RETENTION OF REFLECTIVE RAISED PAVEMENT MARKERS

by

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16. Abstract

This report is the third in a series of four, and it presents the procedures and results of various studies conducted to determine (1) the causes of marker retention failures, and (2) possible counter measures to increase the service life of the markers and traffic buttons.

It was clearly established that marker retention is an inverse function of the number of tire hits. Truck tires, especially high pressure tires are particularly damaging. So one of the recommended marker retention categories was to place the reflective markers behind the solid paint stripe they supplement, thus protecting them from many hits. Because of rapid loss rates, resulting in poor cost-benefit ratios, it is suggested the markers not be used to supplement lane line stripes on asphalt surfaces.

The plastic 2x4 markers are the poorest performers, so far as retention is concerned, and should not be considered for Texas highways.

The oval shaped ceramic markers proved to be the best performers on all paving material so far as retention is concerned. This was especially true when the markers were manufactured with small, round studs on the bond surface as originally suggested by Mr. H. D. Jones, District 12.

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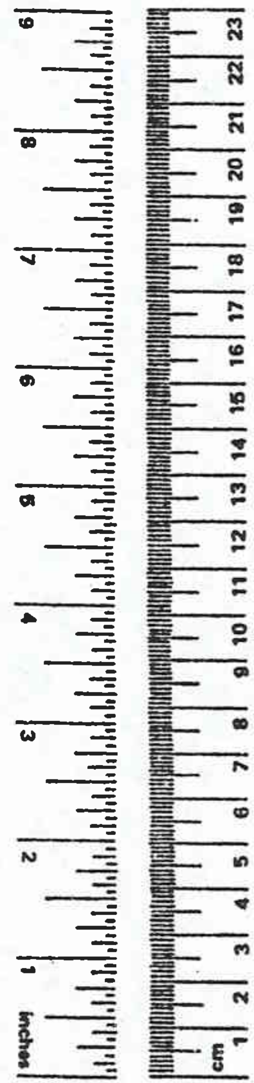
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

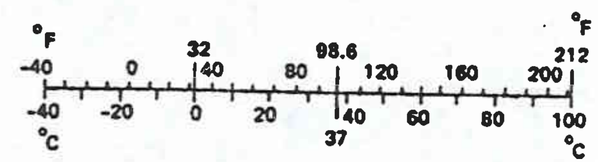
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	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

*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.



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



SUMMARY OF RESULTS

This report is the third in a series of four, and it presents the procedures and results of various studies conducted to determine (1) the causes of marker retention failures, and (2) possible counter measures to increase the service life of the markers and traffic buttons.

It was clearly established that marker retention is an inverse function of the number of tire hits. Truck tires, especially high pressure tires are particularly damaging. So one of the recommended marker retention categories was to place the reflective markers behind the solid paint stripe they supplement, thus protecting them from many hits. Because of rapid loss rates, resulting in poor cost-benefit ratios, it is suggested the markers not be used to supplement lane line stripes on asphalt pavements.

The plastic 2x4 markers are the poorest performers, so far as retention is concerned, and should not be considered for Texas highways.

The oval shaped ceramic markers proved to be the best performers on all paving material so far as retention is concerned. This was especially true when the markers were manufactured with small, round studs on the bond surface as originally suggested by Mr. H.D. Jones, District 12.

Implementation

Due to the severity of the problems associated with the reflectivity of raised pavement markers the results of these studies should be implemented as soon as possible. The laboratory studies were developed to address the more pressing problems involved with initial purchasing and maintenance of - reflective raised pavement markers.

The results of the studies in this report 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 states.

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.

Acknowledgement

The authors wish to gratefully acknowledge the personnel of the State Department of Highways and Public Transportation, and especially Mr. Richard Oliver (D-18T), Mr. Randall Keir (D-18A) and Mr. H. Dexter Jones (District 12), for their assistance and technical advice during the course of this study.

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Key Words: Reflective raised pavement markers, Retention, Service life, Traffic buttons.

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RETENTION OF REFLECTIVE RAISED PAVEMENT MARKERS

INTRODUCTION

The Texas driving public has come to appreciate the use of raised reflective pavement markers (markers) to supplement the primary traffic markings used on their highways. The 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 value under these conditions is further increased when approaching curves, exits and intersections, and during power failures on urban freeways.

But the experience in Texas has been that the use of the markers is extremely expensive. The initial installation cost is more than 400 times that of conventional traffic paint. Once in place they are prone to excessive loss rates and even when they stay their effectiveness deteriorates due to wear out and loss of reflectivity. Because several parameters have been identified as contributing significantly to these problems it is difficult to isolate the influence each has on a specific highway.

In 1965, the Texas State Department of Highways and Public Transportation (SDHPT) persuaded the Federal Highway Administration (FHWA) to share in the cost of installing markers on a new section of Interstate Highway through downtown Houston. Since that time several million of the markers have been installed on Texas highways. The installation costs for most of these were funded by the Pavement Marking Safety (PMS) Program, a Federal program that began in 1973 and has continued until the present.

The SDHPT engineers quickly recognized that the performance of the markers was erratic and often unsatisfactory. Observations by those responsible for highway maintenance and safety convinced them that the wear and/or loss rates were excessive. These observations have led the SDHPT to rank marker loss and wear to be one of the most important, and expensive, problems faced by the Department.

STATEMENT OF THE PROBLEM

Three distinct and separate problem areas associated with the use of the raised reflective pavement markers have been identified. They are:

- poor retention,
- poor resistance to wear and breakage, and
- high costs, both for initial installation and maintenance.

The extent to which these are problems, and some of the factors associated with each, have been defined and will be discussed in later sections of this report.

POOR RETENTION

The most severe problems for maintaining the effectiveness of raised pavement markers in Texas is poor retention. In several instances, involving large statistically significant samples, more than 50% of the plastic markers (RPMs) were found to have disappeared from the roadway within 18 months of their initial installation. This is a statewide problem and usually accounts for more than half of the markers deemed to be ineffective.

POOR RESISTANCE TO WEAR AND BREAKAGE

A second related problem is a rapid drop in reflectivity which was observed between the newly installed markers and markers on the road for only a matter of months. This phenomena was observed to be true for both the plastic raised reflective pavement markers (RPMs) and ceramic reflective traffic buttons (RTBs) and to some extent was attributable to dirt and road film. When this is the case it is usually reversible during wet weather.

But, a more important component of this problem is the rapid deterioration with time and traffic. Structural deterioration accelerates the loss of reflectance. It was observed that breakage is intimately related to the number of times a marker is hit, so it is easy to deduce why lane line markers lost their effectiveness faster than centerline markers and, to an even greater extent, faster than island markers. It was judged that the number of hits a marker experienced was a far better indicator of deterioration than time alone.

COST

Both the initial installation and maintenance costs of the markers are extremely high, especially in view of the fact that they are used as a supplementary traffic marking. Other states have made attempts to reduce the initial installation costs and have been generally unsuccessful. But while the initial costs are high, the maintenance and replacement costs are even higher.

OBJECTIVES

Several objectives of the project were developed based on the nature of the problem. The major objectives specifically related to the retention of RPMs and RTBs were:

1. Compile a list of the types and possible guidelines and reasons for marker retention failure. Markers are used in this connotation to include both RPMs and RTBs.
2. Relate retention of currently available markers to facility type, pavement, installation technique, traffic volumes, traffic content and vehicle impact (322-3).

Included in the second major objective were several minor objectives. These minor objectives included:

1. Perform feasibility analyses (including cost-benefit analyses), using information collected from objectives 1 and 2 and found in the literature, to determine the effectiveness of markers as a function of the various parameters involved (322-3).
2. Relate retention to the type of epoxy being used for the markers (322-3).
3. Secure from the department and include in an appendix to the research report, data and studies relating to the above objectives (322-1, 322-2, and 322-3).

