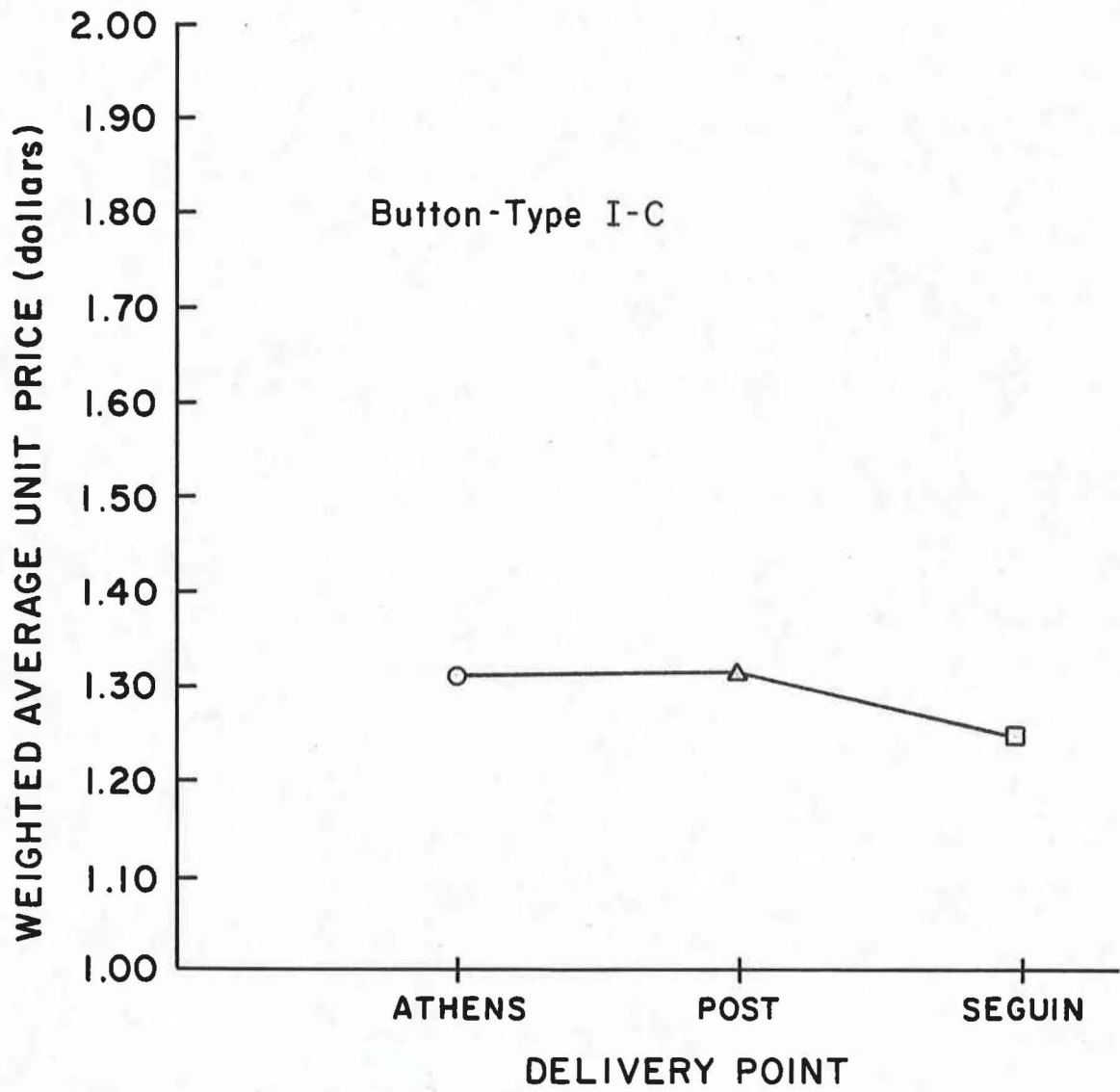
Daytime

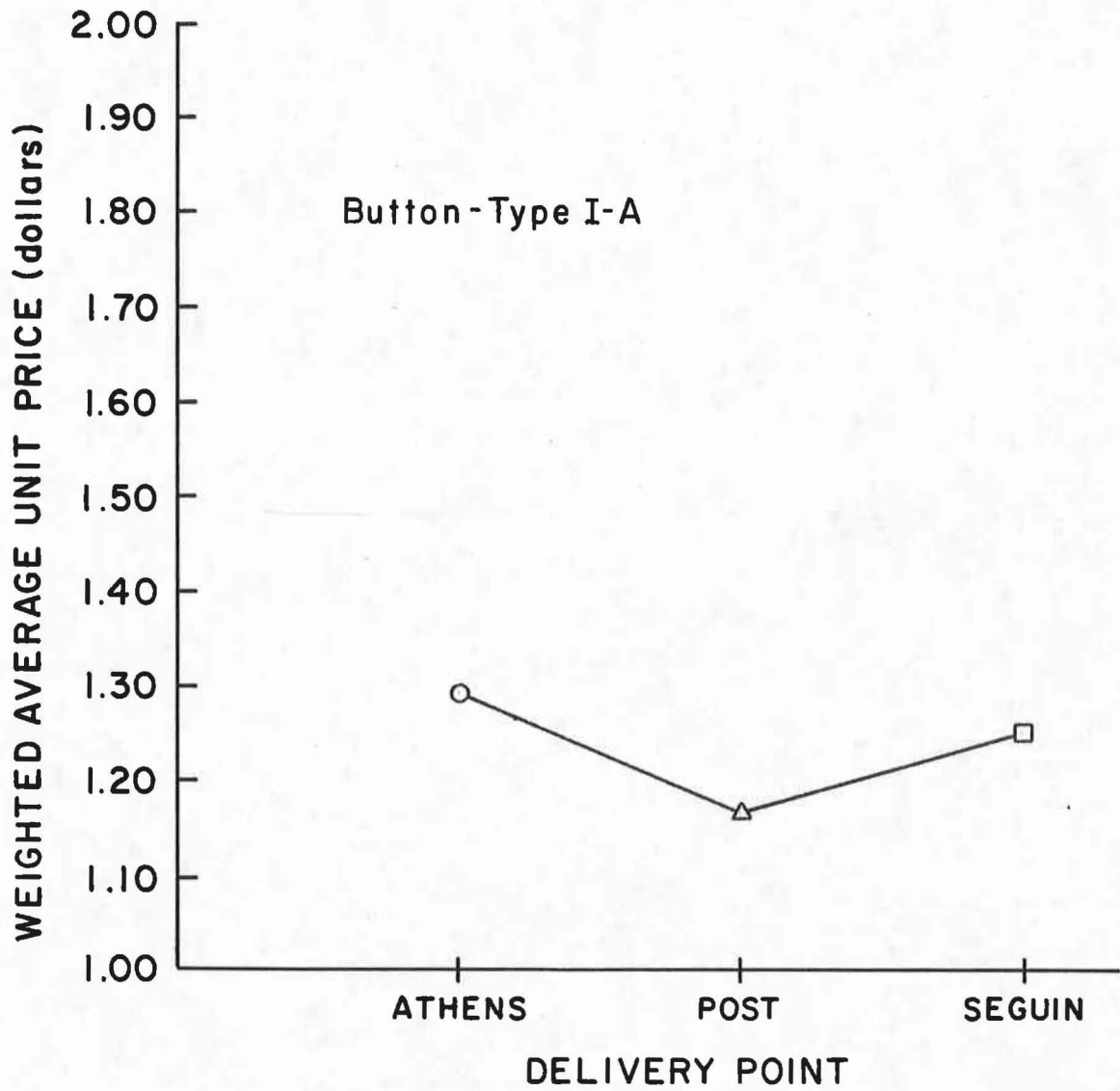
- 1) Highway: U.S. 290
- 2) Location: East and West bound
From Giles Road
To Loop 212 in Manor, 4.5 miles one-way
Approximately a 1-mile long segment
- 3) Traffic: ADT: 5,000 (one-way) (1980)
Truck Traffic: 9.0%
- 4) Surface: Type: Asphalt Concrete Pavement
Date Finished: August, 1978
Width: 2 -12' lanes with 10' Rt and 6' Lt shoulder
- 5) Pavement Markers Studied: II-C reflective pavement marker at 80 o/c
Stimsonite 88
Date Placed: June, 1979
Test Period: 2 years, 10 months

<u>Traffic Button, TY II-CR (Stimsonite 88)</u>	<u>Total Number of Markers</u>	<u>Percent</u>
EASTBOUND		
Unbroken, Effective	110	37.0
Broken, Effective	103	34.7
Submerged	--	--
Broken Ineffective (includes worn surface)	39	13.1
Missing, Epoxy	--	--
Missing, Pavement Failure	45	15.2
WESTBOUND		
Unbroken, Effective	195	65.7
Broken, Effective	42	14.1
Submerged	--	--
Broken Ineffective (includes worn surface)	46	15.5
Missing, Epoxy	--	--
Missing, Pavement Failure	14	4.7

18
100

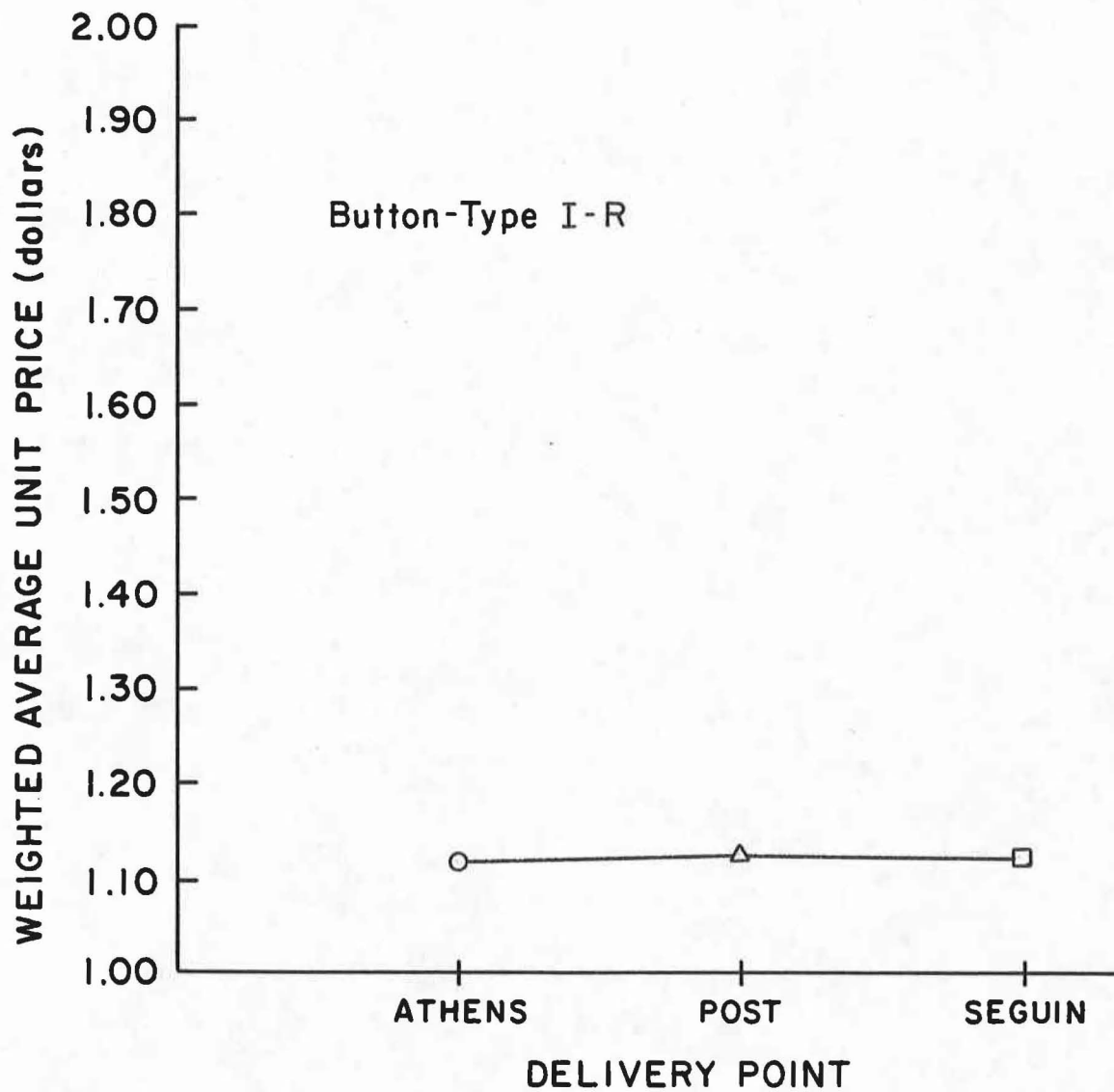
APPENDIX B
Weighted Average Unit Price of RPMs and RTB