The other objectives related to this research project are listed below. After each objective is the research report which contains information supporting that research objective.

1. Compile and publish known installation guidelines and procedures for markers (322-4).
2. Develop guidelines or warrants for use of markers (322-4F).
3. Refine existing photographic techniques so that pictures from actual sites could be obtained using existing light from the driver's eye height and field of view (322-2).
4. Obtain a set of photographs that would be used by maintenance personnel to determine the need for maintenance of RPMs and RTBs (322-3).

5. Indirectly evaluate the current minimum brightness specification with respect to functional levels of reflectivity (322-2).
6. Develop a set of guidelines for application of the markers which would prolong the reflectivity of the markers (322-2).

TYPES OF MARKERS

Two basic types of reflective marking devices in current use by the Texas State Department of Highways and Public Transportation are the RPMs and RTBs. The RPMs are generally square or rectangular in shape whereas the RTBs are usually round or oval, as shown in Figures 1 and 2. All of the RPMs treated in this study were made by either Stimsonite or Ray-O-Lite and all of the RTBs were made by Permark. Both RPMs and RTBs come in either crystal red or amber. All of the marking devices can be purchased with bidirectional reflectivity. The RPMs are made with an acrylic shell into which the reflector is molded and then filled with an epoxy potting compound. RTBs are made with ceramic bases into which a sheeting reflector with a protective plastic rod is glued. Table 1 presents the manufacturer's name, model number, width, length, height and specific intensity of 0_ and 20_ incident angles. The data in Table 1 was obtained from either the manufacturer's representative or highway department tests.

Table 2 gives the average unit prices that Texas paid for the RPMs and RTBs in 1980, 1981, and 1982. While the average prices shown appear relatively stable there was a great deal more variability in the individual lot purchases, sometimes ranging as much as 50%.

No prices are shown for the smaller Stimsonite 947s. The State did not purchase many, if any. However, a review of contract line items, in contracts primarily for the installation of markers indicates the small 2"x4" RPMs cost equally as much if not more than the 4"x4" RPMs.

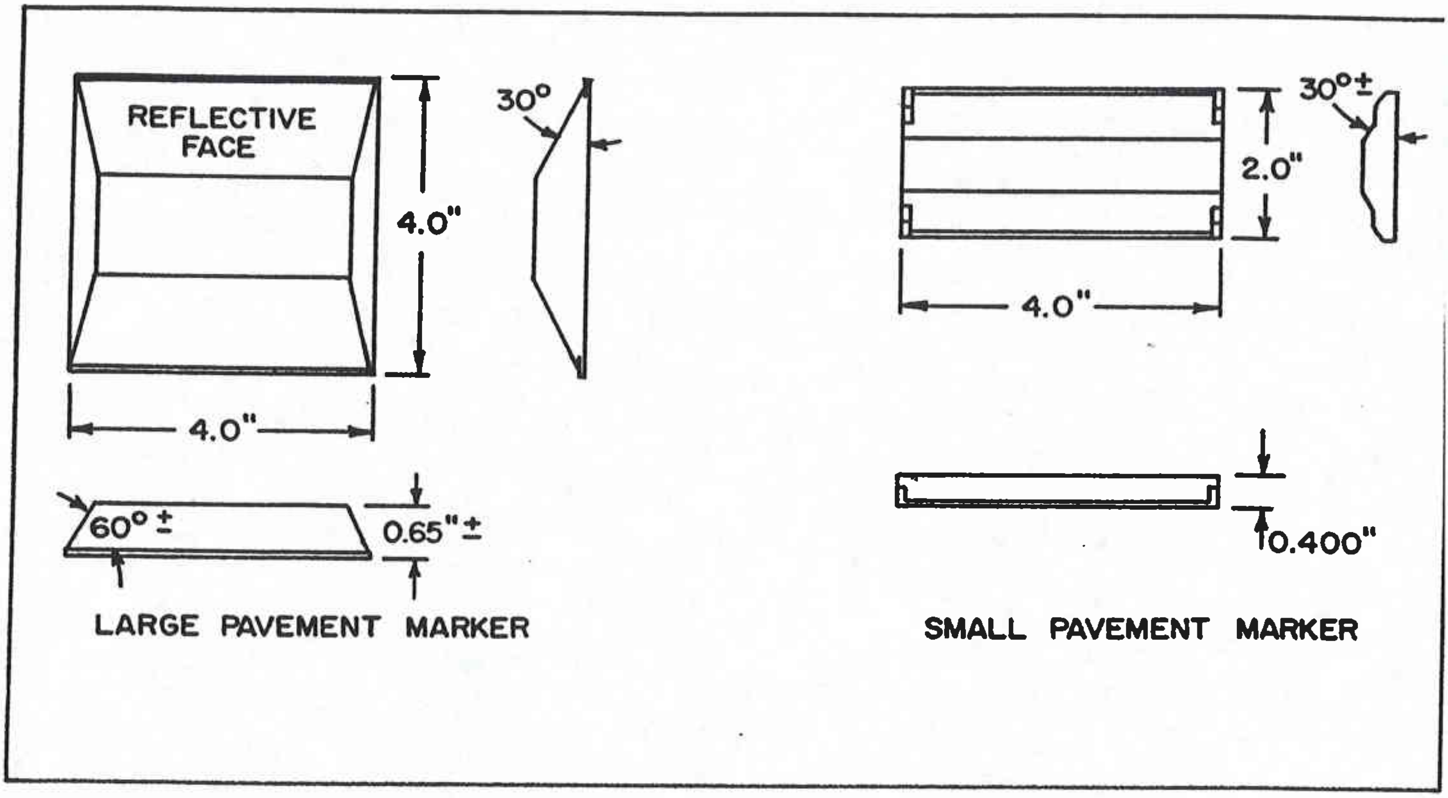

Figure 1. The Two Basic Shapes of RPMs Investigated During the Study. Both Stimsonite and Ray-O-Lite Make the Large Markers While Only Stimsonite Makes the Smaller Ones.

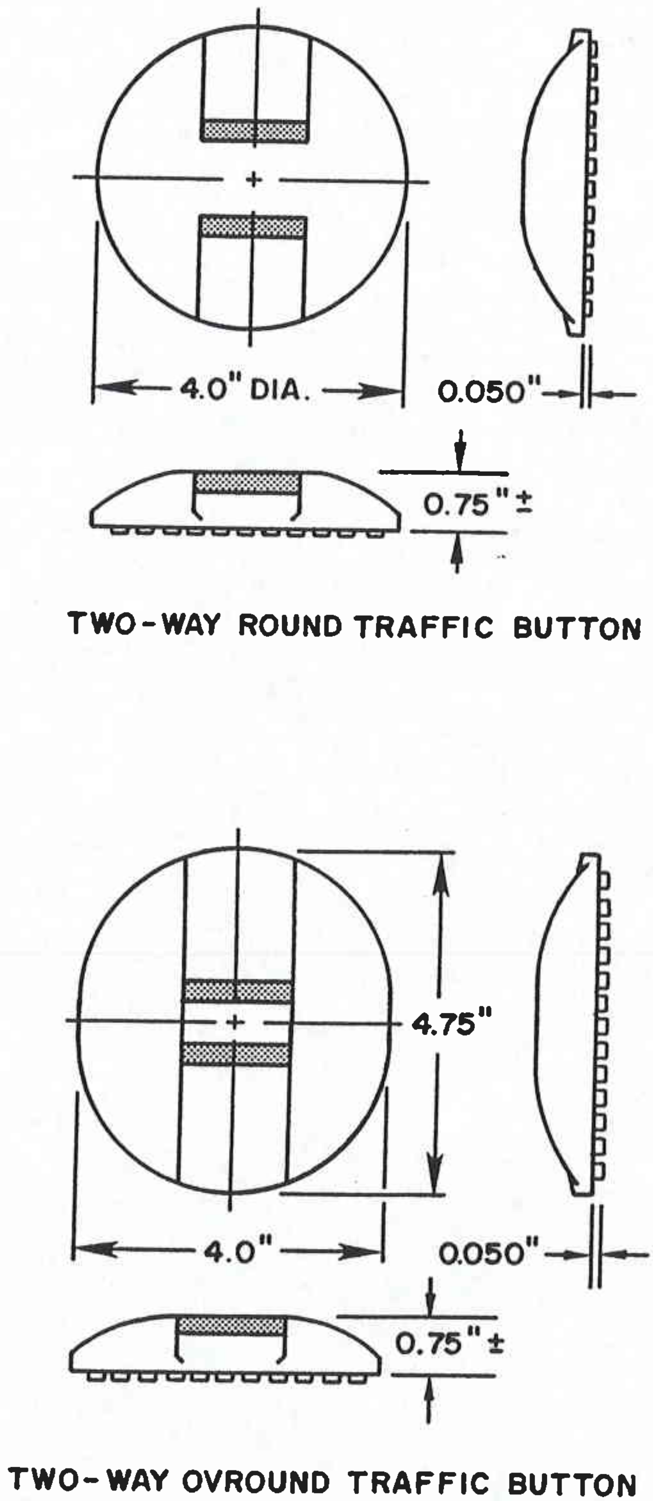

Figure 2a. The Four Basic Shapes of RTBs Investiagted During the Study.

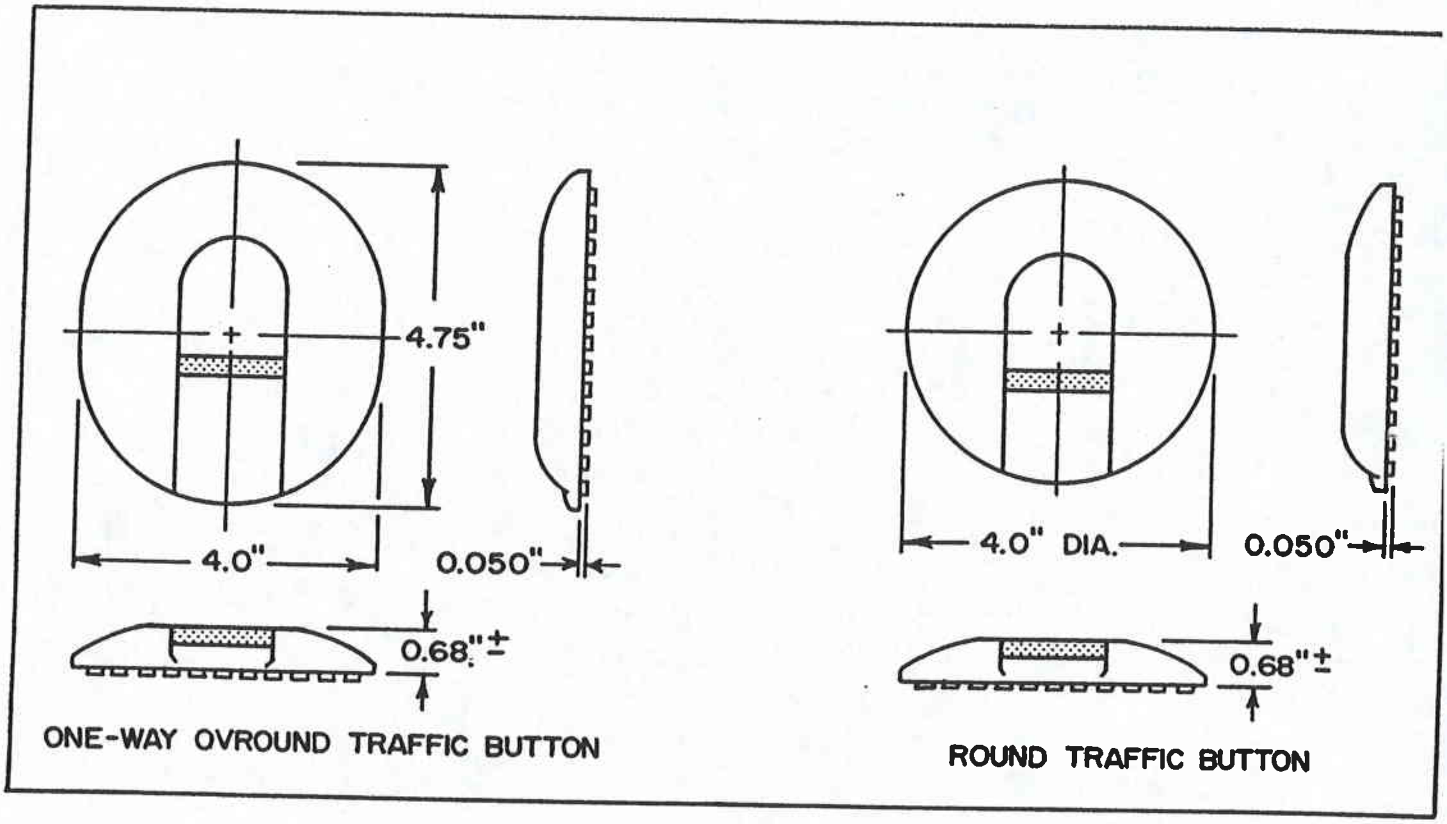

Figure 2b. The Four Basic Shapes of RTBs Investigated During the Study.

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

Manufacturers	Model	Width	Length	Height	Specific Intensity 0°	Specific Intensity 20°
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-O-Lite	28	4"	4"	.69"	3.0	1.2
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

Table 2. Unit Price Paid in Texas for RPMs by Year 1980-1982.

	1980	1981	1982
Plastic Markers (All 4"x4")			
Type I	1.02	0.98	0.94
Type II	1.10	1.16	1.08
Traffic Buttons			
Type I (Primarily P15s)	1.07	1.17	1.36
Type II (Primarily P17s)	1.16	1.19	1.29

APPROACH

The primary approach toward finding solutions to the retention and wear problems and, in turn, the service life cost was to make detailed observations and counts of the performance of markers across the state. These observations were made both by the researchers and by interested personnel in the SDHPT.

The data that resulted from these observations and counts were analyzed by plotting probability distribution "ogive" curves of percent remaining versus number of hits at each location. Physical characteristics and traffic characteristics at each location were obtained and used to evaluate the markers life as represented by the ogive curve. Appendix A describes the mathematical expression of the ogive curve and explains the pertinent parameters.

Then by using the same ogive curves it was possible to evaluate certain maintenance strategies to calculate the resulting service life costs. This was done by convoluting the original ogive curve for the markers not replaced with another curve starting anew for the markers that were replaced. Another way of saying this is that the original markers continue to disappear while the replacement markers will disappear at the same rate as the original markers, disappearing at the same rate as did the first markers when new.