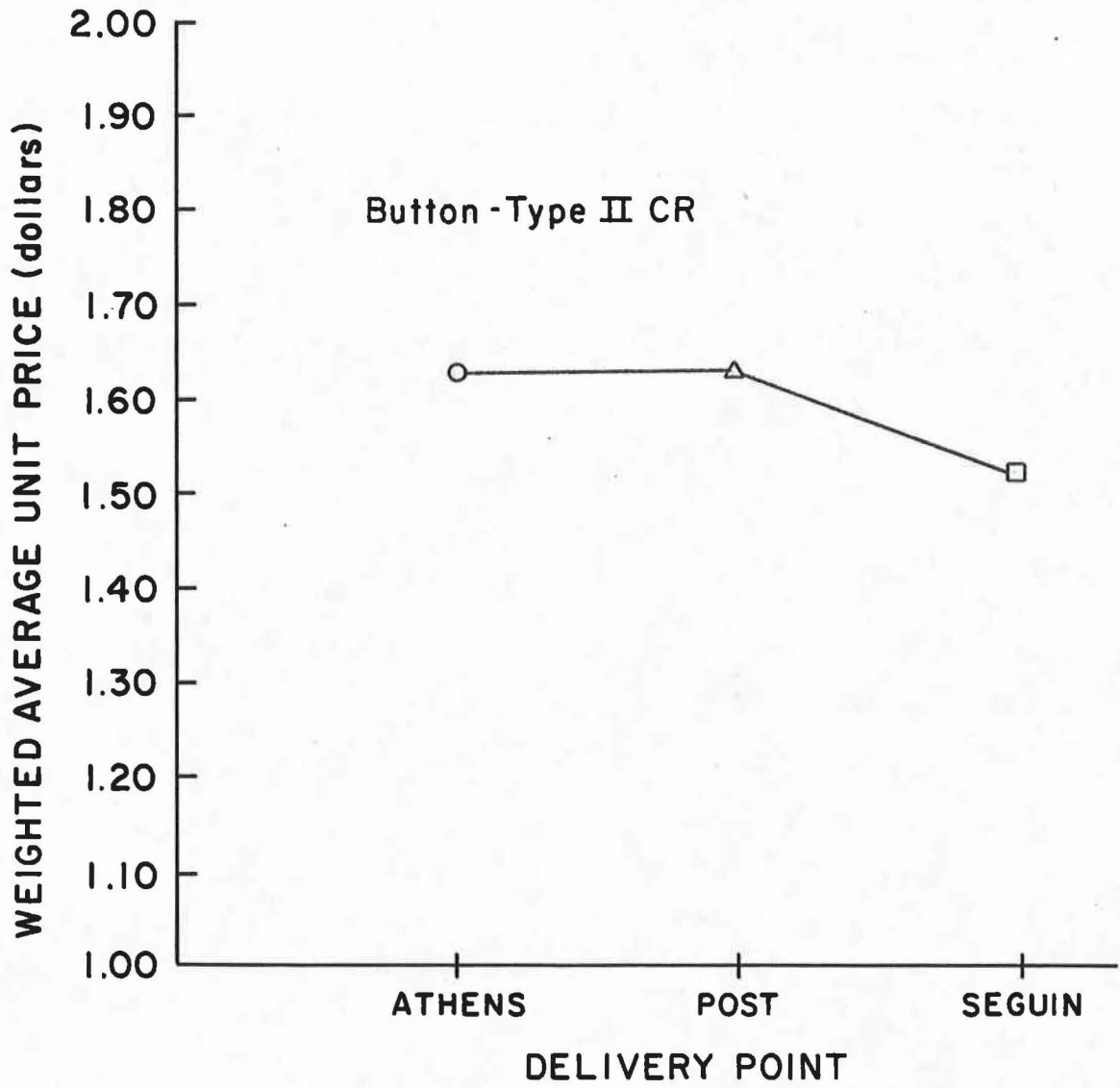


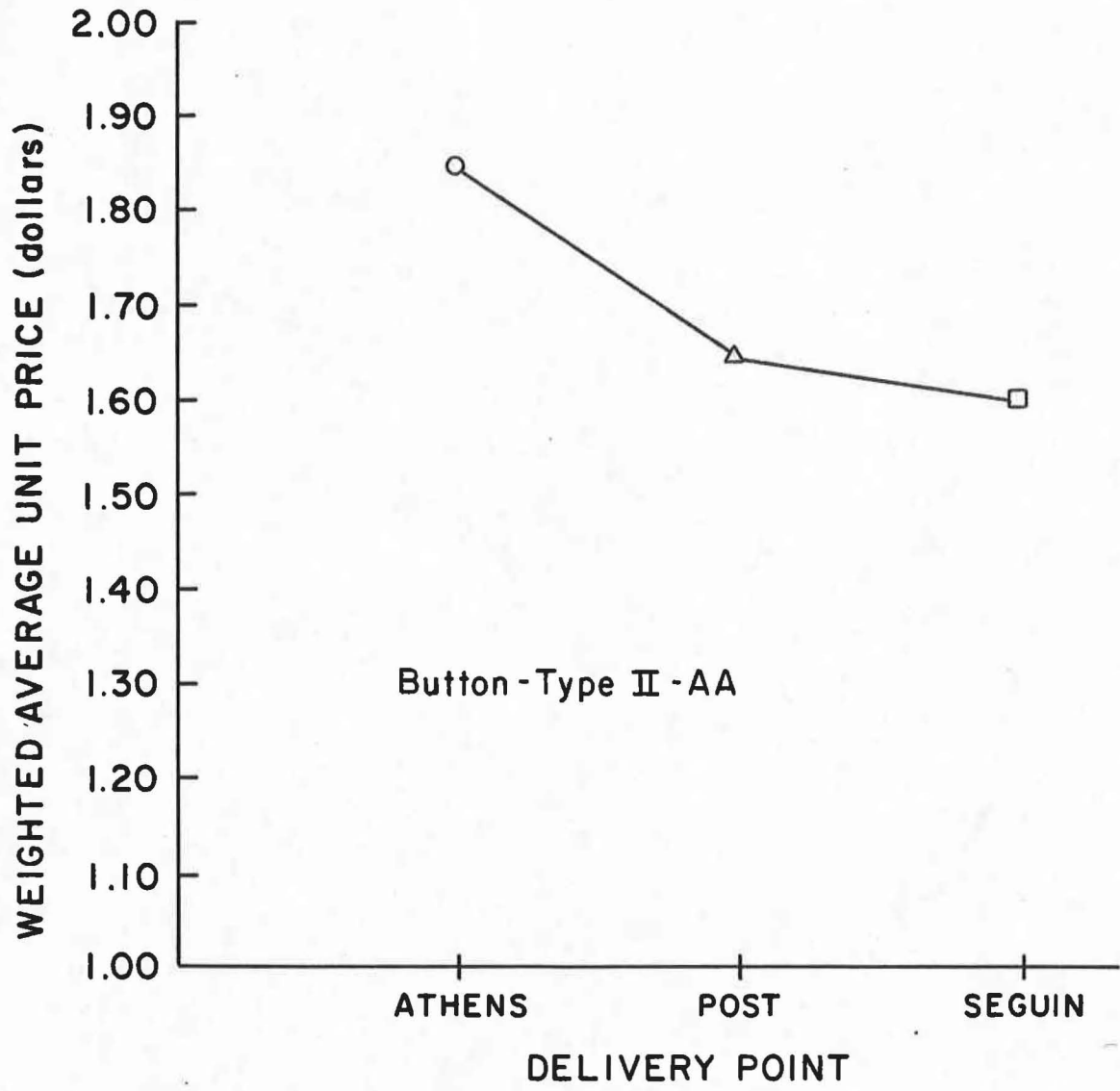


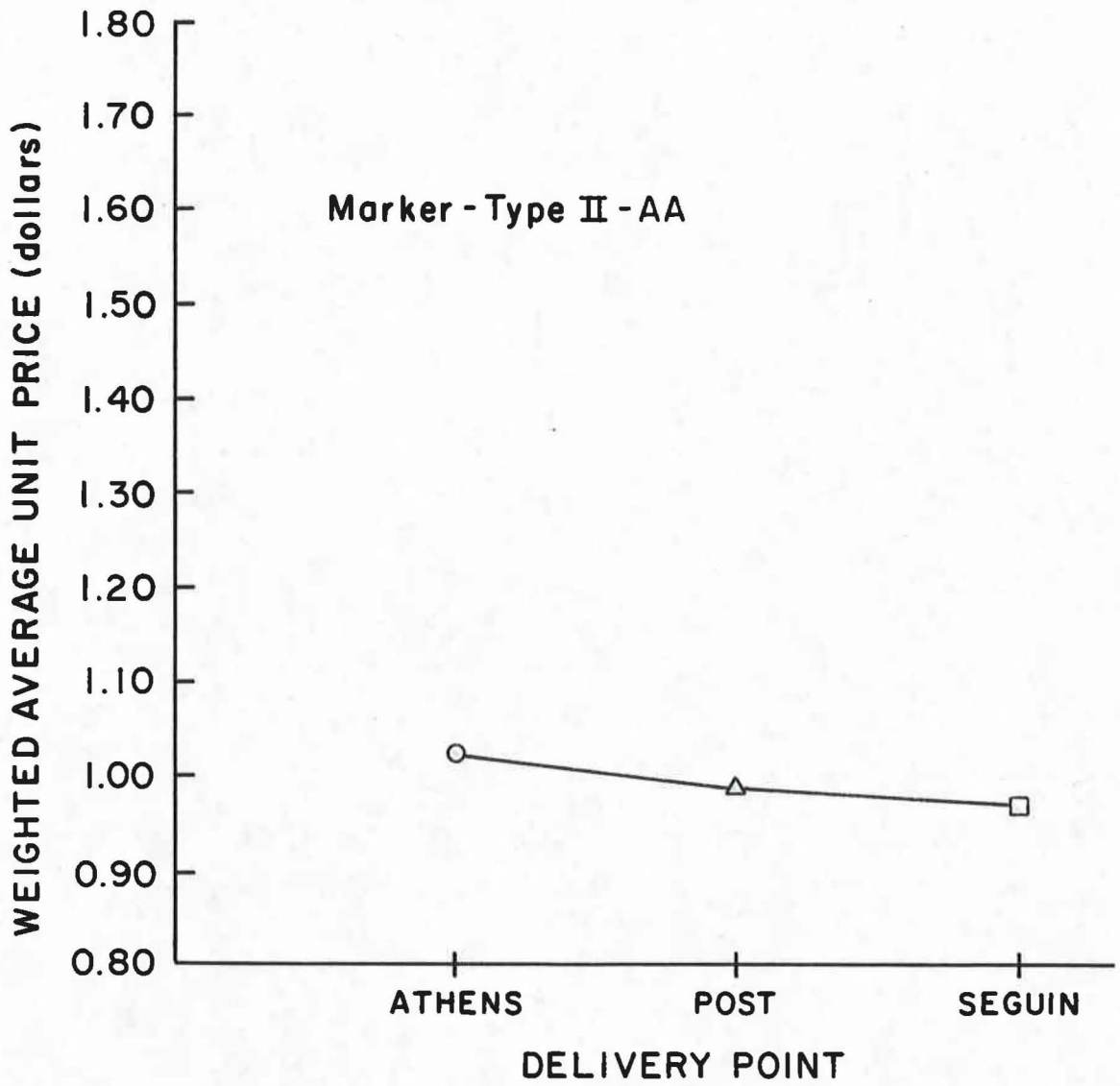
16

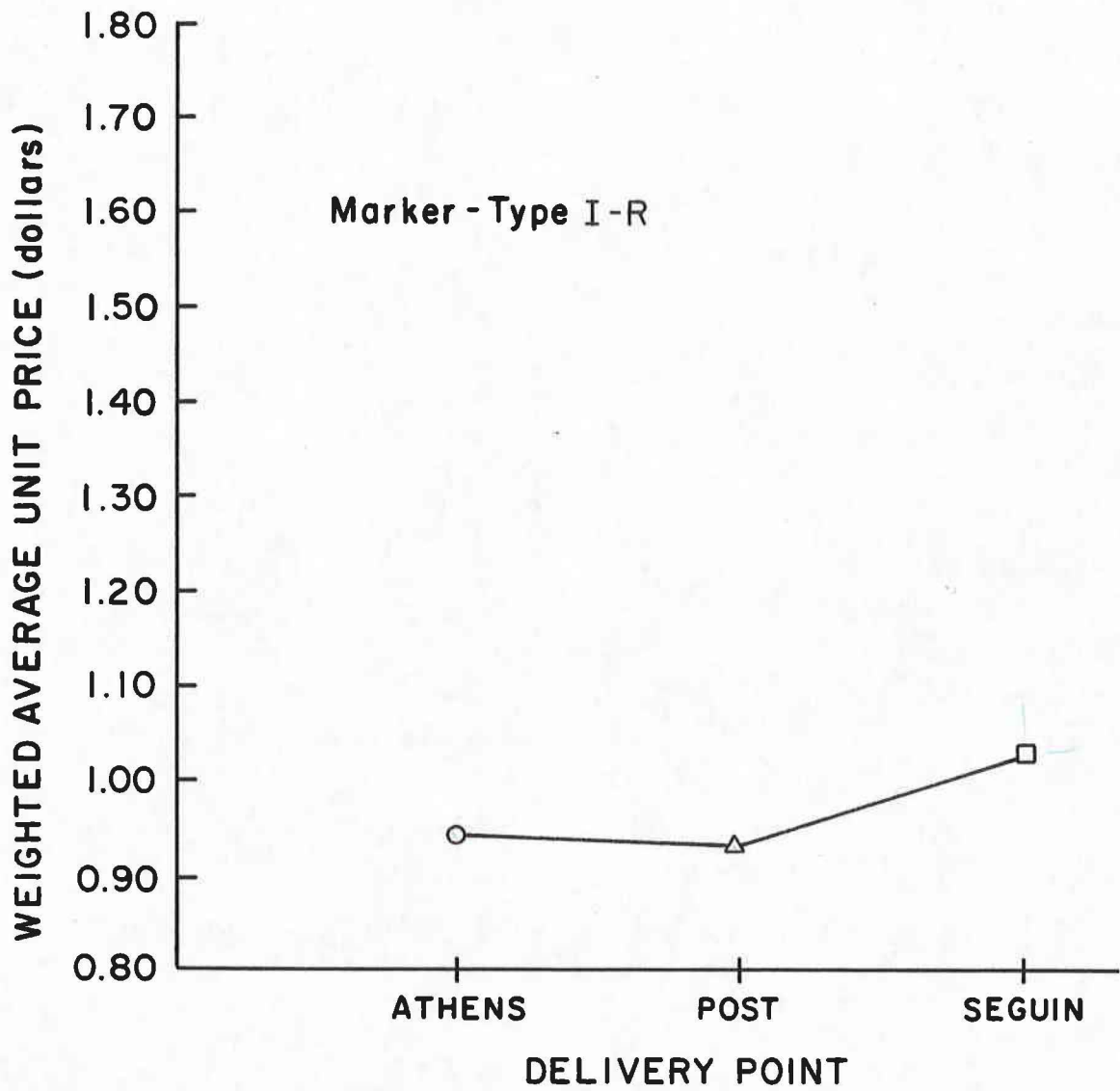
43

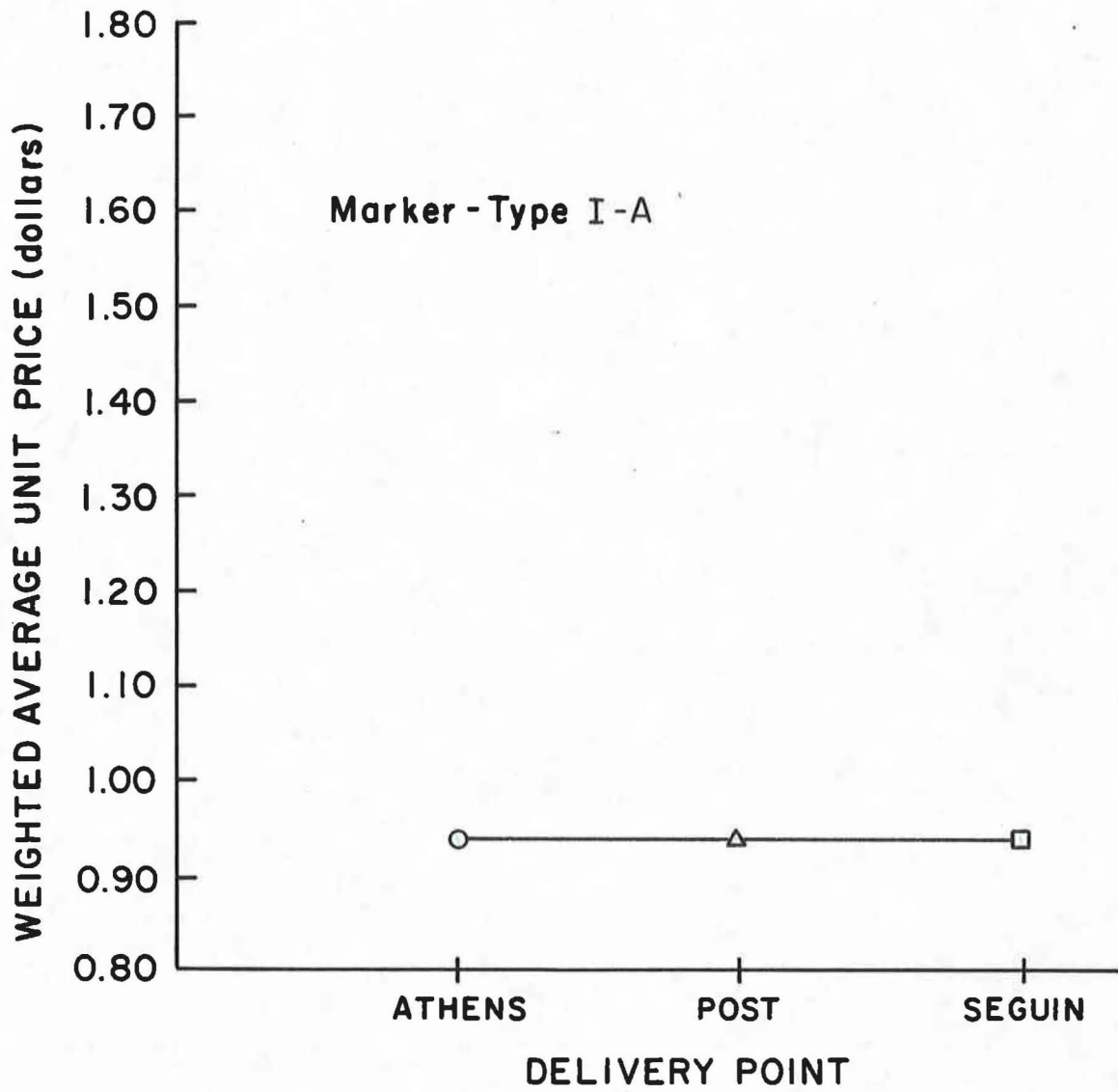


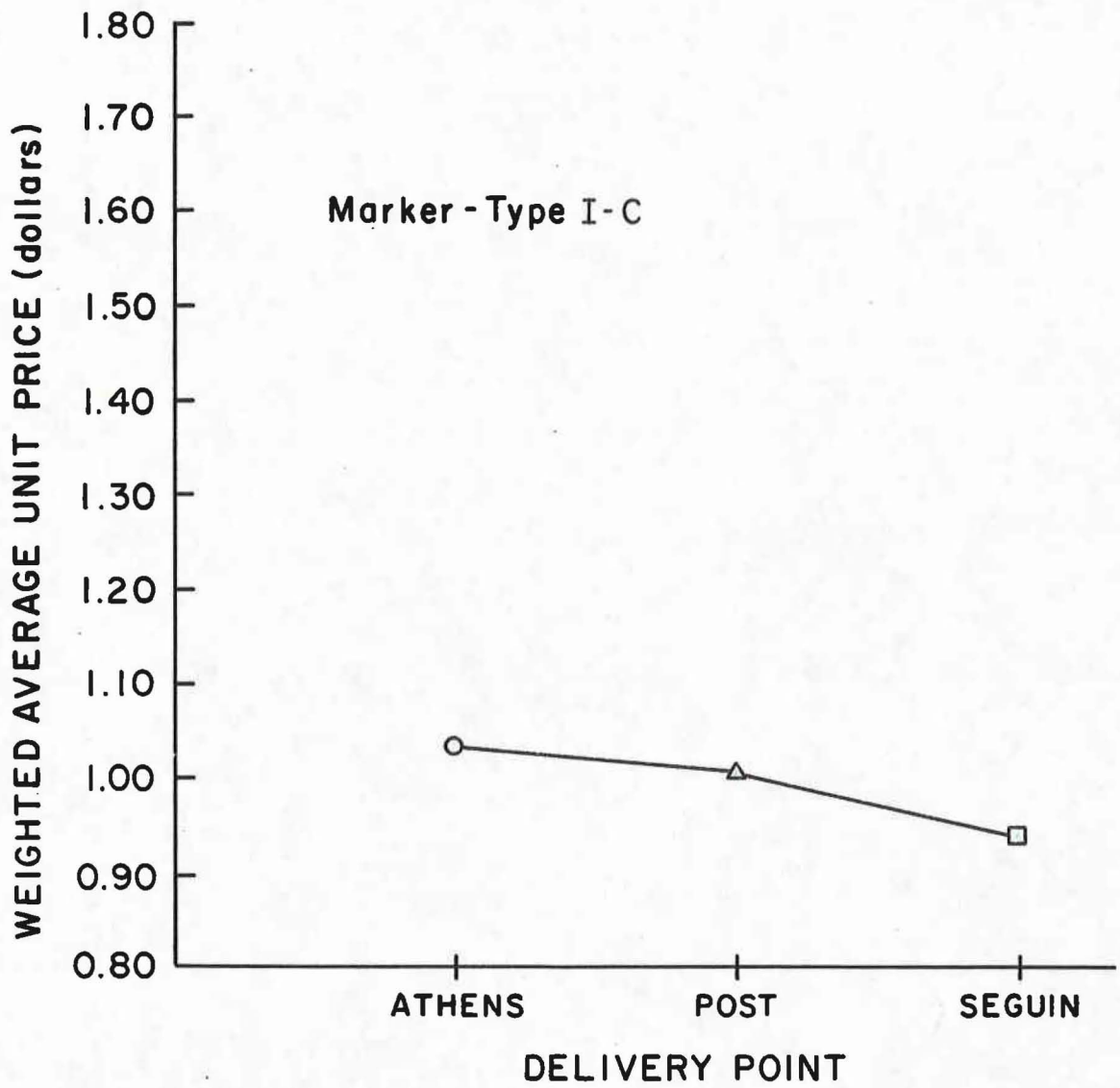


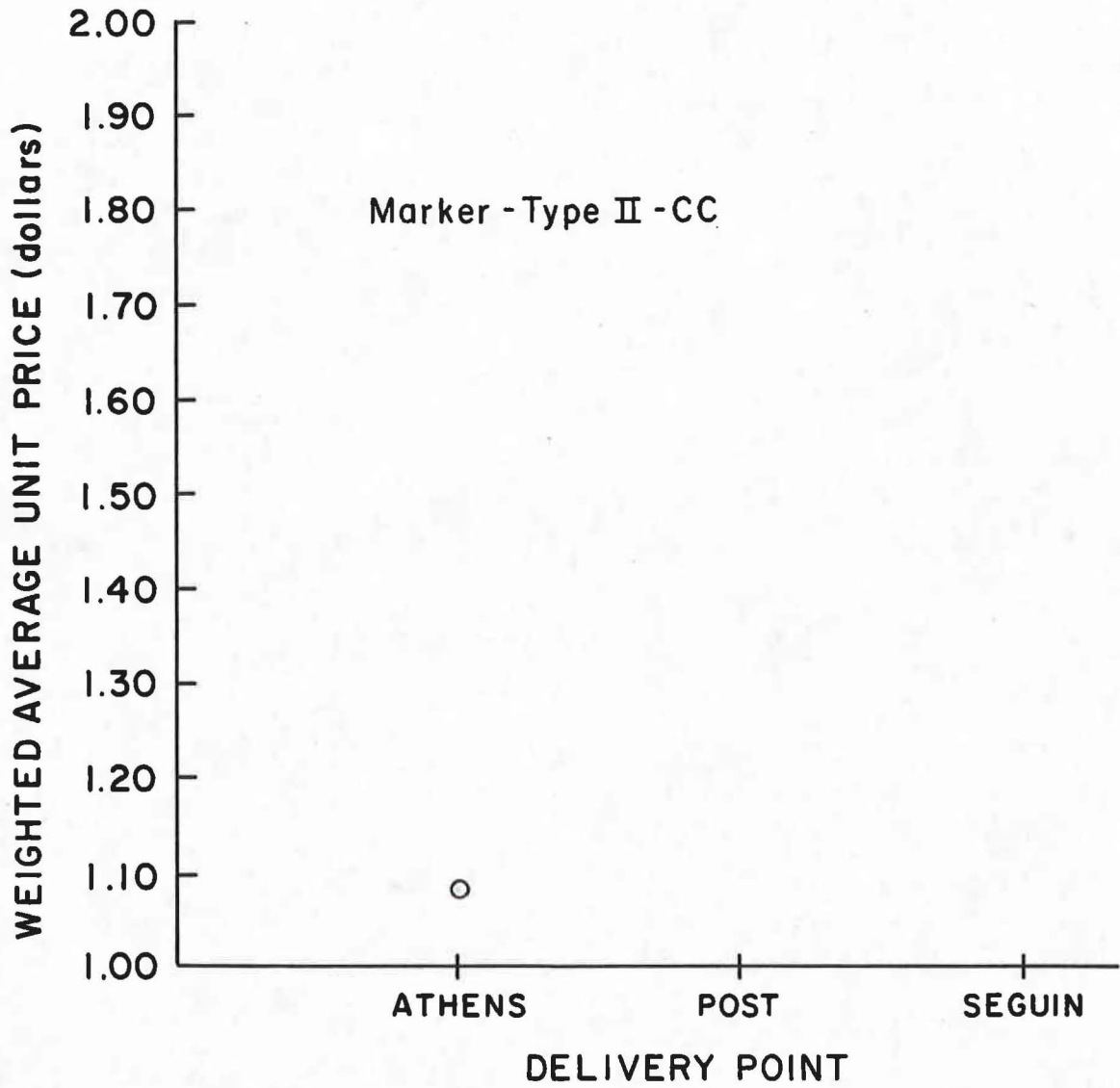


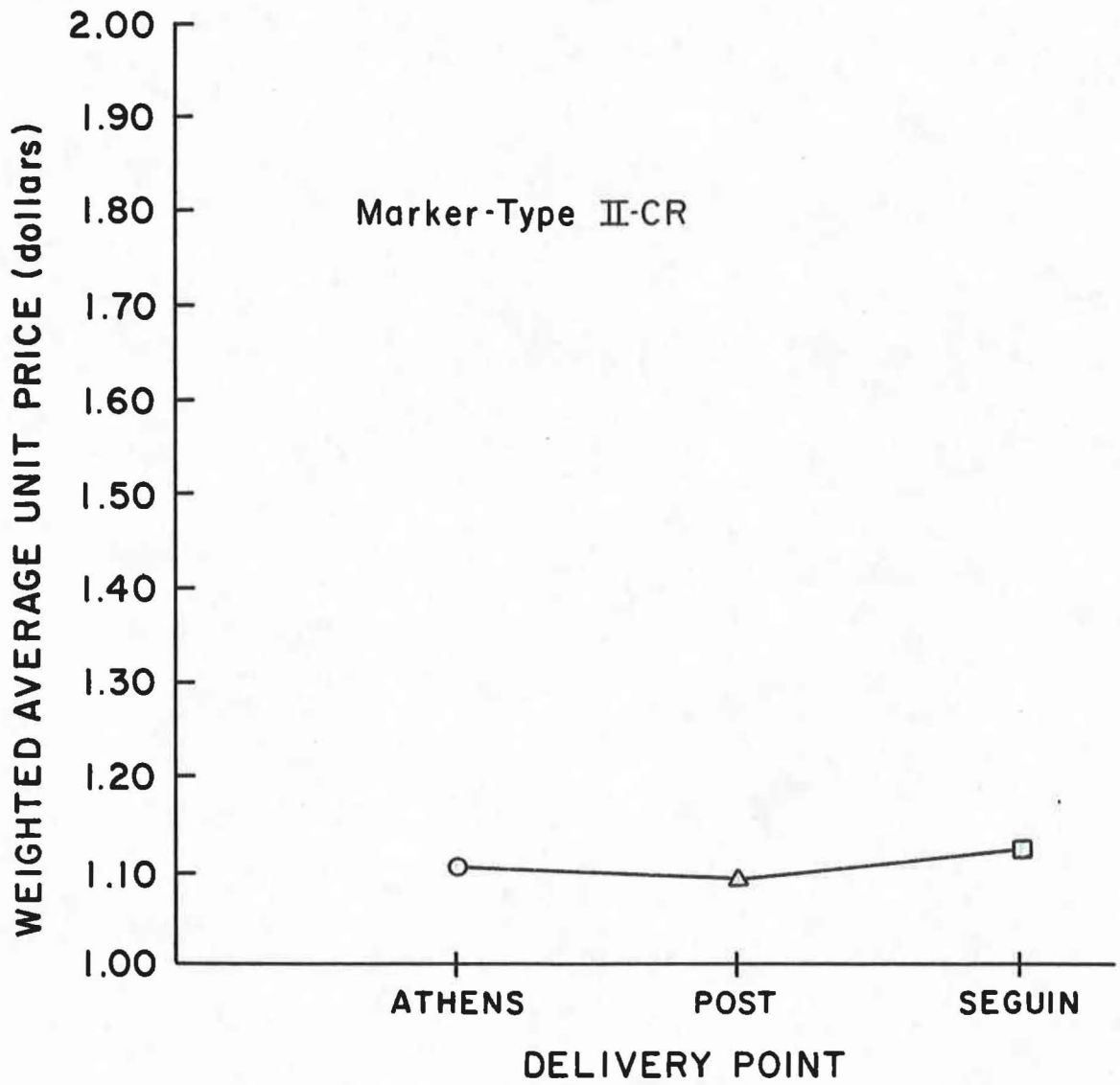


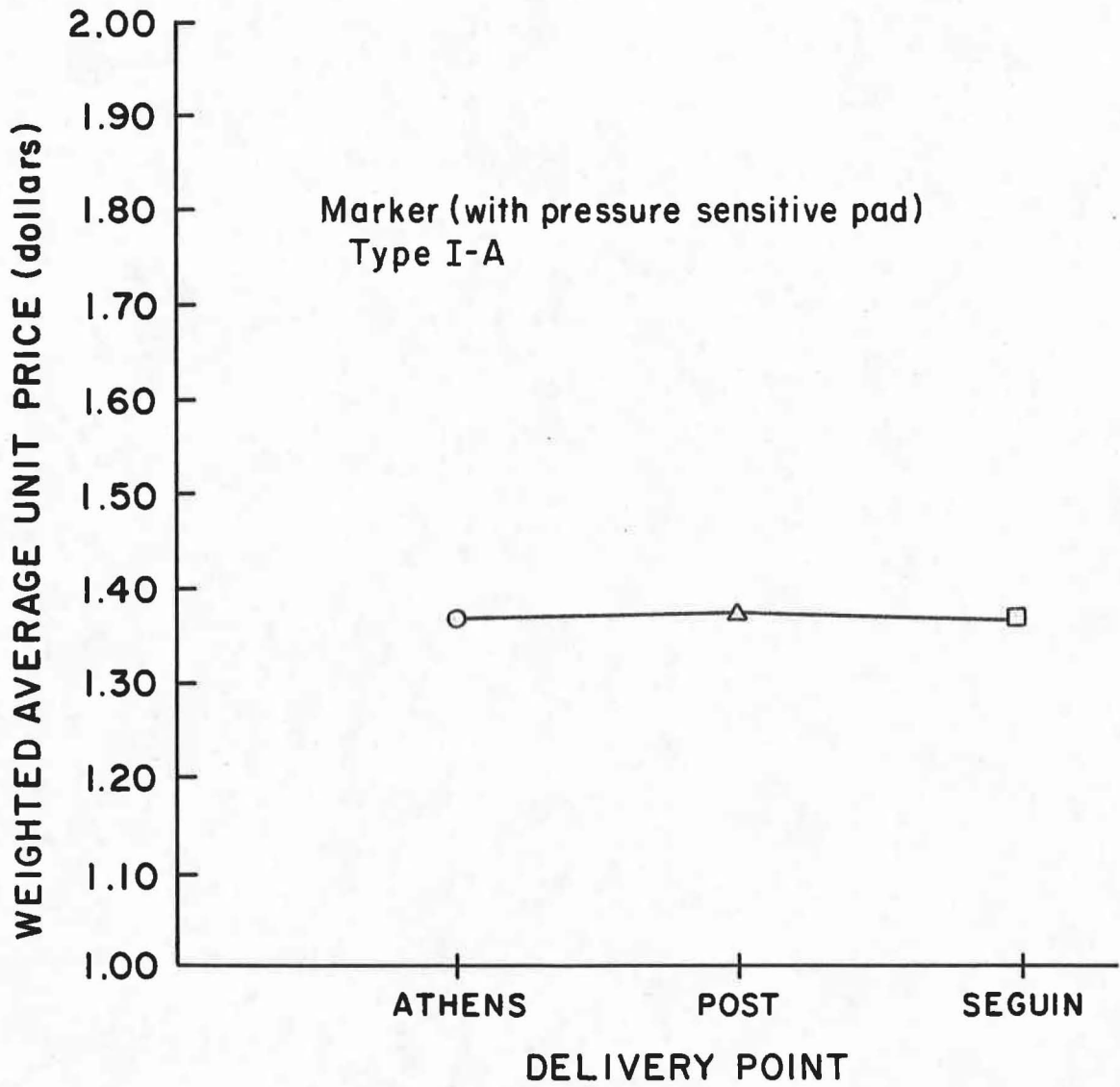


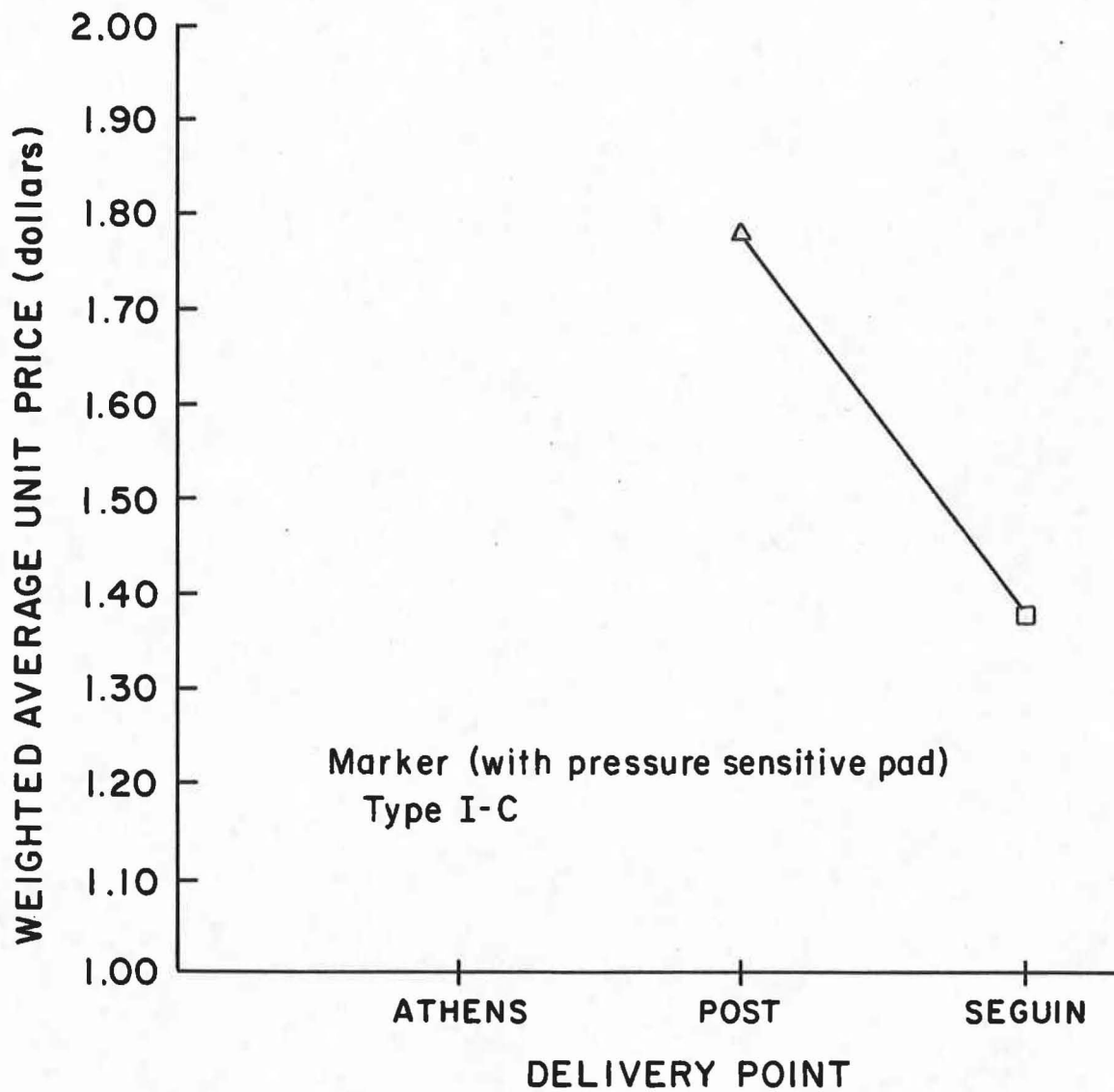


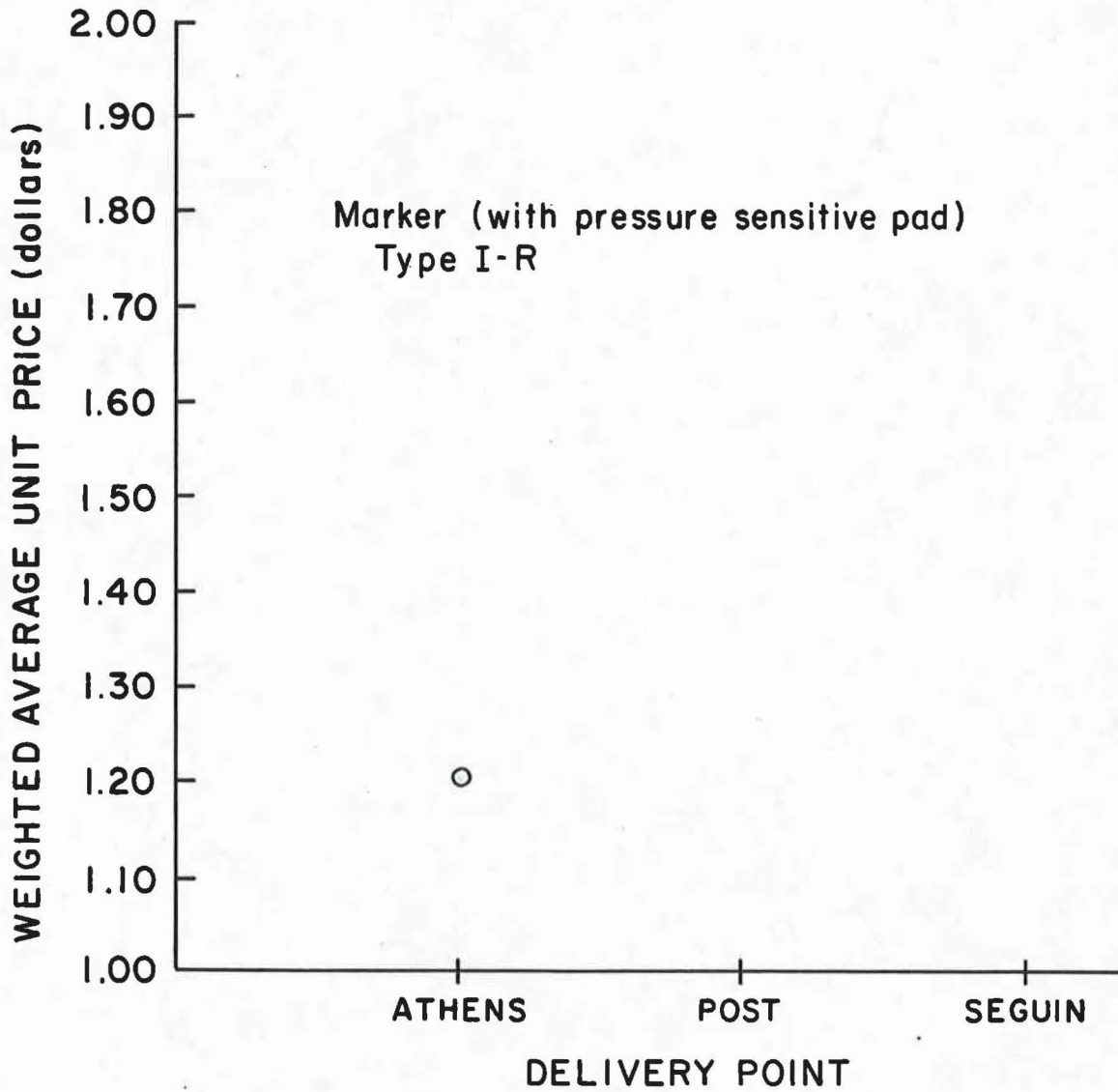


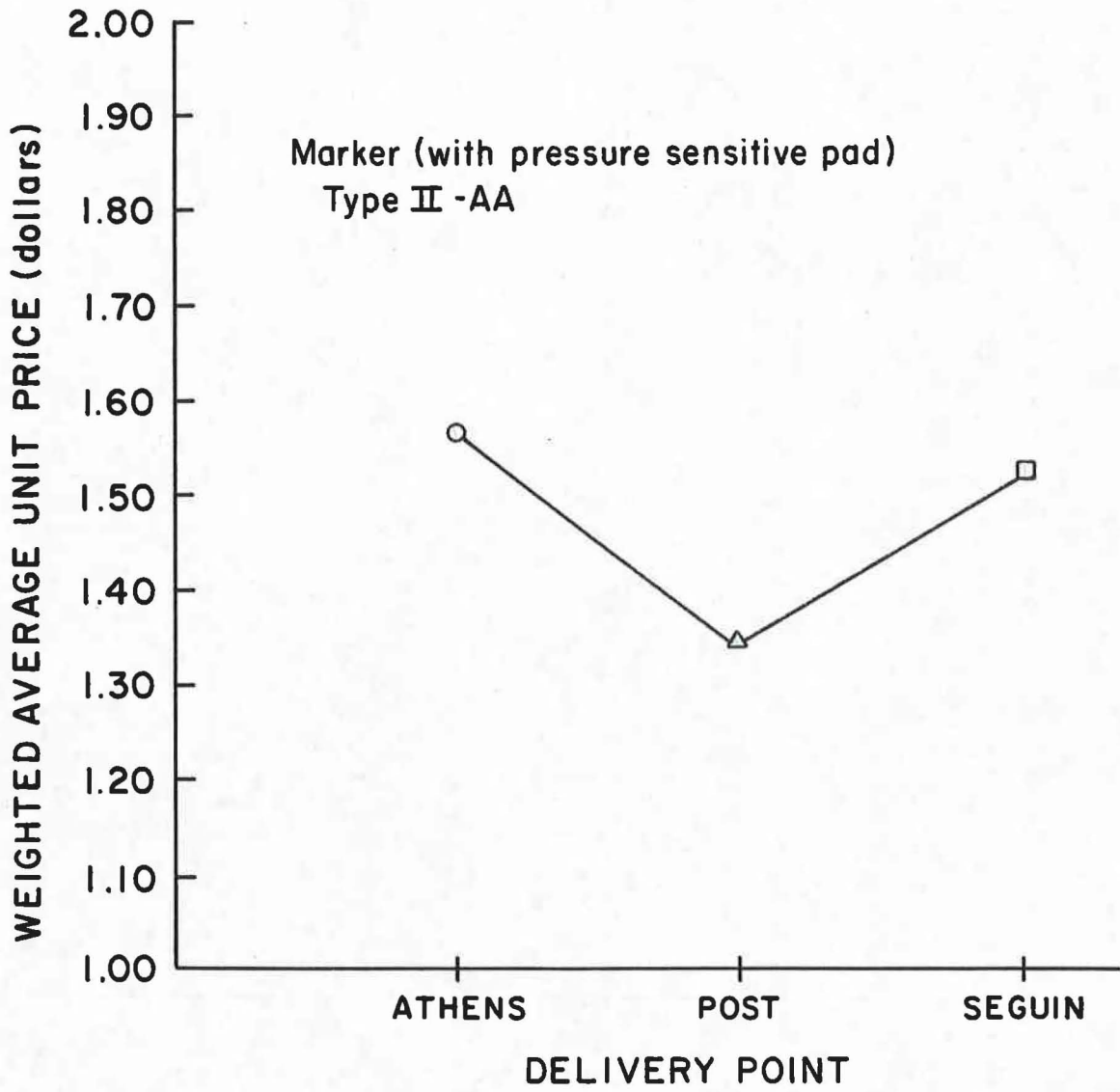


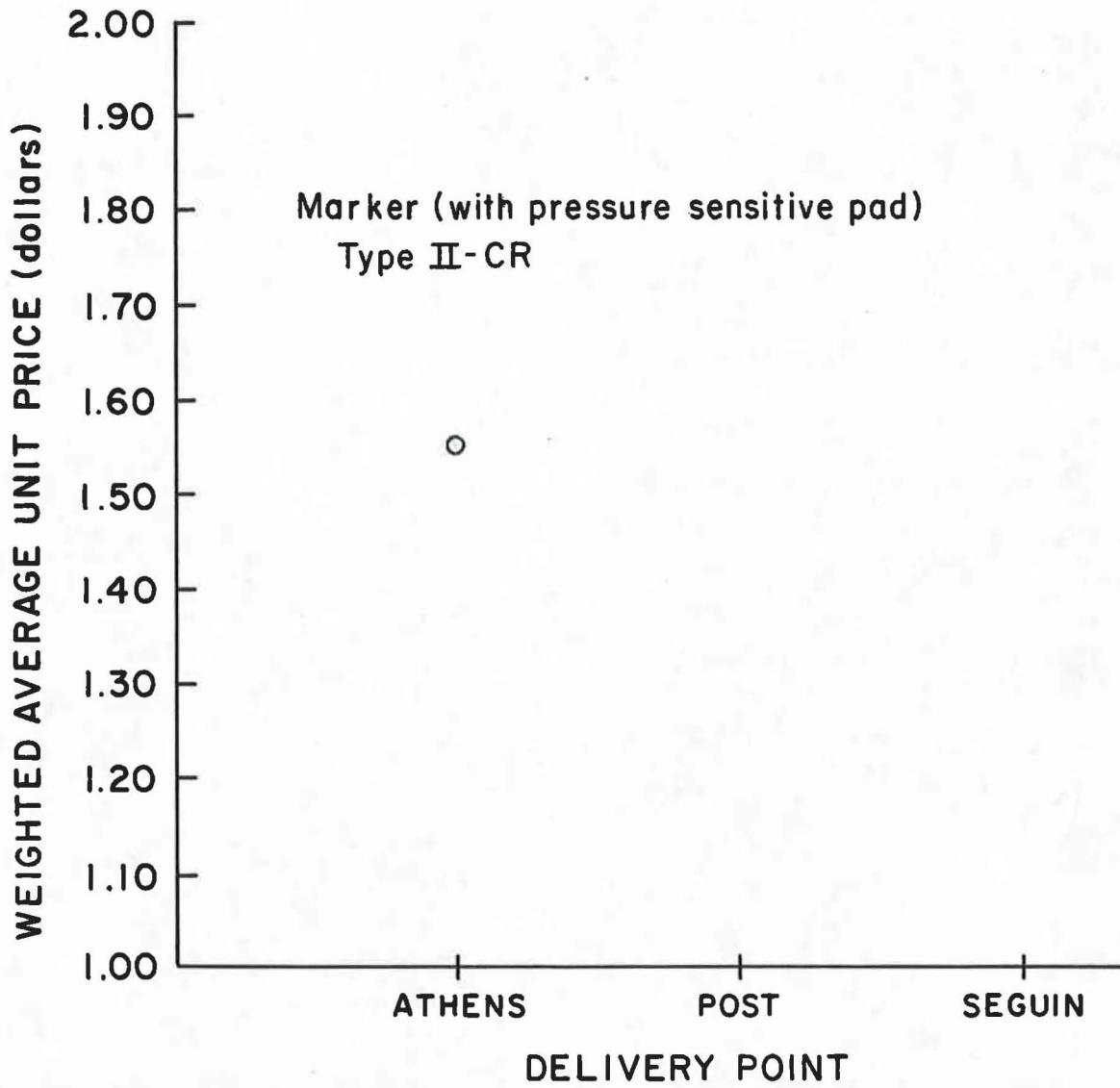












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APPENDIX C
Texas Specifications for Pavement Markers and Traffic Buttons

TEXAS SPECIFICATIONS FOR PAVEMENT MARKERS AND TRAFFIC BUTTONS

ITEM 674

PAVEMENT MARKERS (Reflectorized)

674.1. Description. This item shall govern for the furnishing and installing of reflectorized pavement markers at locations designated on the plans or as directed by the engineer.

674.2. Materials. Copies of Departmental Material Specifications are available from the State Department of Highways and Public Transportation, Materials and Tests Division, 38th and Jackson Street, Austin, Texas, 78703.

The markers shall comply with the requirements of Departmental Specification D-9-4200, "Pavement Markers (Reflectorized)", and the adhesion requirements of Test Method Tex-611-J. Adhesive shall conform to the Item "Epoxy". Markers supplied for any single project shall be of the same manufacture.

674.3. Marker Types. Pavement markers shall be of the following types:

Type I-A shall contain one face that reflects amber light and the body other than the reflective face shall be yellow.

Type I-C shall one face that reflects amber light and the body other than the reflective face shall be white, silver white or light gray.

Type I-R shall contain one face that reflects red light and the body other than the reflective face shall be white, silver white or light gray. The body may be one-half red on the side which reflects red light.

Type II-A-A shall contain two reflective faces each of which shall reflect amber light and the body other than the reflective faces shall be yellow.

Type II-C-R shall contain two reflective faces, one of which reflects white light and one of which reflects red light; the body other than the reflective faces shall be white, silver white or light gray or may be one-half red on the side that reflects red light.

The reflective faces of the Type II markers shall be located so that the direction of reflection from one face shall be directly opposite to the direction of reflection of the other face.

674.4. Construction Methods. The pavement markers shall be placed at locations in such a way that the color of the reflected light is in accordance with the plans or as directed by the Engineer.

The portion of the highway surface to which the marker is attached by the adhesive shall be prepared by any method approved by the engineer in order to be free of dirt, curing compound, grease, oil, moisture, loose or unsound

pavement and any other material which would adversely affect the bond of the adhesive.

The wet epoxy shall be applied in sufficient quantity so as to insure the following:

1. 100% of the bonding area of the marker shall be in contact with epoxy.
2. The marker itself shall not contact the pavement surface but shall sit on an epoxy "cushion".
3. When the marker is pressed onto the pavement, adhesive shall be forced out around its entire perimeter.

Any excess adhesive or other foreign material on or in front of the reflective face(s) of the marker shall be removed so that reflectivity will not be impaired.

When the project is complete, the markers shall be firmly bonded to the pavement, lines formed by the markers shall be true and the entire installation shall present a neat appearance.

674.5. Sampling and Testing. Sampling and testing will be in accordance with the Department's MANUAL OF TESTING PROCEDURES.

674.6. Measurement. Pavement markers will be measured as each pavement marker complete in place.

674.7. Payment. The work performed and material furnished as prescribed by this item, measured as provided under "Measurement", shall be paid for the unit price bid for "Pavement Markers (Reflectorized)", of the type specified, which price shall be full compensation for furnishing all materials, all preparation and installation and for all labor, equipment, tools and incidentals necessary to complete the work.

ITEM 676

TRAFFIC BUTTON

676.1. Description. This item shall govern for the furnishing of traffic buttons complete in place in conformity with details shown in the plans and as described herein.

676.2. Material. Copies of Departmental Material Specifications are available from the State Department of Highways and Public Transportation, Materials and Tests Division, 38th and Jackson Street, Austin, Texas 78703.

Traffic Buttons shall be made from a ceramic material and shall be reflectorized or nonreflectorized. The size, color(s), and direction of reflectivity of the button shall be as specified in the plans. Traffic buttons furnished for any one project shall be of the same manufacturer and shall conform to Departmental Specification, D-9-4300, "Traffic Button".



The adhesive used to bond the buttons to the pavement shall be of the following types:

676.3. Types.

(1) **Reflectorized** traffic buttons shall be of the following types:

(a) **Type I-A** shall contain one face that reflects amber light and the body other than the reflective face shall be yellow.

(b) **Type I-C** shall contain one face that reflects white light and the body other than the reflective face shall be white.

(c) **Type I-R** shall contain one face that reflects red light and the body other than the reflective face shall be white.

(d) **Type II-A-A** shall contain two reflective faces oriented 180° to each other, each of which shall reflect amber light and the body other than the reflective faces shall be yellow.

(e) **Type II-C-R** shall contain two reflective faces oriented 180° to each other, one of which reflects white light and one of which reflects red light; the body of the button other than the reflective faces shall be white.