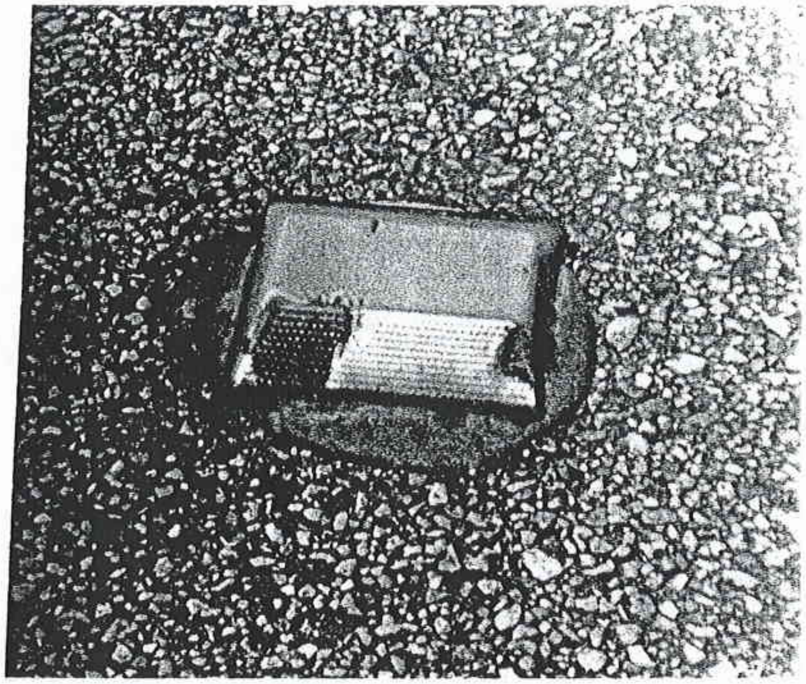

Figure 9. Badly Worn and Broken RPM, Type I-C.

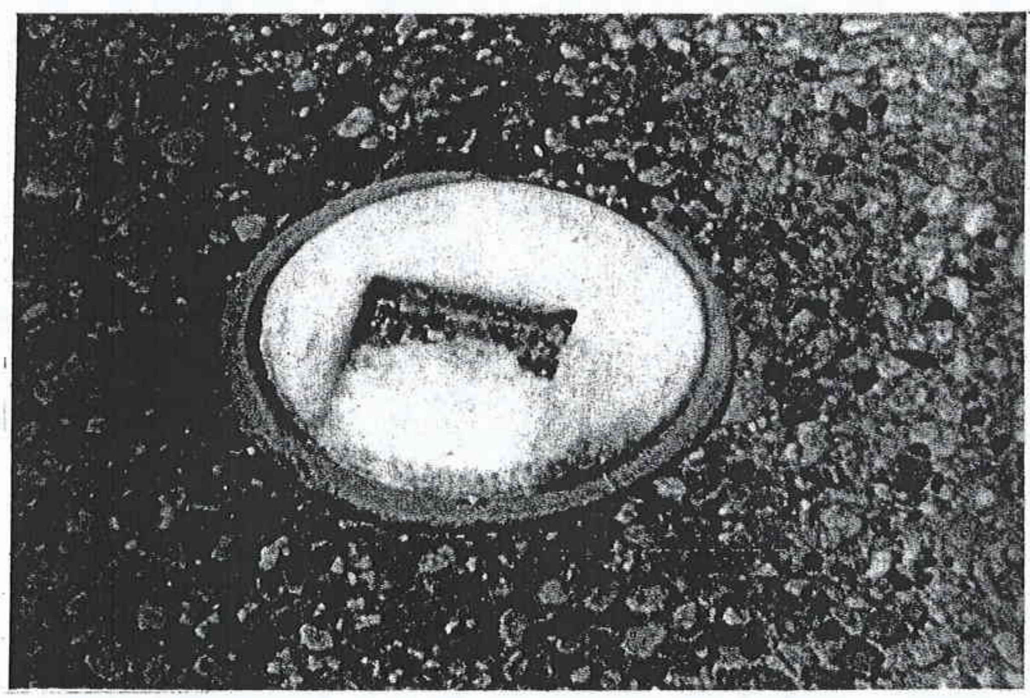

Figure 10. A RTB with the Reflective Lens Completely Missing.

MODES OF FAILURE

Several modes of failure were observed or reported as being especially significant during the project. The most common of these are summarized in Table 3 along with the pavement surface and the significant (or influential) parameters. The table also implies that the most important driving variables were found to be the number of impacts, especially truck impacts, and in a few instances time. One dramatic observation was that markers on the traffic side of a yellow center island stripe often quickly disappeared while those on the protected side remained largely intact. The number of impacts is related to the traffic count and the geometric location on the road. For example, actual observations of traffic behavior on a straightaway four lane, lightly traveled, road indicates about 1.5% of the wheels hit a lane line marker while only 0.5% hit a center line, amber, marker.

The listed parameters are essentially the factors we found to have a significant influence on the susceptibility of a given marker to failure due to the impacts received. Different parameters were found to be significant to each of the several modes of failure. The statistical tests are included in Appendix B.

The most common mode of failure was the disappearance of the RPMS on asphalt pavements due to a failure in the asphalt itself. Many hundreds of such RPMs observed during the field studies laying along the roadside and in the borrow ditch with a dome of apshalt from 1/4 to 1 inch thick adhering to the bottom of the epoxy pad. The research efforts failed to find a single asphalt property that was characteristic of pavements with higher loss rates.

RETENTION

There are several factors influencing RPMs retention. 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 RPM or RTB, prior to installation, was 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 (see Figure 3).

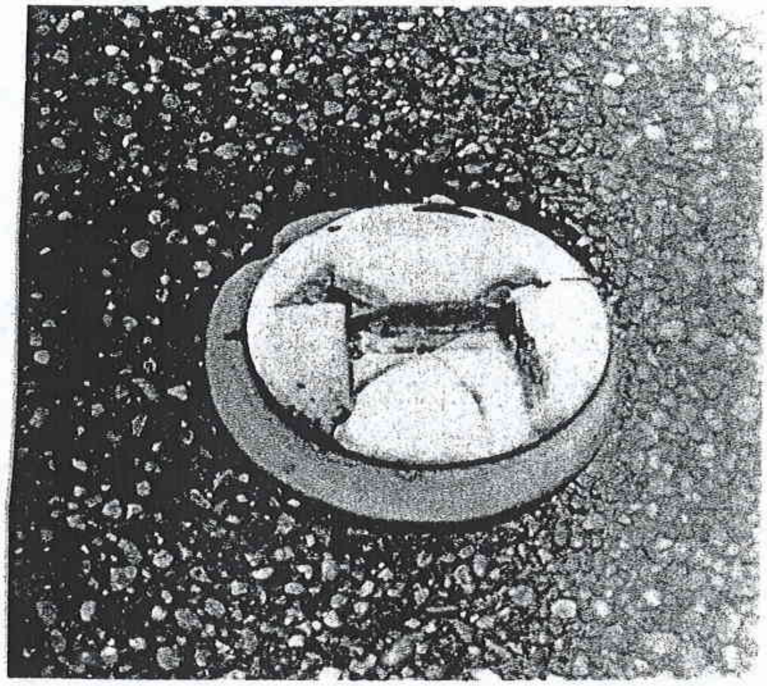

Figure 11. RTB, Type I-C, Badly Broken and Worn.
Lens is Completely Missing.

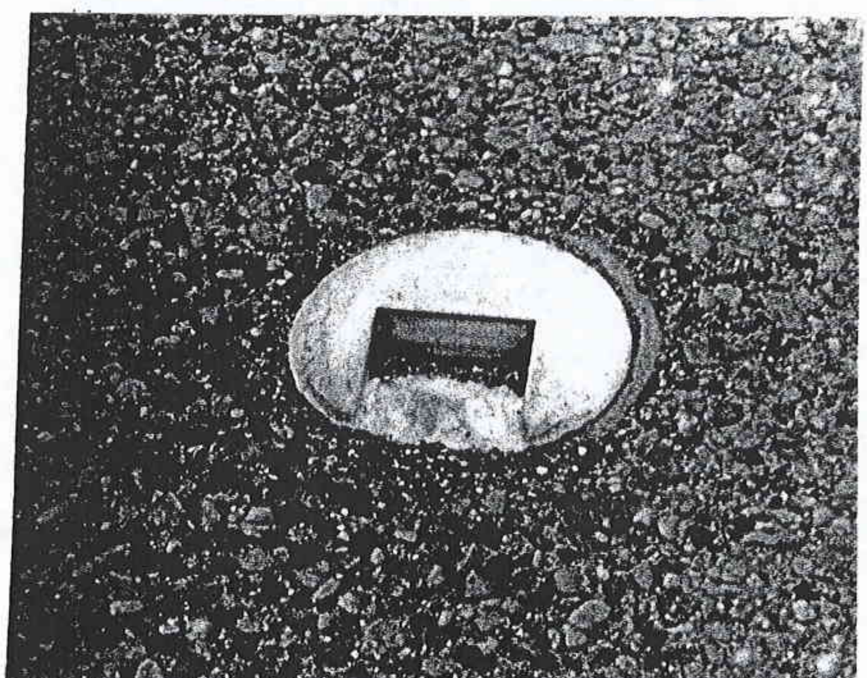

Figure 12. A RTB with the Lens Partially Obscured by Dirt.