(2) **Nonreflectorized** traffic buttons shall be of the following types:

(a) **Type W** shall have a white body.

(b) **Type Y** shall have a yellow body.

676.4. Construction Methods. The traffic buttons shall be placed in accordance with the plans or as directed by the engineer. The portion of the highway surface to which the button is attached by the the adhesive shall be prepared by any method approved by the Engineer in order to be free of dirt, curing compound, grease, oil, moisture, loose or unsound pavement and any other material which would adversely affect the bond of the adhesive. The wet epoxy shall be applied in sufficient quantity so as to insure the following:

1. 100% of the bonding area of the button shall be in contact with epoxy.

2. The button itself shall not contact the pavement surface but shall sit on an epoxy "cushion".

3. When the button is pressed onto the pavement, adhesive shall be forced out around its entire perimeter.

Any excess adhesive or other foreign material on or in front of the reflective face(s) of the button shall be removed so that reflectivity will not be impaired.



When the project is complete, the buttons shall be firmly bonded to the pavement, lines formed by the markers shall be true and the entire installation shall present a neat appearance.

674.5. Sampling and Testing. Sampling and testing will be in accordance with the Department's MANUAL OF TESTING PROCEDURES.

674.6. Measurement. Traffic buttons will be measured as each traffic button complete in place.

674.7. Payment. The work performed and material furnished as prescribed by this item, measured as provided under "Measurement", shall be paid for the unit price bid for "Traffic Buttons (Reflectorized)", of the type specified, which price shall be full compensation for furnishing all materials, all preparation and installation and for all labor, equipment, tools and incidentals necessary to complete the work.

APPENDIX D
Texas Specifications for Epoxies

TEXAS SPECIFICATIONS FOR EPOXIES

570.5. Payment. Work performed and materials furnished as prescribed by this item, measured, as prescribed under "Measurement" will be paid for at the unit price bid for "Metal Series Railroad Crossing Signs" which price shall be full compensation for furnishing all materials, equipment, labor, tools, transportation and incidentals necessary to complete the work.

ITEM 575

EPOXY ADHESIVE

575.1. General. This item consists of furnishing and applying for basic types of epoxy designed to bond ceramic, glass or plastic traffic markers of roadway and bridge surfaces. Those adhesives designated as Type I through IV are intended for hand mixing and application. On projects where the adhesive is to be handled by automatic metering, mixing and application equipment, Types I-M through IV-M, which are designed specifically for machine application, shall be used. Each adhesive shall be furnished in two components, herein referred to as the epoxy-resin component and the hardener component, the two components to be mixed immediately prior to use.