Table 3. Observed Failure Modes With Most Important Independent Variables And Parameters.

Type Failure	Pavement Surface	Parameters	Independent Variables
Marker Loss (in pavement)	Asphalt	Season (maybe temperature) Moisture Type of Marker Green Asphalt Asphalt Properties Epoxy Pad Size	Impacts Truck Impacts Time
	Portland	Moisture Type of Marker Epoxy Pad Size PCC Properties Green PCC	Impacts Truck Impacts Time
Epoxy-to-Pavement Failure	PCC and Asphalt	Faulty Installation Type of Epoxy	Impacts Truck Impacts
Epoxy Failure	Rarely Observed		
Epoxy-to-Marker Failure	Immaterial	Faulty Installation Cleats Type of Epoxy Type of Marker Wet Porcelain	Impacts Truck Impacts
Marker Fracture	Asphalt	Type of Marker Temperature Type II CR Seam Welds	Impacts Truck Impacts
	Portland Cement Concrete	Type of Marker Temperature Type of Epoxy Type II CR Seam Welds	Impacts Truck Impacts
Marker Wearout	Immaterial	Type of Marker Marker Shape	Impacts Truck Impacts
Reflectivity Loss	Immaterial	Type of Marker Glass Coating	Impacts Truck Impacts

The three factors found to be most significant to retention failures were (1) deficient installation procedures, (2) defective (in some instances erratic and unexplained) epoxies and (3) weak pavement materials. Missing RPMs are a statewide problem and account for between 25% and 75% of the markers deemed to be ineffective. However, there is a 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 RTBs.

Evidence of installation errors was found statewide. Personal observations of the placement of markers on surfaces having loose dirt particles, using excessively darkened premixed epoxy, and using insufficient epoxy to completely cover the bonding surfaces were all noted. Figure 4 shows a RTB bonded over an existing paint stripe and Figure 5 shows a RPM over a seam between lifts in the asphalt. Similarly, Figure 6 shows a RPM with the bond surface so incompletely covered that a pocket knife blade can be inserted under a corner. Figure 7 illustrates one mode of failure that will result from this particular installation error.

Other installation errors include: sand blasting or grinding the bond surface too deeply before installing the marker, installing the markers in cold and/or wet conditions, pushing the marker too firmly onto the pavement surface (thus squeezing the epoxy out and away from the bond surfaces), installing markers on uncured concrete (both Portland Cement and Asphalt) and using inadequately mixed epoxy. All of these are common problems for both the Department and the marker vendors and can to a great extent be attributed to uninformed inspectors and installation personnel.

Less is known concerning the second factor: erratic epoxy behavior. Instances were found where many markers in a row had slid -- sometimes as much as 10 inches -- after they had been put into place. A streak of epoxy was evident over the entire path of one slide, indicating that the epoxy was behaving in a watery manner as though not fully cured. Figure 8 illustrates such a failure. Adjacent to these markers are other markers which did not slide. Inquiries indicated that both the materials and procedures were the same for both areas. A similar unexplained epoxy behavior, often observed, is a spreading of the epoxy around a marker to a width and thinness that is characteristic of a much less viscous material. This can be seen in Figure 9.

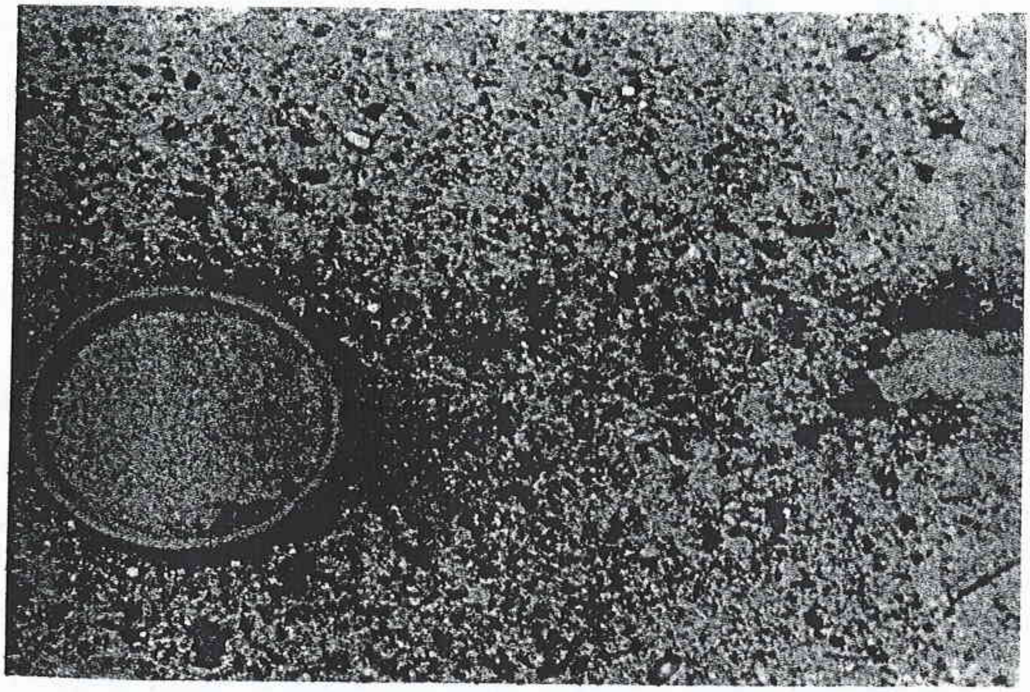

Figure 3. Two Types of Raised Pavement Marker Retention Failures. On the Left the RTB Cleanly Separated from the Epoxy. On the Right a Portion of the Portland Cement Concrete Pavement was Extracted with the RPM and Epoxy.

Figure 4. A RTB Bonded Over an Existing Paint Stripe.