The type of adhesive to be used on a specific project shall be designated by the Engineer based upon the setting time required under the prevailing weather and traffic conditions. The various types of adhesives are as follows:

Type I and I-M Rapid Setting Marker Adhesive (For use when a very fast set is required or if markers must be placed when pavement temperature is below 60°F. Type I is not recommended for general use as it is more toxic and currently more expensive than the other types.

Type II and II-M Medium Setting Marker Adhesive

Type III and III-M Standard Setting Marker Adhesive

Type IV and IV-M Slow Setting Marker Adhesive (For use where rapid setting is not a consideration)

Approximate set times at different temperature for adhesive meeting the maximum set time allowed for each type are shown below.

Approximate Set Time, Hours

Pavement Temp., °F	Type I & I-M	Type II & II-M	Type III III-M	Type IV & IV-M
115	0.4	0.5	1	3
95	0.5	1	2	6
77	0.5	2	4	12
60	0.9	4	8	24
50	1.5	--	--	--

575.2. Materials. (1) Component Properties. For Type I through IV, the ratio of the resin and hardener components to be mixed together to form the finished adhesive shall be specified by the manufacturer and the components packaged in the proper proportions.

For Type I-M through IV-M, the ratio of the epoxy-resin and hardener components to be mixed together to form the finished adhesive shall be 1 to 1 by volume.

Packaging of the two components shall be specified for the individual job or requisition.

The resin component shall be pigmented white and the hardener component black.

All pigments, fillers and/or thixotropic agents in either the epoxy-resin or hardener component must be sufficiently fine particle size and dispersed so that no appreciable separation or settling will occur during storage.

The fillers present in the "M" adhesives must be of such a nature that they will not abrade or damage the application equipment. No alumina, silica flour or other hard abrasive materials shall be used.

Each component of the "M" adhesives shall be 100-percent solids. Adhesives for machine use shall contain no solvents.

(2) Adhesive Properties. The adhesive mixture must be of such a consistency that it can be applied to the surfaces which are to be bonded without difficulty. The adhesive must be capable of wetting the surfaces to be bonded so that good adhesion will be obtained. Type "M" adhesives must comply with the following specific consistency requirements.

	Minimum	Maximum
Viscosity of the individual components at 77°F ±, Poise	100	1500
Average viscosity of the resin and hardener components, Posies	500	1500
Average Viscosity =		
<u>(Viscosity of epoxy-resin comp. + Viscosity of hardener comp.)</u>		
2		
Ratio of viscosity of most viscous component to the viscosity of other component		7
Pot Life at 77°F		

The minimum pot life at 77°F for the various adhesives is shown below:

Type I, II, and III	10 minutes
Type IV	30 minutes
Types I-M, II-M, and III-M	7 minutes
Type IV-M	20 minutes

Set Time.

Set requirements for these adhesives are shown below:

	<u>Type I & I-M</u>	<u>Type II & II-M</u>	<u>Type III & III-M</u>	<u>Type IV & IV-M</u>
Set Time at 77°F, Maximum	40 min.	2 hr.	4 hr.	12 hr.
Set Time at 40°F, Maximum	3 hr.	--	--	--

(3) Physical Properties. The mixed marker adhesive shall comply with the following physical requirements.

<u>Property</u>	<u>Requirements</u>
Thixotropy (Avg. Thickness of cured material remaining on test panel, mils.) (Minimum)	80
Adhesive Shear Strength, psi, Minimum	1800
Cleavage Strength, psi, Minimum	800
Water Gain, percent by wt., Maximum	0.4
Impact Strength at 70-80°F Ft-Lbs., Minimum	6-1/2
Wet Strength, psi, minimum	300

575.3. Test Methods. The procedures to be followed in determining the various properties called for in this specification are given below.

(1) Consistency. This determination shall be made with a Brookfield Synchro-Lectric Viscometer of suitable range. The samples shall be placed in a container of such size that at least one inch of clearance is provided between the bottom and sides of the spindle and the container when the spindle is immersed to the proper depth in the liquid. The temperature of the samples for all viscosity determinations shall be 77°F ±1.

When making a viscosity determination, the proper spindle shall be attached to the lower end of the motor shaft. With disc type spindle, first immerse the spindle in the liquid at an angle to eliminate air bubbles, then screw it onto the shaft. Adjust the height to bring the liquid level to the indentation in the spindle. Level the instrument, set the speed control at 20 rpm and start the motor. Allow the spindle to rotate for approximately two minutes before taking a reading. The scale reading obtained shall be

converted to viscosity in poises by multiplying by the factor supplied by Brookfield for the combination of spindle and speed used.

The spindle used shall be either a No. 5, 6 or 7 as required to result in a scale reading between 20 and 80.

(2) Set Time at 77°F. The ambient temperature and the initial temperature of the materials used in this test shall be 77°F.

Mortar briquettes shall be prepared according to ASTM C 190-63 (Tensile Strength of Hydraulic Cement and Mortars) using Type III cement and sand meeting the requirements for No. 1 Fine Aggregate, of the Item, "Concrete for Structures".

The briquettes shall be cured for a minimum of seven days and then sawed at the centerline perpendicular to the long axis. A diamond tooth saw or other cutting tool capable of producing clean smooth faces on the briquette halves shall be used. The halves shall be mixed with metal spatula in a 6-ounce ointment can for three minutes. The cut faces of the briquettes shall then be coated with the adhesive and put together with light pressure. The excess adhesive shall be removed from the edges of the bonded area and the briquettes allowed to remain undisturbed until time for testing. No more than 10 minutes shall elapse during preparation of the specimens. A minimum of three briquettes shall be prepared. The amount of time allowed to elapse between initiations of mixing and testing shall be as follows:

Type I & I-M	40 minutes
Type II & II-M	2 hours
Type III & III-M	4 hours
Type IV & IV-M	12 hours

The briquettes shall be subjected to tensile loading with the Richle briquette tester and the load at failure recorded.

Requirements. The briquettes shall evidence an average strength of 180 psi minimum. If any of the briquettes tested fail in the mortar at strengths below 180 psi, an additional set of specimens shall be prepared and tested.

(3) Set Time at 40°F. The initial temperature of the adhesive components and the ambient temperature shall be 77°F + for this test. A total of 100 grams of the adhesive shall be weighed into a 6-ounce metal ointment can, the time recorded and the two components mixed for three minutes with a metal spatula. The sides and bottom of the can should be scraped periodically during the mixing. For Type I, I-M, II, II-M, III and III-M adhesives, the following procedure shall then be followed.

The can shall be set on a wooden block and probed every minute with a glass stirring rod, starting five minutes from the initiation of mixing.

For every Type IV and IV-M, the can shall be set on a wooden block and probed every two minutes with a glass stirring rod, starting 16 minutes from

the initiation of mixing.

(5) Thixotropy. The initial temperature of the adhesive and the materials used in this test shall be $120^{\circ}\text{F} \pm 3$.

The two components of the epoxy adhesive shall be stirred together for the least one, but not more than two minutes and then applied to a smooth clean steel plate to form a panel of epoxy material 2 inches wide, 4 inches in length and 0.10 inch (100 mils) in thickness. A removable form of the proper dimensions may be used in placing the epoxy on the steel plate. The epoxy maybe poured into the form and the excess struck off level with the adhesive, the steel panel shall be placed in a forced draft oven maintained at a temperature of $120^{\circ}\text{F} \pm 3$. The 4-inch dimension of the epoxy panel shall be perpendicular to the horizontal. Not more than 4 minutes shall elapse between the initiations of the mixing and the placing of the panel in the vertical position. After the adhesive has hardened, the average thickness of material remaining within the original 2x4-inch area of the panel shall be determined.

(6) *Adhesive Shear Strength. The procedure used shall be as outlined in ASTM D 1002-64 (Strength Properties of Adhesives in Shear by Tension Loading--Metal to Metal). Steel specimens shall be used. The surfaces of the test specimens used in the adhesive shear strength test shall be prepared by blasting to white metal. The blasted surfaces shall be washed with methyl ethyl ketone and allowed to dry before applying the adhesive. The test specimens shall have a prepared surface of equivalent "anchor pattern" to that which would be obtained by abrasive blasting the surfaces to be bonded with a gun pressure of 50 to 75 psi using a 1/4-inch diameter nozzle and employing Garnet Blasting Abrasive "Gem Blast" 60 mesh (No. 45 to No. 74, U.S. Standard Screens), as marked by Clemtex, Inc., of P.O. Box 15214, Houston, Texas 77020.

(7) *Cleavage Strength. The procedure used shall be outlined in ASTM D 1062-51 (Cleavage Strength of Metal to Metal Adhesives). Steel specimens shall be used. Surface preparation shall be as outlined in Adhesive Shear Strength.

(8) *Water Gain (24 Hour Immersion at 23°C). The procedure used shall be as outlined in ASTM D 570-63 (Water Absorption of Plastics) with the indicated modifications

The given ASTM procedure shall be modified in that the specimens shall be prepared by casting disks of the epoxy adhesive 2 3/4-inches in diameter and approximately 3/8-inch thick. Prior to testing, the plane surfaces of the disks shall be ground or machined flat and parallel. The batching or grinding must be done in such a way as to not heat the disks above 120°F . The thickness of the disks after preparing the surfaces shall be 0.30 ± 0.02 inch.

(9) *Impact Strength at $70-80^{\circ}\text{F}$. For this test the specimens shall be prepared as outlined in Article 575.3, Subarticle (8), Water Gain. The finished specimens shall be placed on a concrete slab and a one pound steel ball dropped onto the center of the disks from an initial height of 5 feet. The height shall be increased by 1/2-foot for each successive drop until the specimen fails by cracking or shattering. The height of drop at which failure occurs shall be recorded as the impact strength in foot-pounds. A minimum of

three specimens shall be tested and the average reported to the nearest 1/2-foot pound.

(10) Wet Strength. A minimum of four specimens shall be prepared as outlined under Set Time at 77°F. The bonded briquettes shall be allowed to cure for one day at 70° to 80°F, followed by two days in an oven maintained at 120°F +3. The cured specimens shall be immersed in distilled water maintained at 100°F +3 for a total of seven days. The specimens shall then be removed from the bath, placed in water maintained at 73°F +3 for one hour, then subjected to tensile loading with the Richle briquette tester and the load at failure recorded. If any of the briquettes tested have failed in the mortar strengths below 300 psi., an additional set of specimens shall be prepared and tested.

575.4. Handling Instructions. Each component shall be clearly labeled concerning toxicity and handling precautions. The manufacturer shall furnish instructions regarding mixing of the adhesive. In the cases of Types I, II and III adhesives no more than one-quart of finished adhesive should be mixed in a given batch due to the short working life of these materials.

* These tests are to be performed on specimens that have been cured for seven days at 70-80°F.

575.5. Measurement and Payment. No direct measurement or payment will be made for the work to be done or for the materials to be furnished under this Item, but they shall be considered subsidiary to the particular items required by the plans and specification.

BITUMINOUS INSTALLATION ADHESIVE*

Specific Gravity	1.80
Weight Per Cubic Foot	50 kg
Softening Point	105°C <u>±</u> 5°C
Recommended Pouring Temperature	200 - 220°C (400 - 425°F)
Bitumen Content	25/30%
Filler Minimum 80% Passing 200 Mesh	70/75%
Packing	Silicone lined cardboard tubs with metal bottoms containing approximately 90 kg each.
Softening Point (R&B) of Asphaltic Concrete	80°C <u>±</u> 5°C
Penetration at 25°C	22°C <u>±</u> 5°C
Shelf Life	Unlimited

*Southwestern Materials
P.O. Box 991
Austin, Texas 78767

APPENDIX E
Annotated Bibliography

ANNOTATED BIBLIOGRAPHY

Australia Standards House Standards Association

Retroreflective Materials and Devices for Road Traffic Control Purposes.
Part 1. Retroreflective Materials
Sydney 2060, New South Wales, Australia, 1976.

This standard relates to materials and devices intended to provide the required night-time luminance of traffic signs and road delineators by retroreflective means, utilizing the headlight beam of the road vehicle in which the observer (driver) is traveling. It covers only material for use on roadside devices displaying a vertical or near-vertical surface to drivers, and excludes reflectorization of devices, such as pavement markings and raised reflective pavement markers, which are intended to be traversed by vehicle wheels. Chromaticity coordinates and photometric performance are specified for a range of colors designated by the Australian Committee on Road Devices (ACORD) and included in AS 1743. Also specified are the physical properties and durability of the material. Tests to check compliance within specified limits are described.

Beaton, J.L., Rooney, H.A.

Raised Reflective Markers for Highway Lane Lines
Highway Research Record, No. 105, Highway Research Board, 1966, pp. 1-7.

California uses a broken 9 foot painted/15 foot unpainted stripe to delineate traffic lines. The painted portion is beaded for night visibility. During periods of inclement weather at night water tends to accumulate on the pavement to a depth sufficient to cover and obscure the beaded painted centerline traffic stripe. In order to select a marker which is visible in both clear and rainy weather day and night, California has recently used a partially beaded marker. Experimental installation of a raised marker that is wedge shaped and reflective as the reflex reflectors used on guide posts were studied. The following facts concerning the suitability of white plastic markers under various conditions were determined (1) the fully reflectorized markers (beaded) are ineffective for daylight delineation in clear and rainy weather, particularly on portland cement concrete, (2) the fully beaded button marker is more effective in rainy weather at night than the wedge marker, (3) on asphaltic concrete pavements, the wedge marker is more durable than the button type, (4) the glass beads used in the reflective button variety (1.90 minimum) and (5) under overhead lighting or in the daytime the non-beaded markers are more effective than the beaded type in both clear and rainy weather.

Beede, B.K., Shelley, T.L.

Development and Evaluation of Traffic Markers, 1971-1974
California Department of Transportation, Sacramento, CA
December 1975, Final Report, 33 pp.
Report No. CADOTT65152-3-75-20; PB-254696/AS

Evaluation and development of traffic delineators by the State of California is a continuing project. Six reflective and three combination reflective and nonreflective pavement markers were evaluated and are described in this report. None of the new raised reflective pavement markers submitted to the Laboratory for testing and evaluation have shown better performance than the current State adopted ceramic and retroreflective cube corner markers. One combination day/night ceramic marker which was tested is being recommended as an alternative to the presently specified system in median areas or on low volume roads.

Blaauw, G. J., Padmos, P.

Nighttime Visibility of Various Types of Road Markings; A Study on Durability, Including Conditions of Rain, Fog and Dew
Society of Automotive Engineers, 1982, 9 p.

Nighttime visibility distance of various retroreflective stripes and raised pavement markers were determined on a dry and wet pavement and in the absence of public lighting. In addition, optical characteristics were measured in relation to the time lapse after application, in order to assess the effects of dirt and wear. Results were described in terms of coefficients of retroreflection, which were also used to predict visibility distances under other conditions than measure. Prepared for SAE Meeting 22-26, February 1982.

Cahoon, Roger

Use of a Rumble Stripe to Reduce Maintenance and Increase Driving Safety
Highway Research Board Special Report n107 pp. 89-98
Monograph HS-011 167

Heavy traffic volume shortens the life of painted pavement markings, sometimes wearing them off within 30 days. A great deal of research has been done to produce better paint and reflective bead products. Different methods of marking pavement have also been investigated, the method best known being the raised traffic markers. California has used these for years and found them to have much better visibility and longer life than painted stripes, as well as producing a noise that warns a driver that he is moving outside his traffic lane. The main trouble with raised traffic markers is that snowplows cut them off. For two years the Utah Department of Highways has been researching the possibility of recessing a design or texture to produce the same advantages as raised markers. Grooved painted stripes are recommended for areas where snow removal is necessary.

Calhoun, J.D.

Raised Reflective Lane Markers for Urban Roadways
Louisiana Department of Highways
104 pp; November 1970

Four representative brands of raised reflective roadway markers were evaluated for one year. Reflectivity of the markers from illumination of automobile headlamps was measured periodically using a Luckiesh Taylor brightness meter. The reflectivity of all brands dropped immediately to a mean of about 50% of the new reflectivity, then varied above and below this value depending on weather and fouling. The loss of markers from the roadway was evaluated. The epoxy adhesives were satisfactory for plastic markers, all losses were due to failure of the asphalt roadbed under the markers. Failure of the plastic markers was negligible. The ceramic markers was negligible. The ceramic markers suffered drastic loss of the reflective elements.

Calhoun, J.D.

Raised Reflective Lane Markers for Urban Roadways
Louisiana Department of Transportation

Four representative brands of raised reflective roadway markers were evaluated for one year. Reflectivity of the markers from illumination of automobile headlamps was measured periodically using a Luckiesh Taylor brightness meter. The reflectivity of all brands dropped immediately to a mean of 50% of the new reflectivity, then varied above and below this value depending on weather and fouling. The loss of markers from the roadway were evaluated. The epoxy adhesives were satisfactory for plastic markers, all losses were due to failure of the epoxy to marker surface. The use of rubber pad adhesive was a failure under the conditions of this test. Failure of the plastic markers was negligible. The ceramic markers suffered drastic loss of the reflective elementsion

Chatto, D.R.,; Shelley, T.L.

Formation and Evaluation of New Adhesives for Highway Use
California State Department of Transportation
Report No. TL-635150

New epoxy systems have been developed and older epoxy specifications revised to meet today's changing technology have been implemented with new and updated state specifications. The subjects covered include Structural Adhesive Development related to Rapid Set Epoxy Mortar; Loop Detector Sealants; and Urethane Adhesives; Formula Component Replacements such as asbestos and Butyl Glycidyl Ether; Consistency of Physical Properties; Pavement Marker Adhesive Development; Accelerated Epoxy Aging Tests; and Commercially Available Adhesives.

Chatto, D.R.; Shelley, T.L.; Spellman, D.L.

Development of a Rapid Set Epoxy Adhesive for California Highway Markers
California Division of Highways

The development of a prototype rapid set epoxy adhesive to bond raised pavement markers to portland cement concrete and asphaltic concrete in California freeways and secondary roads were first reported in June 1969 as State Specification 68-F-44. Since then, four formula revisions have been made to improve adhesion and application characteristics. The current specification, designated as State Specification 721-80-42, has been in use since 1972.

Clary, A.G.

The Role of Equipment in Maintenance Operations
Highway Research News, Highway Research Board, 1969, No. 35, pp. 44-58

Maintenance research and maintenance equipment research conducted in Kansas, California, North Carolina, Missouri are described and discussed. Moving needs, costs and practices are reviewed. Despite the high unit cost of guardrail mowing and other hand-type mowing operations, the bulk of the mowing dollar is spent on large-area mowing and the greatest potential for savings comes from studies of that operation. Time studies have shown that mower production rates are affected by the amount of downtime, distance of travel to the job site, etc. Large units, such as tractors with 15-foot rotary mowers, should be used only on types of terrain where their inherent high capacity can be utilized. There is a study underway at the University of Illinois on radio-controlled mowers. The triumph Machinery Company has developed and is testing a much bigger model, similar in concept.

Developments in pavement striping equipment are discussed. Equipment and costs now represented only 10% to 25% of the striping costs in a well-conducted striping operation. Material costs now represent the major component of striping costs. Raised reflective markers and glass beads are discussed in relation to their dislodgement by carbon steel-tipped snowplow blades. One possible approach to this problem is to use rubber snowplow blades that would flex as they pass over the markers. Paint striping equipment research in Florida has enabled traffic strips to be placed that do not require any protection against tracking. The striping machine operates at the same over-the-road speed as conventional machines. An experimental striping unit developed in Texas places a small quantity of epoxy of the pavement and then drops 1/4 inch reflecting beads into the epoxy to produce a traffic marker. This machine and its successors appear to mechanize the placement of raised reflective buttons. Snow and ice control equipment are discussed. The most efficient means of snow removal is the displacement snowplow even though it does not provide the bare pavement now demanded by the traveling public. Pavement surface maintenance problems are discussed. Test equipment used by the highway departments such as the Minnesota roadmeter, the dynaflect, and the BPR roughmeter provide a means for predicting future pavement needs as well as providing a yard stick for comparing conditions across section lines. A preventive maintenance program can be developed that will properly reflect budget considerations, management decisions, and a fair apportionment of maintenance funds to the operation divisions. A litter-gathering machine used in Texas is described.

Clemens, G.G.; Reynolds, J.W.; McCormick, R.; Montador, A.J.; Hasija, V.

Concrete, Aggregates, Marking Materials, Corrosion, and Joint Seals
Transportation Research Board

Grand method of endpoint determination in chloride analysis by potentiometric titration; Comparison of performance of concrete bridge decks in British Columbia; Concrete-deck deterioration-concrete-filled steel grid bridge decks have the answer; Possible explanation of concrete pop-outs; Case histories of unsatisfactory and abnormal field performance of concrete during construction; Map cracking in limestone-sweetened concrete pavement promotes D-cracking; Resilient response of railway ballast; Snowplowable raised pavement markers in New Jersey (Abridgement); Test for the adhesion of thermoplastic highway-marking materials; Vehicle corrosion in perspective; Preformed elastometric joint sealers for bridges.

Dale, J.M.

Development of Formed-in-Place Wet Reflective Pavement Markers
Highway Research Board NCHRP Reports 1970, Rept. 85, 28 pp.

The results are presented of field testing of a low-cost pavement marker that is visible at night during rain and wet pavement conditions. This technique incorporates into one system the ability to be applied like paint and yet perform like raised, reflectorized markers. The system consists of formed-in-place markers approximately 4 inches in diameters by 0.25 inches in height which are applied by a self-propelled machine. The machine employs a circular wire brush to clean the pavement surface. Onto the cleaned surface, a pigmented and catalyzed epoxy resin is discharged as a viscous liquid to form the body of the marker. Nineteen 0.25-in-diameter coated glass beads are dropped into the epoxy and they submerge to just over their horizontal axes. Depending on the environmental conditions, the epoxy normally requires from 10 to 20 minutes to set or harden. The action of traffic over the markers removes the coating from the exposed portion of the glass beads. The coating on the embedded portion of the beads remains in place and serves to make the beads highly retroreflective and they remain so even during periods of precipitation. The new marker is not recommended on highways where snow removal is carried out using pressure-bearing steel snowplow blades. However, this damage can be controlled by the use of rubber-tipped snowplow blades or the use of shoes fitted to the blades to raise them above the pavement surface. Beads made from plastic may be a promising solution to this problem. Conclusion is made that the need for delineation during periods of inclement weather is so great, (and the cost of the developed markers is sufficiently low), that their use should be considered at all locations, event hose where steel snowplow blades are used.

Davis, T.D.

Construction-Zone Delineation (Abridgement)
Transportation Research Board, Washington, D.C.
NPR811; 81; pp. 15-19

A study conducted to find the need for improving delineation in construction zones with long-term closures or diversions is described. The need for improved delineation was established through two means: (a) a committee of traffic, construction, design, research, and specifications engineers and (b) positive guidance, a technique that develops improvements to the highway information system for the driver's viewpoint. Once the need was established, improved delineation concepts were developed and tested in actual construction zones and evaluated for effects on traffic performance and driver visibility. The experiments showed that (a) although 12.70 x 25.40-cm (5 x 10-in) yellow high-intensity reflectors were less expensive, more easily checked, and more reliable than steady-burn lights, reflectors did not change vehicle speed averages and variances or the proportions of vehicles using up to less space and could be seen over the tops of lead vehicles when compared with type 3 barricades, panels decreased lane encroachments and did not change vehicle mean speeds or variances; (c) raised pavement markers as a paint supplement reduced undersirable lane weaves and encroachments, day and night; (d) removable traffic tape was easy to install and easy to remove and caused no problems while in use; and (e) raised pavement markers as a paint replacement were easy to install and easy to remove, and they reduced lane weaves day and night and reduced nighttime lane encroachments.

Derby, J.

What's New in Traffic Research-Reflective Markers
California Department of Highways
1968 2p HS-002 268

Discusses use of raised pavement markers on freeways.

Doughty, J. Robert

Traffic Signs and Markings
Pennsylvania Department of Highways
HS-022 136, "Transportation and Traffic Engineer in 1976 Monograph g Handbook"
197 6 Ch 16 p7 HS-022 144

All traffic signs and markings in the U.S. should follow the accepted standards of the "Manual on Uniform Traffic Control Devices for Streets and Highways" (Uniform Manual). Each device should fulfill a need, command attention, convey a clear, simple meaning, command user respect, and give adequate time for response. Traffic signs may be functionally classed as regulatory, warning, or informational/guiding. Some signs convey messages for use at certain times of day or under certain traffic conditions. Standard shapes, colors, and sizes aid in providing attention value, legibility, and recognition. Letter sizes and spacing are designed for legibility at normal traffic speeds, aided by reflectorization and illumination. Sign location, type of mounting and supports are designed for ease of identification, reduced

glare, minimum maintenance and driver safety (breakaway construction). Warrants provide a guide to sound sign application and serve to prevent the overuse of regulatory signs. An improper installation, failure to replace or repair a damaged or missing control device, or failure to conform to Uniform Manual standards may lead to liability of a government agency or responsible official. Materials in general use for sheeting, fiberglass, and plastic. Paint, adhesive-coated plastic film, porcelain, reflective sheeting, or bead coatings with a binder are used for sign faces. Inventory and adequate maintenance are necessary. Traffic markers include all traffic lines (longitudinal and transverse), symbols, words, object markers, delineators, cones, or other devices. Special markings include lane reduction transitions, obstruction markings, reversible lane markings, two-way left turn lanes, and channelization. Traffic lanes may be painted or made of thermoplastic or prefabricated tape. Other types include raised markers, reflectorized powder, and glass beads. Barricades, traffic cones, barricade warning lights, rumble strips, and mileposts are also used to guide traffic.

Ellis, R.W., Bartholomew, J.

Raised Pavement Marker Stimsonite 99
U.S. Transportation Department
December 1969; pp. 12-18

Feasibility tests were conducted on the use of Stimsonite 99 raised pavement markers in areas where snow plowing is necessary on an installation located on the south Sacramento freeway, Route 99. Markers were installed in September under good weather conditions for good adhesive cure, and test performed in October. A front-mounted plow on a four-ton truck chassis made six passes at speeds up to 25-30 miles per hour on the installations with no appreciable damage. A motor grader weighing about 14 tons made a series of passes using high blade pressure and blade angle about 40 degrees. Markers between the wheel tracks failed within three more passes. Blade damage was excessive. A previous installation on I-080 near Kingvale during the winter that showed that normal snowplowing operations with a motor grader removed all markers with 24 hours. The Stimsonite 99 raised pavement marker will not withstand severe snowplowing operations of the kind performed in this test.

Ethington, G.C., Pigman, J.G., Agent, K.R.

Reflective Marker Paint Stripe Skipper
Kentucky Department of Transportation, Lexington, Kentucky
Rd-March 1981

The objectives of this study are to test and evaluate a device developed by the California Department of Transportation that reduces the incidence of painting over reflective raised markers for pavements. Two prototypes of the reflective markers paint stripe skipper were fabricated for additional field testing and evaluation elsewhere. The device consists of a photocell and digital counter mounted on the paint stripe. By detecting the reflective marker, the device turns the paint off 6 inches in front of the marker and turns it on 6 inches past the marker. The digital counter provides an inventory of the markers by counting those in place. Satisfactory test results were obtained and a brief report was provided to the FHWA in June 1980.



Feldhutter, R.

Glass Reflectors for Safer Roads at Nighttime
Swarvosli and Co., Wattens, Austria
Conference Paper; No Date; 16 pg

About one third of all road accidents and more than half of all fatal road accidents occur at night, largely because of limited visibility. Two remedies exist: to provide street lighting (which is limited to urban areas because of high cost) and to equip with retroreflective markers. There are two types of retroreflectors: corner cube reflector and Cat's Eyes. Both types have been used on guard posts and guardrails for many years. Their use on roads is a more recent development. Raised reflective pavement markers are superior to paint stripes because, unlike paint lines, they maintain their reflectivity even in rain. They exercise a warning effect on vehicle drivers as they are heard and felt when crossed. According to an OECD Report (Paris 1975) their application on a six-lane freeway in the United States reduced the total number of accidents by 20 percent and personal-injury accidents by 61 percent. Glass reflectors are superior to acrylic plastic reflectors which lose 80 percent of their reflectivity after a comparatively short period.

Forsberg, A.

Optical Guidance on Roads Illuminated by Vehicle Headlamps
National Swedish Road Administration, Stockholm, Sweden
Monograph: #VTI Report NR 152; 78; 66 p.

This is a state of the art report on optical guidance in darkness in roads without public lighting. The purpose of the work was to form a basis for further work in this field with a special interest in Swedish conditions. Firstly, the requirement for information for the road users is briefly discussed. Then the following subjects are dealt with: pavement, road markings, raised pavement markers and delineators with respect to technical design, practical use on the road, function and effects on traffic behavior. Finally, possible test methods for some of the measures described are discussed in general terms.

Freeman, K.D., Vincent, E.W.

Raised Reflective Pavement Markers: Installation, Performance and Specification
Australian Road Research Board Conference, Victoria, Australia
V9 N5; 79; pp 345-347

This paper was presented at Session 36 - Signing, Delineation and Guidance 1. Raised reflective pavement markers have become an accepted delineation device by most highway authorities in Australia. This paper describes experience to date in the selection, testing and organization and methods used to install and maintain large numbers of markers under traffic. The subsequent in-service performance of the markers is discussed and estimates are given of the life and long term costs of raised reflective pavement marker installations, together with an appraisal of the deficiencies of the original specification. A model specification for the supply of

markers is included.

Graf, C.R., Roberts, A.W.

Snowplowable Raised Reflective Pavement Markers at Hazardous Locations in New Jersey

New Jersey Department of Transportation, New Jersey

Report No. 80-011-4668, September 1979, 62 p.

Snowplowable raised reflective pavement markers were installed at three hazardous sites in New Jersey--a winding two lane rural road, a two lane downhill approach to a circle, and one direction of a three lane curve. The major evaluative findings after one year of use are that: (1) total accidents were an average of 29 per year before and 31 during the first year after installation, (2) after one year of use the markers could be seen as far as 1,400 feet from a car with low beams on a dark road, (3) during the first year up to 9.5 percent of reflectors needed to be replaced, but no castings were damaged, (4) the estimated installations costs at these sites varied from \$20 to \$26 per marker, and (6) the installation equipment design should be improved. Detailed methods and findings with comments can be found in the report.

Gurney, G.F., Gupta, P.K., Roth, W.G.

Evaluation of Raised Snowplowable Pavement Markers

New York State Department of Transportation, New York

Final Report #FHWA/NY/rr-80/84; Sept. 80; 51p

In October 1977, over 200 Stimsonite Model 96 raised pavement markers were installed in New York State--half in a moderate winter environment near Albany, and half in a severe winter environment near Syracuse. The markers did not survive one winter at Syracuse but were performing acceptably after two winters near Albany. Tungsten carbide plow blades and leading-edge nose-shoes continue to be the main factor contributing to marker damage. Casting failures can be expected after 125 passes with a tungsten-carbide plow blade traveling at 20 to 35 mph. Reflector life is naturally limited by casting durability, but can be further shortened by use of the nose-shoes. Reflector visibility on these unlighted tests areas was directly related to size of the reflective surface area. The corner-cube reflector used on the Model 96 can be expected to provide adequate visibility until it loses half of its original reflective surface area. Reflector replacement at this damage level should significantly increase visibility. However, a site can be most efficiently maintained by first evaluating the overall delineation provided, then focusing on the performance or damage levels of individual units. The markers will chip tungsten-carbide plow blades, but have no difficulty avoiding properly placed markers.

Harrington, E.T.

New Materials and Systems for Improved Traffic Lane Delineation
FHWA, Washington, D.C.
V41 N3; Dec 77; pp 126-131

This article reviews the Federal Highway Administration's (FHWA) program in highway delineation materials research and attempts to place it in the perspective of the important needs for future delineation systems. A critical problem in the use of traffic paint with reflective glass beads is that at night in the rain the beading becomes flooded and loses its reflectivity. Current research is aimed at providing a snow-plow compatible wet-night delineation system. A commercially developed snowplowable raised reflective marker has been tested and the results have been mixed. An alternative approach has developed from research conducted on pavement grooving to increase wet-night delineation. Several other approaches have been investigated such as low-profile markers, self-luminous markers, radioluminescent and chemiluminescent markers. Although present day traffic paints can be placed economically and with minimal disruption of traffic, they are limited by their susceptibility to wear from traffic, snowplows and deicing salts, and abrasives. FHWA is sponsoring research in an effort to develop new delineation materials to solve some of the problems of paints and thermoplastics. Further research is also being conducted to develop a more durable, generic marking materials. Research has been successfully concluded on the formulation of yellow traffic paints using organic pigments in place of lead chromate. Development of installation equipment for the recessed reflective marker system developed by NYDOT is being initiated. Three methods of pavement markings removal were developed as a result of research in this area. The first method was on inexpensive hand-propelled burner assembly using a propane-oxygen flame. The second method used an externally mixed propane-oxygen flame with the residue removed by a scarifier. The third method weakened the paint-pavement bond with a steel cutter which was then broken with high-pressure water jets.

Haxo

Development of Rapid-Set Epoxy Adhesive for Traffic Markers
Federal Highway Administration Materials Division

This research is to develop an economical, asbestos-free, durable, rapid-setting epoxy adhesive for installing raised or flush pavement markers on either bituminous or portland cement concrete pavement, more rapid curing than currently available adhesives, without compromising durability or resistance to environment and snowplows and scale-up to production level.

Jagannath, M.V., Roberts, A.W.

Evaluation of Snowplowable Raised Reflective Pavement Markers in New Jersey
New Jersey Department of Transportation, New Jersey
August 1976 Final Report 54 pp. Report No. FHWA-NJ-RF77-0047708

The Stimsonite Model 99-K snowplowable raised reflective pavement marker was evaluated for its ability to withstand snowplowing operations and traffic

in central New Jersey. Castings are evaluated for their durability as well as the damage they cause to snowplow blades. Five reflector assembly types are also evaluated and rated for loss and damage by castings, whereas tungsten carbide inset blades caused gouging and scraping on casting surfaces. Carbide insets were damaged in the tests. Reflector losses are attributed to the effects of traffic as well as to snowplowing. An estimate of the cost to install and maintain markers is itemized.

Jagannath, M.V., Roberts, A.W.