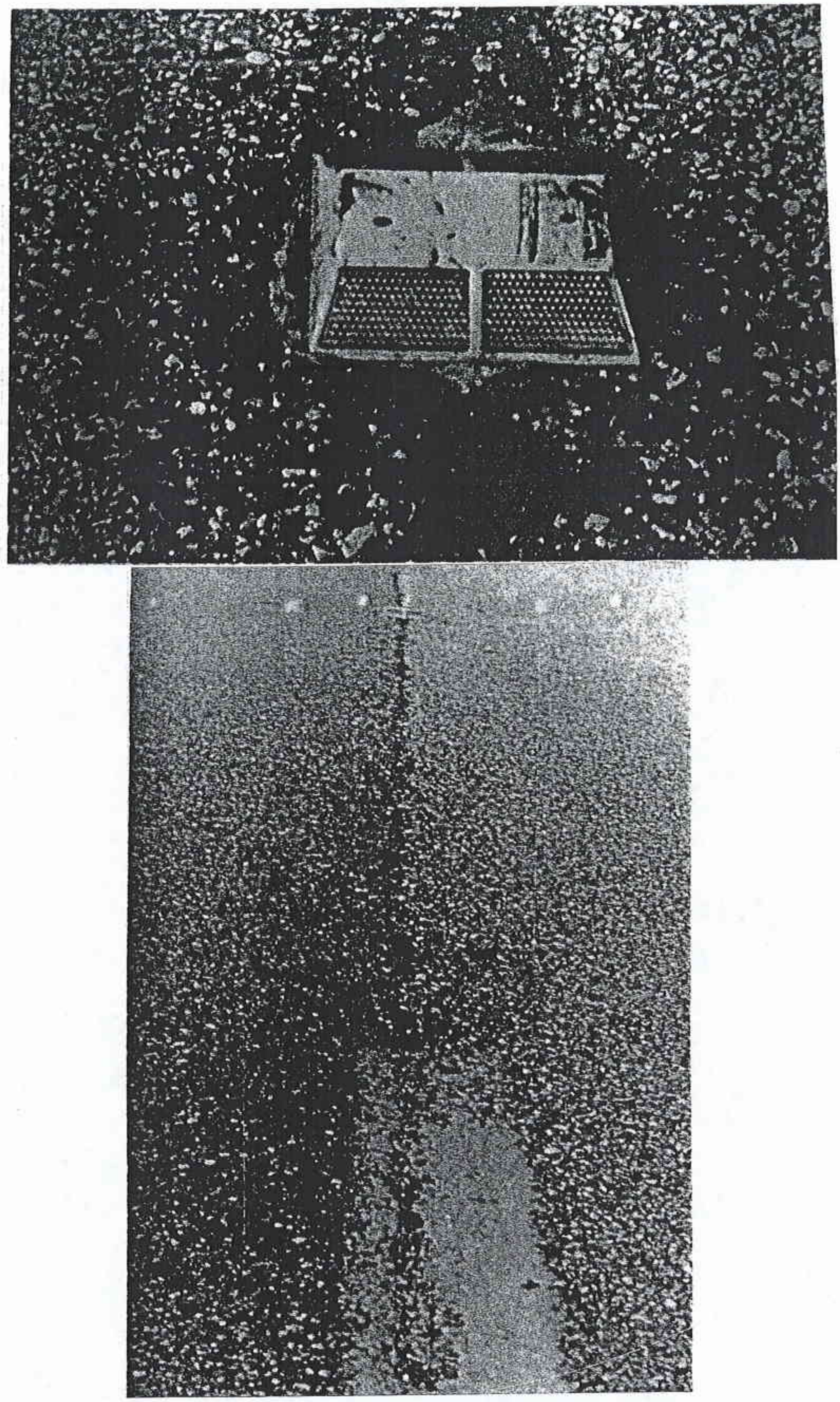

Figure 5. Two Views of a RPM, Type II-AA, Installed on the Seam Between Asphalt Lifts. Note the Poor Performance of the Paint Over the Seam.

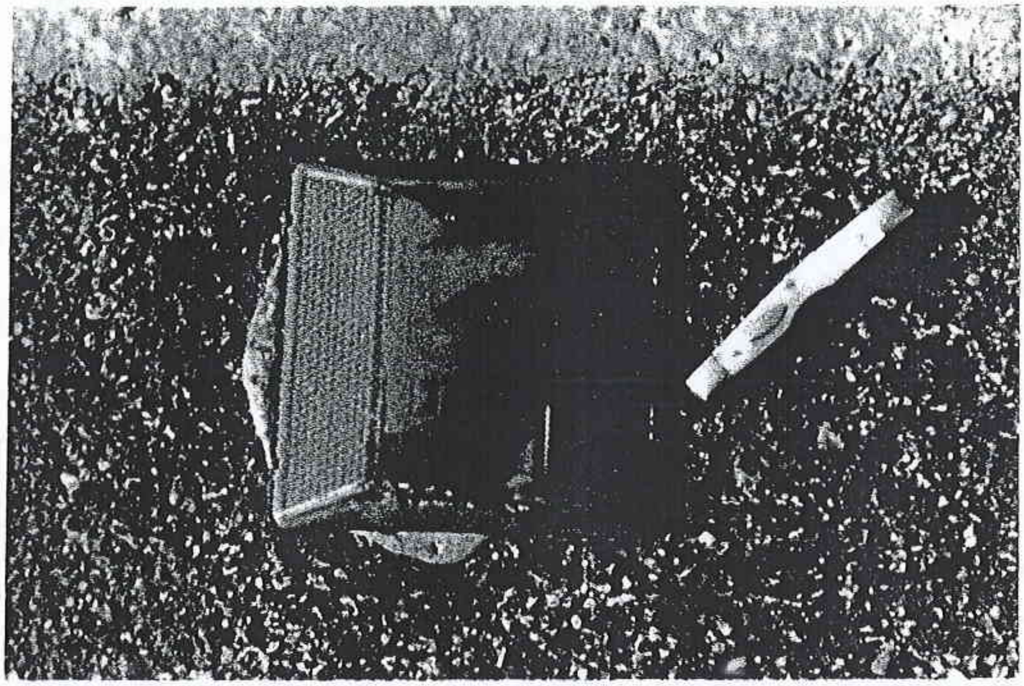

Figure 6. A Poorly Bonded RPM, Type II-AA. While Epoxy was Extruded from Two Sides it is not from the Other Two Leaving the Corners Unsupported.

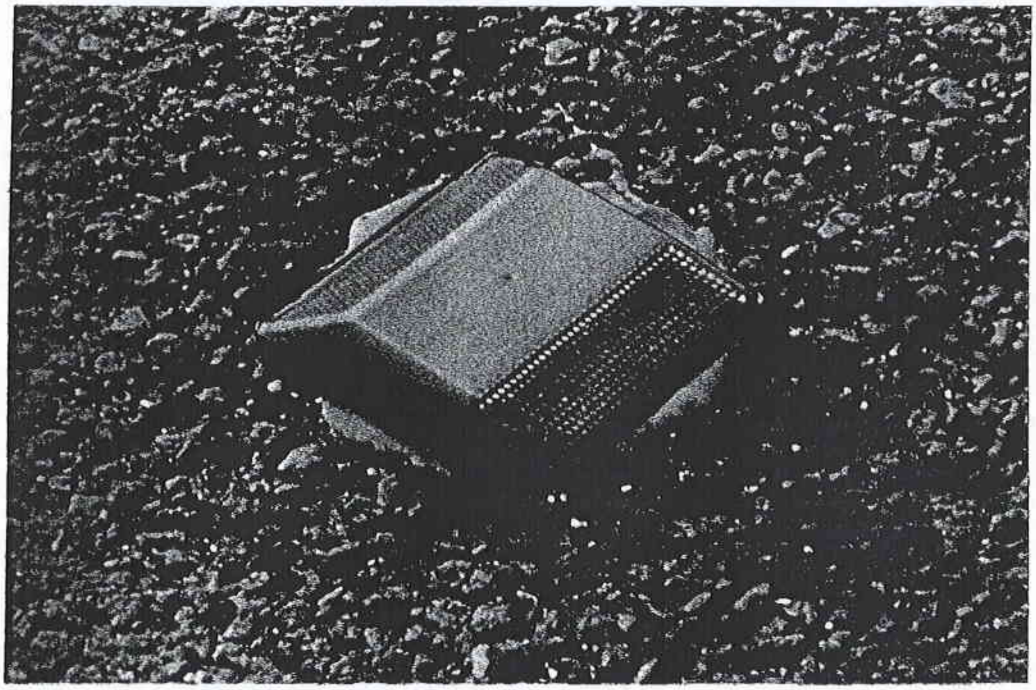

Figure 7. Improper Placement of the Epoxy Leaves the RPM Corners Unsupported and Susceptible to Failure as Shown.

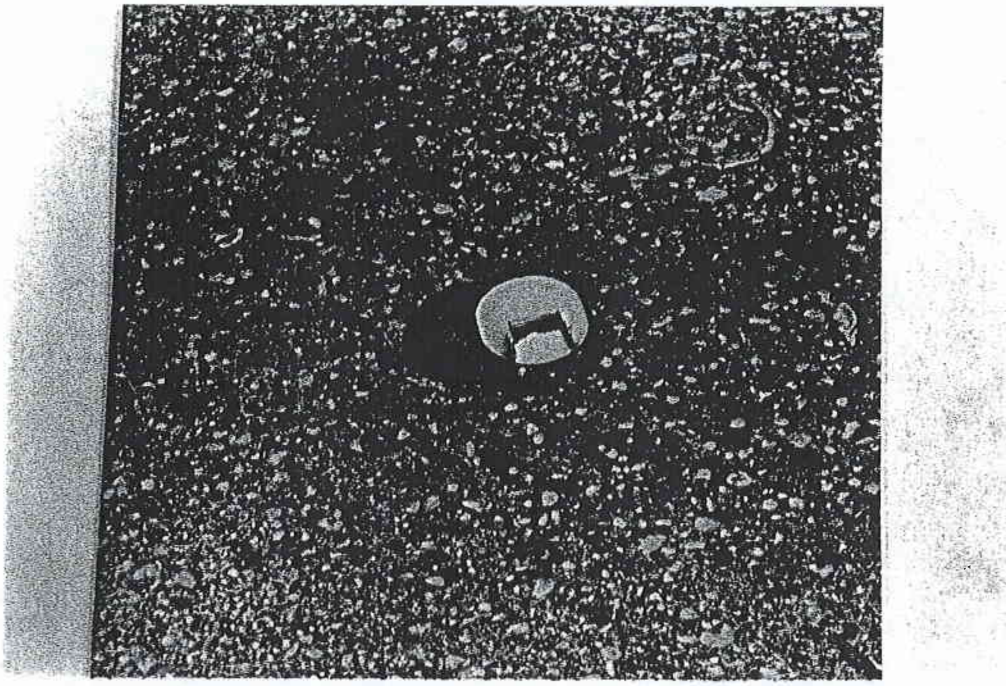

Figure 8. Photograph of a Sliding RTB Indicating the Epoxy did not Properly Cure.

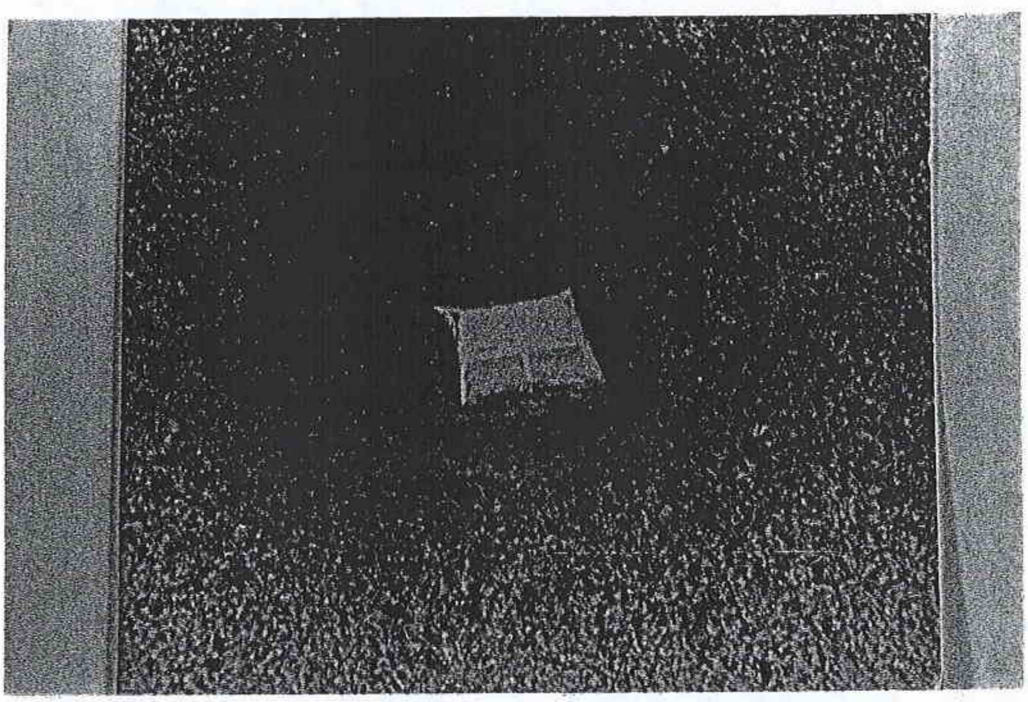

Figure 9. Photograph of a RPM Showing Excessive Flow of the Epoxy. Again Incomplete Cure is Suspected Although the Applicator May Have Used a Wide Putty Knife to Level the Excess Epoxy Obstructing the Reflector.

The most severe of the three factors is the loss of RPMs due to failure within the paving materials itself. While this is a problem with Portland cement concrete pavements, it is many times more severe on asphalt pavements. Here, too, the problem is complicated by erratic behavior from one location to another but it seems to be primarily a function of the mechanical properties of the asphalt. Observations made on IH 10 near San Antonio revealed the retention of markers on an asphalt concrete northwest of the city is excellent while the retention of similar markers on IH 10 east of the city is poor. These markers were installed by the same contractor essentially at the same time. Figure 10, a photograph taken in District 17, shows an extreme example of these types of failures and also gives convincing evidence that traffic wheel loadings are the primary dislodging factor.

WEAR AND LOSS OF REFLECTIVITY

A second related problem is a rapid drop in reflectivity which was observed between the newly installed markers and markers on the road for only a matter of months. This phenomenon was observed to be true for both the RPMs and the RTBs and was attributable to dirt and road film. The phenomenon is to some extent reversible during wet weather.

All markers showed a rapid deterioration with time and traffic. Structural deterioration accelerates the loss of reflectance. So wear and breakage are related to loss of reflectivity and indicate why lane line markers lose their effectiveness much faster than centerline markers and, to an even greater extent, faster than island markers. It was judged that traffic (the number of hits marker experienced) was a better indication of deterioration than time alone.

Examples of loss of reflectivity due to wear and breakage are plentiful wherever markers have been in extended service. Worn lenses (Figure 11), missing lenses (Figure 12), cracked bodies (Figure 13) and dirt-covered lenses (Figure 14) are more often the rule than the exception on Texas highways. Sometimes the reflectivity is degraded when the marker is pounded down vertically into the pavement as shown in Figures 15 and 16. Large rolls of extruded epoxy in front of the marker can similarly degrade its reflectivity.

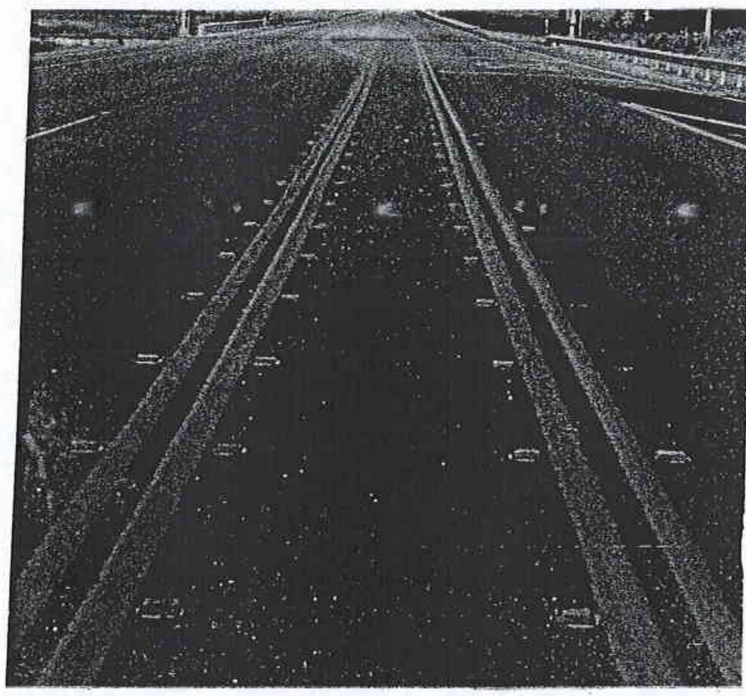

Figure 10. Photograph Showing the Influence of Traffic on Early RPM Loss. The RPMs Inside the Island and in the Turning Lane (on the left) Remain Intact While Those in the Traffic Lane (on the Right) are Missing. These RPMs have been in Place Three Months.