Snowplowable Raised Pavements Markers in New Jersey (Abridgement)
Transportation Research Board 561, Washington, D.C., pp. 39-42

After two winters during which snowplow operations had been carried out at all three locations using both steel and tungsten carbide insert blades, five types of raised reflective pavement markers specifically designed for use on roads subject to snow removal which had been installed at three locations in New Jersey were evaluated for durability: one with a spring clip over the reflector - Model 2; one with a stud shield and a spring clip over the reflector - Model 3; one with an adhesive pad between the casting and reflector but with no spring clip - Model 4; and one with a spring clip, an adhesive pad between the reflector and the stud shield, but no pad between the casting and the reflector - Model 5. It was found that while steel blades neither damaged nor were damaged by the castings, the opposite was the case for tungsten carbide blades, thus making it advisable to either use steel blades or keep the tungsten carbide blades from coming into direct contact with the pavement. Neither types of blade caused damage to the reflectors, however. There was damage to the nose shoes in test utilizing three types of modified nose shoes. However, in tests where plow shoes and plow wheels rode over the reflectors there was no damage noted. The principal cause of reflector loss and damage appears to be tire studs and other tire forces. A comparison of the various types of reflectors revealed that those protected with shields had less damage than those without, thus making the former especially desirable in areas where studded tires are legal. Among the types with shields, this with spring clips had less damage and fewer losses than those using adhesive pads. The adhesive did not attach well in cold weather, causing either damage to the reflector after loss of the shielding or loss of the reflector itself due to lack of proper adherence to the casting. The spring clip type reflector was also found to be easiest to install. Therefore, considering minimum loss and damage and ease of installation, the Model 5 assembly appears to be the most practical.

Kentucky Department of Transportation, Lexington, Kentucky

Raised Pavement Markers as a Traffic Control Measure at Lane Drops
Res. Rept., No. 384, Feb. 74; 26 pp.

Raised pavement markers are an effective means of reducing erratic movements at lane-drop locations, particularly under nighttime driving conditions. The cost of raised pavement markers and their installation is nominal (\$150 per location). It is recommended that raised pavement markers be installed at other lane-drop locations. Markers installed at locations described in this study have been in place for a sufficient time to determine

their durability; however, reports from other states indicate their durability is sufficient to render them economical. If raised pavement markers are installed routinely, steps should be taken to insure they are not damaged by snowplow operations. Rubber-tipped blades have been used successfully.

Kidd, S., Long, D., Young, R.

Construction Zone Delineation (Raised Pavement Markers)
Mississippi State Highway Department, Jackson, Mississippi
FHWA 8595

To evaluate the use of raised reflective pavement markers as a means of providing improved delineation through construction and maintenance zones.

Lanz, L.J.

Road Marking Materials, 1st Interim Report
Mississippi State Highway Department
July 1972; 32 pp

Traffic paint, thermoplastic and raised markers are discussed: merits and shortcomings noted in evaluations are listed. Results of paint and bead studies were published in a previous report. However, they are included for comparisons. Thermoplastic sections have been in service for ten years in the state and all but one are still in service. Raised ceramic and reflective markers have been in place in Mississippi roadways for less than two years and experience with these markers is limited. Ninety-eight percent of reflective markers and ninety-four percent of ceramic markers remain in place after one year service. Many of these markers failed because of poor bond. Traffic is detrimental to ceramic markers curves and in areas with much lane crossing. Replacement of ceramic markers is necessary in several locations where up to thirty percent are missing in one-half mile stretches. Combinations of paint, thermoplastic and ceramic markers are recommended with raised reflective markers for low, medium and high volume roads to provide effective delineation for all conditions except snow.

Lanz, L.J.

Road Marking Materials 2nd Interim Report
Mississippi State Highway Department, Jackson, Mississippi
July 1973; 41 pp.

This report of road marking materials is an interim report on a Type B State Study. Traffic paint, thermoplastic and raised markers are discussed and merits and shortcomings noted in evaluations are listed. Results of paint and bead studies were published in a previous report for this study but are included for comparisons. Thermoplastic sections have been in service for eleven years in the state can plan on ten years service for thermoplastic installations. Raised ceramic and reflective markers have been in place on Mississippi roadways for over three years and experience with these markers and 5-10% of ceramic markers. Many of these markers failed because of poor bond. Traffic is detrimental to ceramic markers in curves and in areas with

much lane crossing. Replacement of ceramic markers is one-half mile stretches. Raised reflective markers are recommended to supplement paint or thermoplastic stripes to provide lane delineation during inclement weather. Reflective markers must be used with ceramic markers to provide nighttime delineation.

Liptak, R.E.

Raised Pavement Markers at Hazardous Locations -- Report I
Connecticut Department of Transportation
FHWA-CT-RD495-1-78-8; Feb 79; n.p.

Snowplowable raised pavement markers are being installed at hazardous locations in Connecticut as a means of providing improved delineation and added safety. This report primarily describes the application and installation of the markers at three (3) locations. Installation procedure, problems encountered and brief observations on their performance are reported. Costs associated with the initial installations of the markers are included.

Liptak, R.E.

Raised Pavement Markers at Hazardous Locations
Connecticut Department of Transportation
FHWA CN-FCP-4113-304, Nov 81

The major objective of the study is to determine if raised pavement markers provide improved delineation at hazardous locations in Connecticut, particularly at night under adverse weather conditions. Accident data and roadway geometry such as curves, lane drops, and gore areas will be determined and the effects on snow removal operations will be observed. The overall evaluation shall include visual observation of the markers supplemented by colored slides, photolog documentation, accident data before and after, public acceptance and a cost analysis.

Monograph

Raised Reflective Markers for Safer Night Driving
Public Works
Report No. HS-003 317; Subfile HSL

Raised pavement markers bonded to the highway with epoxy adhesive provides safer night driving during rain. Current pavement delineations vanish when wet.

McNaught, E.D.; Capelli, J.D.

Raised Snowplowable Pavement Markers
New York State Department of Transportation

Results of a 1973-74 evaluation of Stimsonite Model 99 raised markers, intended for use with tungsten-carbide snowplow blades, are reported and

experience with earlier versions of this marker are summarized. It was found that (1) present casting may be suitable for use with steel blades, (2) extensive casting damage occurred when plowed by tungsten-carbide blades, (3) casting shape allows the snowplow nose-shoe and cutting edge to contact and damage reflector, (4) some snowplow blade damage will occur its extent and effect on plow serviceability cannot now be predicted, (5) the reflector retention method was unsatisfactory at the start of the test (indications are that a modification to the spring clip retention method or use of adhesives may prove satisfactory). (6) markers should not be installed where the possibility of wrong-way plowing exists, and (7) in several early installations some failures observed were due to improper installation practices.

McNaught, E.D., Capelli, J.D.

Raised Snowplowable Pavement Markers
New York State Department of Transportation, New York
Interim Report; NYSDOT-ERD-75-RR-34; Oct. 75f; 29 pp

Results of a 1973-74 evaluation of Stimsonite Model 99 raised markers, intended for use with tungsten-carbide snowplow blades, are reported and experience with earlier versions of this marker are summarized. It was found that (1) present casting may be suitable for use with steel blades, (2) extensive casting damage occurred when plowed by tungsten-carbide blades, (3) casting shape allows the snowplow nose-shoe and cutting edge to contact and damage the reflector, (4) some snowplow blade damage will occur its extent and effect on plow serviceability cannot now be predicted, (5) the reflector retention method was unsatisfactory at the start of the test (indications are that a modification to the spring clip retention method or use of adhesives may prove satisfactory), (6) markers should not be installed where the possibility of wrong-way plowing exists, and (7) in several early installations some failures observed were due to improper installation practices.

Neale

Raised Pavement Markers at Hazardous Locations
Georgia Department of Transportation, Georgia
FHWA 9398, Dec 78; Mar 80

Evaluate the effects of raised pavement markers as a means of improving safety and traffic operations at high hazardous locations.

Neill, C.

Pavement Delineation Study
Georgia Department of Transportation, Atlanta, Georgia
Study No. 7503, Jan 82

The objectives of the study are to compare and evaluate from both performance and economic aspects various pavement delineation systems. The experiments will include various systems of thermoplastic delineation materials and new developments in raised markers both reflective and nonreflective.

Niessner, C. W.

Construction Zone Delineation (Raised Pavement Markers)

FHWA Washington, D. C.

FHWA-TS-222, June 1978, 20 pp.

The implementation Division of the Office of Development initiated a series of projects to evaluate the effectiveness of raised pavement markers as a means of guiding traffic through construction zones. The Tech Share document summarizes the results of those projects. One of the major findings of this evaluation was that the raised reflective pavement markers provide positive daylight and nighttime guidance through both wet and dry periods. The additional safety, improved operations, reduced vandalism and unanimous favor by the public, Government, and construction personnel justify their expanded use. The use of raised reflective pavement markers on construction detours also indicates a trend toward reducing the number of accidents. From an economic standpoint, the cost of markers and paint is equal to or less than the cost of paint striping and removal.

Niessner, C. W.

Reflective Marker Paint Stripe Skipper Instruments

FHWA Washington, D. C.

FHWA-TS-81-205, February 1981, 14 pp.

The report summarizes the information on design and testing of two instruments that have been developed to avoid painting over reflective raised pavement markers. The two devices were developed by the California and Ohio Departments of transportation. The California instrument optically scans the roadway for reflective surfaces, whereas the Ohio one consists of a mine detector type metal sensor to denote the presence of a marker. Both devices will automatically cut off the flow of paint in front of a marker.

Niessner, C. W.

Raised Pavement Markers for Construction Zone Delineation

FHWA Washington, D. C.

V43 N2, September 1979, pp. 69-73

The cost, spacing, ease of application and removal of the markers, and their effectiveness as traffic guides during the day and at night were evaluated. The public's acceptance of the markers was also assessed. The study showed that raised pavement markers provide positive daylight and nighttime guidance. Markers used on construction detours tend to reduce the number of accidents.

Niessner, C. W.

Recessed Snowplow Markers

FHWA Washington, D. C.

FHWA-TS-80-225, March 1980, 28 pp.

Raised reflective pavement markers are currently being used in a number of states as a supplement to painted lines. In areas of little or no snow these markers provide excellent wet-night delineation. However, in areas of heavy snowplowing, the markers are easily removed from the pavement by the plows. In an effort to provide markers in the snow belt areas, two different approaches have been followed. One is to protect the marker by means of casing and allow the snowplow to either ride up over the marker or to depress the reflector into the casing. The second method is to place the marker in the groove so that the top of the reflector is below the pavement surface. This report summarizes the work that has been completed on the installation and evaluation of the recessed snowplowable markers. The evaluation indicates that the recessed reflector marker system is a feasible method of protecting the reflector from snowplow damage. After 4 years of service, this system has continued to provide a useable degree of wet-night delineation.

O'Connor, D.L.

Development of an Adhesion Tests for Traffic Buttons, Markers and Jiggle Bars
Texas State Department of Highways and Public Transportation

A procedure was developed to determine the degree of adhesion obtainable to traffic markers using a standard epoxy adhesive. Bond tests to several different types of markers were performed at 0, 77, and 140 F, and also after freezing and thawing. A bond strength of 500 psi at 77 F, was selected as the minimum for satisfactory performance.

Pigman, J. G., Agent, K. R.

Raised-Aggregate Lane-Delineation Stripe

Kentucky Department of Transportation, Lexington, Kentucky

CN-KYR-73-48, 13 pp.

Experimental raised-aggregate $\frac{1}{2}$ inch (13 mm) to 1 inch (25 mm) traffic stripes were installed on approximately 0.4 miles (644 m) of US just north of the intersection with US 421 in Franklin County. Installation was during June, 1974. Aggregate stripes were painted yellow and used as skip lines inside the continuous channelization stripes to indicate no crossing into the two-way left-turn lane except for turning movements. Observations indicated that the raised aggregate stripes had good durability after being exposed to 2 years of wear. During dry nighttime conditions, the paint stripes were slightly more effective than the aggregate stripes; but raised pavement markers simulating a paint stripe were superior to either method of delineation. Aggregate stripes provided a substantial improvement over paint stripes during wet nighttime conditions, but raised pavement markers were most effective. The aggregate stripes produced an increase of approximately 3 dBA

in the noise level compared to an increase of 5 dBA when driving over raised pavement markers arranged to simulate paint stripes. Raised-aggregate stripes were uneconomical when compared to regular paint stripes, thermoplastic striping, and raised pavement markers. The cost of aggregate stripes would most likely decrease if installation were on a larger scale.

Pigman, J. G., Agent, K. R.

Raised Pavement Markers at High-Hazard Locations
Kentucky Department of Transportation, Lexington, Kentucky
#Report RR 522, June 1979, 40 pp.

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.

Pigman, J. G., Agent, K. R., Rizengburgs, R. L.

Evaluation of Raised Pavement Markers
Kentucky Department of Transportation, Lexington, Kentucky
Research Report 425, April 1975, 39 pp.

The purpose of this study was to evaluate the operational applicability of raised pavement markers and to determine their effectiveness with respect to brightness and durability. Seven different types of markers were evaluated. The primary application of markers in this study was as a supplement to lane lines. They were also used as a traffic control measure at lane drops, as delineation for hazardous curves, and as directional arrows. Luminosity and durability were monitored for approximately one year. It was found that raised pavement markers can be very effective method of roadway delineation. Markers evaluated had varying levels of brightness and durability. Costs varied considerably among types. Specifications which classified and described the markers were proposed. Details for the recommended design layout of markers as supplements to and replacement for lanes were proposed.

Niessner, C. W.

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O'Connor, D.L.

Development of an Adhesion Tests for Traffic Buttons, Markers and Jiggle Bars
Texas State Department of Highways and Public Transportation

A procedure was developed to determine the degree of adhesion obtainable to traffic markers using a standard epoxy adhesive. Bond tests to several different types of markers were performed at 0, 77, and 140 F, and also after freezing and thawing. A bond strength of 500 psi at 77 F, was selected as the minimum for satisfactory performance.

Pigman, J. G., Agent, K. R.

Raised-Aggregate, Lane-Delineation Stripe
Kentucky Department of Transportation, Lexington, Kentucky
CN-KYR-73-48, 13 pp.

Experimental raised-aggregate $\frac{1}{2}$ inch (13 mm) to 1 inch (25 mm) traffic stripes were installed on approximately 0.4 miles (644 m) of US just north of the intersection with US 421 in Franklin County. Installation was during June, 1974. Aggregate stripes were painted yellow and used as skip lines inside the continuous channelization stripes to indicate no crossing into the two-way left-turn lane except for turning movements. Observations indicated that the raised aggregate stripes had good durability after being exposed to 2 years of wear. During dry nighttime conditions, the paint stripes were slightly more effective than the aggregate stripes; but raised, pavement markers simulating a paint stripe were superior to either method of delineation. Aggregate stripes provided a substantial improvement over paint stripes during wet nighttime conditions, but raised pavement markers were most effective. The aggregate stripes produced an increase of approximately 3 dBA in the noise level compared to an increase of 5 dBA when driving over raised

pavement markers arranged to simulate paint stripes. Raised-aggregate stripes were uneconomical when compared to regular paint stripes, thermoplastic striping, and raised pavement markers. The cost of aggregate stripes would most likely decrease if installation were on a larger scale.

Pigman, J. G., Agent, K. R.

Raised Pavement Markers at High-Hazard Locations
Kentucky Department of Transportation, Lexington, Kentucky
#Report RR 522, June 1979, 40 pp.

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.

Pigman, J. G., Agent, K. R., Rizengburgs, R. L.

Evaluation of Raised Pavement Markers
Kentucky Department of Transportation, Lexington, Kentucky
Research Report 425, April 1975, 39 pp.

The purpose of this study was to evaluate the operational applicability of raised pavement markers and to determine their effectiveness with respect to brightness and durability. Seven different types of markers were evaluated. The primary application of markers in this study was as a supplement to lane lines. They were also used as a traffic control measure at lane drops, as delineation for hazardous curves, and as directional arrows. Luminosity and durability were monitored for approximately one year. It was found that raised pavement markers can be very effective method of roadway delineation. Markers evaluated had varying levels of brightness and durability. Costs varied considerably among types. Specifications which classified and described the markers were proposed. Details for the recommended design layout of markers as supplements to and replacement for lanes were proposed.



Pigman, J. G., Agent, K. R.

Raised Pavement Markers and High Hazard Locations
Kentucky Transportation Research Program
CN-DOT-FH-9279, March 1981

The objective of this study was to evaluate the use of raised reflective pavement markers at hazardous locations as a means of providing improved roadway delineation and added safety. The study included the following tasks: (1) site selection, (2) purchased and installation of markers, (3) evaluation of the installations, and (4) reporting of findings.

Public Works, Monograph HS-003317

Raised Reflective Markers for Safer Night Driving

Raised pavement markers bonded to the highway with epoxy adhesive provides after night driving during rain. Current pavement delineations vanish when wet.

Reilly

Effect of Raised Markers on Traffic Performance
New Jersey Department of Transportation

The objectives of this project are to determine the effects snowplowable raised pavement markers have on traffic safety, efficiency, and driver visibility at exit gores and hazardous curves at night and in the rain.

Richardson, W. C.

Paint Skip: A Solution to the Problem Respecting Raised Pavement Markers
Ohio Department of Transportation, Columbus, Ohio
Final Report; March 1978, 41 pp.

Principles of operation, construction, and installation details are presented for a device which will cause a paint striper to skip over cast iron, snowplowable raised pavement markers. Paint-Skip is a low cost device which can interface with either electromechanical or solid-state host controller.

Schreuder, D. A., Jackson, J.

International Symposium. Visual Aspects of Road Markings
Paris, May 1983, 43 pp.

Reports and papers are presented under five sections as follows: Section 1 (Schreuder, D. A.); Reflectorized Road Markings, Their Contribution to Traffic Safety (Jackson, J.); Raised Lane-Line Pavement Markers as an Aid to the Performance of impaired Drivers (O'Hanlon, J. F.); Visual Processing of Vehicle Guidance (Riemersame, J. B. J.) Section 2; Contrast Requirements of

Markings and Studs: Report Section 2 (Blaauw, G. J.); The Marking Visibility Due to Contrast With the Pavement in Various Conditions of Illumination (Serres, A. M.); Overview of ARRB Research on Delineation (Jenkins, S. E. and Lay, M. G.). Section 3, Influence of Beads and Their Application: Report section 3 (Bry, M.); Surface Treatment and Night Time Visibility (Fournier, J. S.); the Retroreflection Level of Road Markings in France (Lothe, M). Section 4, Products and Materials; Report Section 4 (Schrieber, G.); Factors of Night Time Visibility of Delineation in Case of Rain (Cathelain, M.); The Influence of Different Road Surfaces to the Night Visibility of Points and 2-Component Road Markings (Reidt, W.); Section 5, Photometric and Colormetric Properties: Report Section 5 (Kebuschull, W. and Stephenson, H. F.): Measured Data for the Reflection Properties of Road Surfaces and Road Markings in Headlight Illumination (Lndkvist, S. O.); Model Considerations on the Reflection Properties of Road Surfaces and Road Markings in Headlight Illumination (Sorenson, K.); Effects on Sample Size, Geometry and Illuminants on the Measurement of the Luminance Factor and Day Time Color of Reflective Material (Rennilson, J. J.); A Portable Reflection Measuring Meter for Measuring Road Marking Reflectivity (Fleischer, J.); Measuring Box for Estimation of the reflection Properties of Road Markings in Headlight and Daytime Illumination (Gudum, J.); Comparison of the Measuring Results of Retrometers of Different Type and Make (Meseberg, H. H.); Objectives and Quality of field Reflectometers (Paumier, J.L.).

Shelly, T. L., Rooney, H. A., Beede, E. K., Chapman, B. J., Maggenti, E., Page, J. W., Ford, R. W.

Development and Evaluation of Raised Traffic Lane Markers
California Division Highways/Materials & Res. Department
M&R No. 635152, October 1971, 49 pp.

This report presents the results of investigations from 1968-1971 on raised traffic lane markers. Previous work from 1953-1968 is briefly reviewed. The evaluation covers the durability of both reflective markers and ceramic daytime markers, particularly pertaining to cleaning and wearability of surfaces and loss of and life reflection. The following new markers were evaluated: (1) reflectorized tape encased between 4" glass bars showed good initial nighttime visibility; (2) ceramic daytime markers with a reflective element consisted of an encased reflective tape designed to give continuous daytime and nighttime delineation; (3) glass-domed unit encased in rubber base resulted in glass breakage and poor nighttime delineation; (4) reflectorized tape encased between two 4" plastic bars indicated 6-month durability; (5) metal case with replaceable reflectorized element designed so that the reflective element can be replaced became ineffective as a marker since recessed areas were difficult to clean and maintain; (6) epoxy markers with glass beads cast-in-place resulted in poor performance, day and night; (7) a "low profile" daytime ceramic marker designed to minimize tire impact noise caused by lane changing failed to have the strength of high-strength ceramic marker; (8) a reflectorized unit consisting of an epoxy filled acrylic shell provided good delineation for 2 years until the plastic casing began to separate from the epoxy filler; (9) a glass daytime marker has lower reflectance and tends to undergo severe cracking; (10) a plastic marker with replaceable reflective elements and containing no filler failed to remain in place for either the reflective elements or the adhesive pad; (11) a modified snowplow marker for use in snow free areas indicated that nighttime

observations showed from fair to good delineation.

Shepard, F. D.

Evaluation of Raised Pavement Markers for Reducing Incidence of Wrong-Way Driving (Abridgment)
Transportation Research Record 597, Washington, D. C.

In view of the fact that wrong-way drivers must fail to see or properly interpret the directional signs, warning signs, and pavement markings placed in the intersection for their guidance, something beyond conventional devices is obviously needed. A concept that is believed to have merit involves the placement of raised pavement markers on off-ramps in such a configuration that the driver will be alerted as a result of viewing an unexpected phenomenon. The preliminary research report in this paper was undertaken to determine the efficacy of random configuration of such markers. The investigation was limited to one Interstate interchange, and only an off-ramp under night conditions was considered. The markers, which possess good reflective qualities, were placed to reflect only the light of a vehicle traveling in the wrong direction. Forty-five markers were randomly placed in a section 36.58m (120 ft) long. The results of the investigation showed that the raised pavement marking system was effective in alerting drivers because they viewed an unexpected phenomenon. Also, it was thought that the marking system did help to call attention to the wrong way signs and that it would be effective in causing a wrong-way driver to realize his or her mistake and act accordingly. Based on the findings of this initial work, the system has been implemented at two sites for further study.

Shepard, F. D.

Evaluation of Raised Pavement Markers for Roadway Delineation During Fog
Virginia Highway and Transportation Research Council, Charlottesville,
Virginia
FHWA/VA-77/R21, October 1976, 28 pp.

The feasibility of using reflex reflective devices and materials for roadway delineation and vehicle guidance during fog was investigated, with emphasis on the nighttime visibility characteristics. Also, consideration was given to various experimental methods of marker placement for roadway delineation and to protecting the marker from snowplow damage. Two types of corner-cube raised markers were placed along the highway edge line on 20-foot (6.1 m) centers. In one placement concept, snowplowable and non-snowplowable markers were placed on the pavement surface. In a second concept, the markers were recessed below the pavement surface in grooves. The marking systems were subjectively evaluated by observing the legibility properties during fog and noting the number of markers visible. Based on the observations, the raised pavement markers were thought to provide sufficient nighttime roadway delineation for vehicle guidance during light to medium density fogs. Although data were not available for dense fog, it is felt that adequate delineation would be provided for such fog conditions. The method of grooving the pavement in the vicinity of the edge line for the purpose of recessing the markers to provide snowplowability was found to be feasible, providing adequate drainage is provided and a groove is placed in front of the marker.

The length of the groove depends upon the reflectivity-distance requirements.

Shepard, F. D.

Evaluation of Recessed, Snowplowable Markers for Centerline Delineation
Virginia Highway and Transportation Research Council

Determine the feasibility of using raised pavement markers placed in pavement grooves as a guidance aid for motorists during wet-night conditions.

Shepard, F. D.

Installation of Raised Pavement Markers for reducing Incidence of Wrong-Way
Driving
Virginia Highway and Transportation Research Council
VHTRC-77-R58, June 1977, 23 pp.

On the basis of previous research, raised pavement markers were installed at two interstate off-ramps known to have experienced incidences of wrong-way driving to further evaluate their effectiveness in alerting motorists entering from the wrong way. Descriptions of these installations are given in the report along with the results of the evaluation which includes a subjective investigation of the visibility and alerting characteristics of the markers and a determination of their durability qualities. Based on the results, it is felt that the configurations of markers used are effective in alerting drivers as a result of their viewing an unexpected phenomenon. It is recommended that the raised pavement markers, placed in configuration as noted in the report, be considered for placement in ramp areas or similar locations where wrong-way entries have been a problem.

Shepard, F. D.

Installation of Raised Pavement Markers for Reducing Incidence of Wrong-Way
Driving in Snow Plow Regions
Virginia Highway and Transportation Research Council

The objective is adaptation of the system of raised pavement markers found to be effective in alerting wrong-way drivers to areas where snowplowing is prevalent.

Smith, M.DS.

Rapid Set Epoxy Adhesives
Oklahoma Department of Transportation Research Division
Contract No. DOT-FH-11-9124

Compare the performance of rapid set epoxy adhesive with standard set epoxy adhesive by periodically observing pavement markers which are bonded to the pavement with both standard and rapid set epoxy adhesives and determining the number of markers remaining bonded.

Spencer, L. J.

Construction Zone Delineation (Raised Pavement Markers)
Arkansas State Highway and Transportation Department, Little Rock, AR
DOT-FH-11-8899, March 1978, 27 pp.

The problem of safely carrying traffic through construction and maintenance zones is becoming increasingly more complex. The contractor must coordinate his activities to maintain normal traffic flow and provide positive guidance so that accident potential situations are kept to a minimum. Raised reflective pavement markers provide excellent wet weather and nighttime reflection and appear to be an effective means of maintaining safe traffic flow. This study evaluated the use of raised reflective pavement markers as a means of providing improved delineation through construction zones.

Stimpson, W. A.

Field Evaluation of Selected delineation Treatment on Two-Lane Rural Highways.
Executive Summary
FHWA, Washington, D. C.
FHWA-RD-77-119, October 1977, 20 pp.

The objectives of this research project were to establish relationships between traffic performance and accident probability on two-lane rural highways; to develop an experimental design for field testing the effectiveness of conventional and novel delineation treatments; to evaluate the effect of selected delineation treatments on traffic performance and associated accident probability; and to make recommendations for the design and use of delineation treatments. In the first phase of study, regression analysis was used to correlate delineation-related accident potential to a few systematically derived speed and lateral placement measures. In the second phase of study, additional accident and traffic performance data were collected to test the for relation models and to evaluate the safety effectiveness of 21 unique delineation systems. This Executive Summary provides an overview of the experimental approach utilized in meeting the four project objectives. The two validated lateral placement hazard indicators, off-center driving and longitudinal change in placement variance, are briefly described. Lastly, recommendations are made for immediate implementation on two-lane rural highways of a 10:30 broken centerline pattern, narrower edge lines, and the selective use of post-mounted delineators.

Tamburri, T. N., Lowden, Jr., P. R.

Wrong-Way Driving (Phase III)
(Driver Characteristics, Effectiveness of Remedial Measure and Effective of Ramp Type), Interim Report No. 2
Department of Public Works, Sacramento, California
HS-005 790, 1969, 77 pp.

The effectiveness of signs and reflective pavement markers in reducing wrong-way driving violations and accidents on California freeways and expressways was evaluated. Before and after studies indicated a reduction of wrong-way violations by 60% on freeways and 70% on expressways. An estimated

140 accidents were also prevented. The signs were found effective, but the pavement arrows were of no benefit. Study of the 168 wrong-way drivers found that they had more driving violations, accidents, and felony convictions than the average motorist.

Taylor, J. I., McGee, H. W., Seguin, E. L., Hostetter, R. S

Roadway Delineation Systems
Highway Research Board
NCHRP Report 130, 1972, 349 pp.

Roadway delineation treatments and systems are specified and installed to aid drivers in controlling their vehicles, thereby improving the safety aspects of the highway and easing the driving task. There is a logical process by which installation decisions have been and are being made. The information developed in this research project provides meaningful and usable means to strengthen the decision process and enhance the likelihood of cost-effective solutions. A comprehensive state-of-the-art summary covering the application of various delineation treatments to highway situations, delineation material properties, the human factors literature pertinent to delineation, and cost effectiveness considerations was compiled. Emphasis was given to current practices - particularly departures from the standard manuals and recent research findings. Practices and research results of other countries were included. Seven tasks were set fourth to serve as the research framework; (1) review past and current research; (2) prepare a state-of-the-art summary; (3) determine the driver's delineation requirements; (4) establish rational techniques for determining the effectiveness of delineation treatments; (5) test promising delineation systems; (6) develop practical criteria for the selection of delineation treatments; and (7) evaluate colored pavements. Laboratory and field studies were conducted. Recommendations for the application of the various treatments at each of the "classical" situations were drawn upon the axis of these studies, discussions with other researchers and practicing engineers, and review of the literature. Eight principal conclusions were drawn.

Webb, W. E., Dudgeon, J. E.

A Reflectance Measuring System for Field Use
Alabama University, Montgomery, Alabama
HPR-82; PB-283133/7ST, April 1977, 63 pp.

A portable reflectance measuring system suitable for in situ measurement of road signs, pavement markers, and road stripes has been constructed. The reflectometer has adequate sensitivity to allow measurements of road stripes at grazing incidence and to permit measurements to be made from off-the-road locations, thus avoiding obstructing traffic or exposing the operating personnel to unnecessary hazards. The use of phase-lock detection techniques to eliminate background radiation allows measurements to be made on a sun-lit target. The instrument's spectral response simulates the human photopic response when viewing under a 2856K (CIE standard source A) lamp as required by federal specification LS-300A.

Whitefield, F. N.

A Development in Road-Marking Materials; Formed - In Situ Plastic,
Raised Pavement Markers
Australian Road Research Board Conference Proc.
N8, August 1976, pp. 1-4

A process has been developed to enable suitability polyester resin to be applied in cheap, thin-walled poly-propylene plastic cases to form in situ raised pavement markers. These are self adherent to bituminous surfaces and provide an economic means of lane delineation which is long lasting, hard wearing, and visible under wet conditions. This method of application does not appear to have been used elsewhere. The process can be readily adapted to suit a variety of special conditions and to apply markers of different shapes and colors.

Wilson, J. E.

Benefits of Using Raised Reflective Pavement Markers in Roadway Delineation
Int. Road Federation, Washington, D. C.
Proceeding: October 1977, pp. 173-174

An important advancement in traffic engineering for the improvement of safety, mobility, and guidance in recent years has been the introduction of raised reflective pavement markers which are raised above the surface moisture, sloped to permit easy safe crossing by automobile tires, and which employ the cube corner technique of light reflectance from vehicle headlights. Their main advantage over previous pavement marking and delineation systems is that they provide guidance at night and during inclement weather. Typical examples of their use include two-lane centerlines, lane lines on multilane highways, traffic islands, pavement arrows, exit ramp delineation, and construction zones. They are also used where lanes narrow or are reduced in number, as well as at high hazard locations such as sharp or reverse curves, hills, or dangerous intersections. By resulting in the safe increase of traffic volume and density, the use of these markers can improve traffic control. They are also relatively economical due to their use of installation and desirability.

Wilson, J.

Methods Utilizing Reflective Pavement Markers in Snow Country
Transport and Road Research Laboratory, Stockholm, Sweden
1981, 339-343 pp.

Raised reflective pavement markers have proven very effective in guiding traffic at night, and especially during inclement weather when painted or plastic lines tend to disappear under a film of water. After several years of development work, a system of raised reflective pavement markers was introduced for snow areas in the United States. Its success was realized quickly, and now virtually every state has completed testing and are making extensive installations. This system involves the use of an iron casting recessed into the pavement so that it projects above the surface about one centimeter. This casting houses an acrylic cube corner reflector having an

abrasive-resistant surface to protect it from snow removal operations. Casting design and its treatment, (along with the protective surface of the reflector) makes this system acceptable. A second generation system has been developed which consists of placing the cube corner reflector below the surface of the pavement in a recess approximately one centimeter in depth. This recess has a minimum length of 42 inches, or just over a meter. Installed costs of the casting system varies from \$14 to \$25 per unit. The recessed system will cost \$7 to \$12.

Wright, P. H., Zador, P.

Survivability of Reflectorized Pavement Markers
Georgia Institute of Technology
August 1982, 7 p.

Recessed pavement markers were found to outlast raised pavement markers by at least a factor of two in Georgia. It was also found that over 95 percent of the reflectorized pavement markers of the recessed variety installed by the Georgia Department of Transportation to reduce the frequency of run-off-the-road crashes on sharp curves remained in place for up to five years and up to ADTs of 4,700.

Wright, W. R.

Development of a Fog Detection System
Ohio Transportation Engineering Conference, Ohio State University, Columbus,
Ohio
April 1975, V29, pp. 186-177

The results of a study of the effects of fog related to traffic are listed, vehicle guidance under low visibility conditions are described, the results of a study of fog frequency are summarized, and the provision of advance motorist information is discussed. Current and future sign control systems are briefly reviewed. Studies have shown that the probability of overdriving increases sharply as the visual distance decreases. Active, passive and signaling visual guidance systems are outlined. Fog frequency data reveals that dense fog occurs on more than 20 days a year in over 60 percent of the areas covered by Weather Bureau Stations. The "flip-type" fog warning sign with flasher and its operation are described. The erection of a series of signs approaching the fog area, edgelines, and raised pavement markers for better guidance, and electronic fog detectors, including the Transmissiometer, are described.

Zwahlen, Helmut T.

"Optimal Spacings and Placements of SnowPlowable Raised Pavement Markers"
U.S. Department of Transportation, Federal Highway Administration,
Ohio University (Unpublished Study Results)
1984.

A current study conducted at Ohio University and Department of Transportation, FHWA, and the USDOT has the objective to modify the empirical STI model for point sources and to determine the optimal spacings and placement for snowplowable raised pavement markers for tangent section on interstates, highways and for entrance and exit ramps from a visibility and lateral lane deviation point of view. Based upon the analytical visibility and lane deviation calculations using the modified STI model, a spacing of 120 feet for markers placed along skip lines is tentatively recommended for tangent sections on interstate highways for entrance and exit ramps with a 24 degree curvature, tentative recommendations are to place the markers on the outer edge line at a spacing of 25 feet. (Author).

APPENDIX F
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