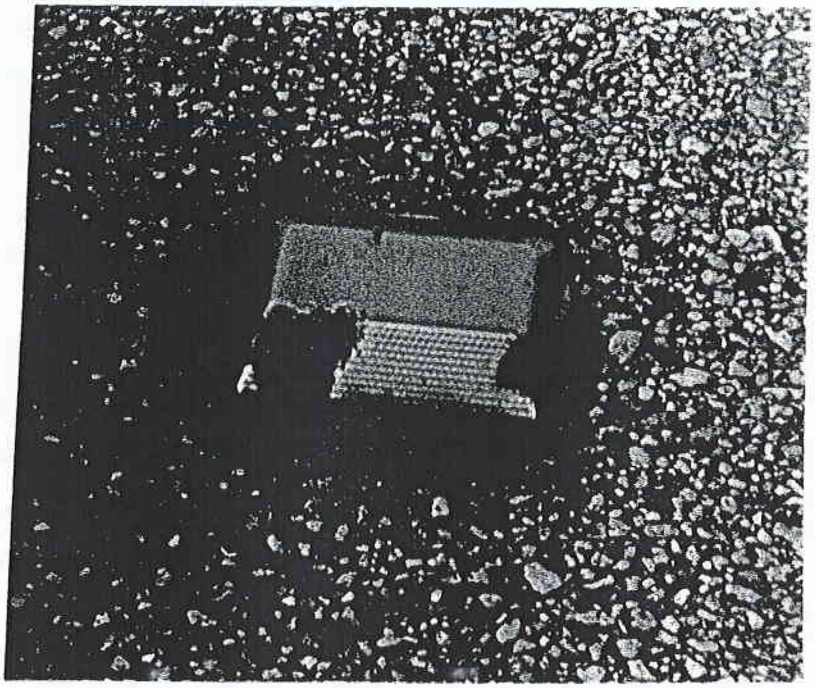

Figure 11. Badly Worn and Broken RPM, Type I-C.

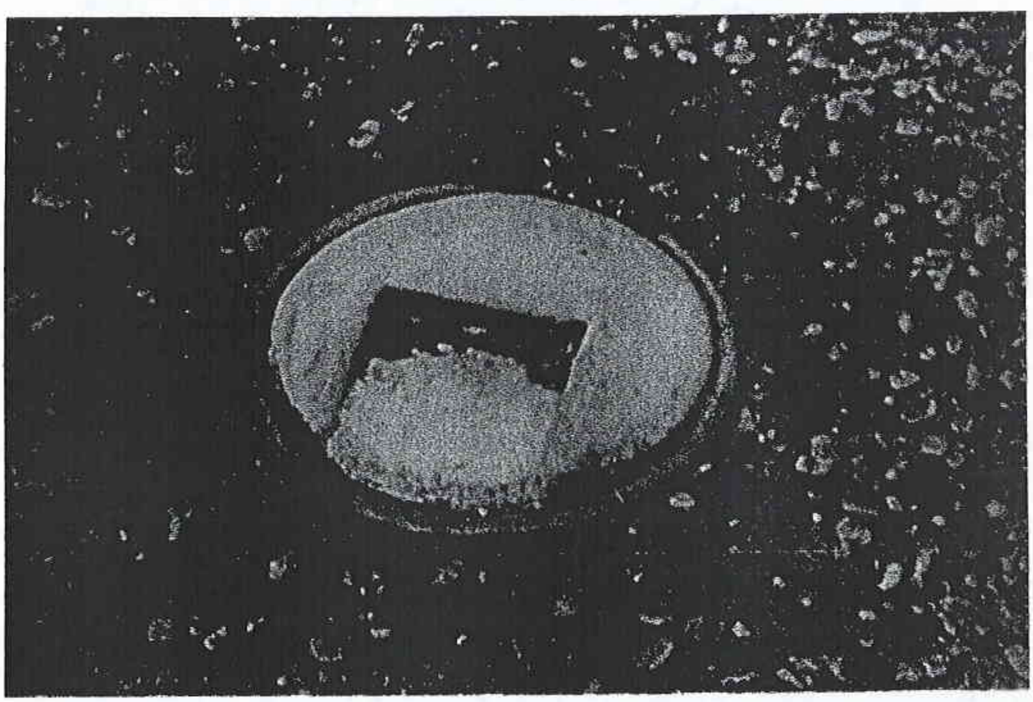

Figure 12. A RTB with the Reflective Lens Completely Missing.

Figure 13. RTB, Type I-C, Badly Broken and Worn. Lens is Completely Missing.

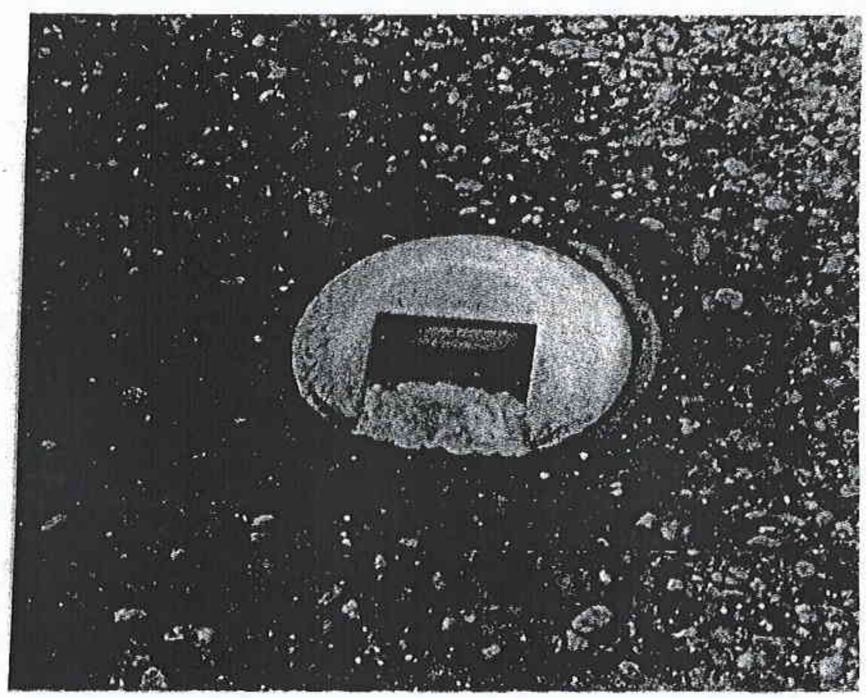

Figure 14. A RTB with the Lens Partially Obscured by Dirt.

Figure 15. A RTB Submerged Into the Asphalt Pavement.

Figure 16. 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.

One new aspect of the problem quickly became apparent. RPMs on asphaltic concrete pavements, with an added retention problem, had a higher breakage rate than on similar pavements without a retention problem. This was especially prevalent with the Type II RPMs which frequently had failures along the weld lines. These failures soon induced a loss of reflectivity. Softening of the filler in RPMs during very hot weather was reported as a rare, but real, mode of breakage.

PERFORMANCE OBSERVATIONS

The first step toward solving the marker retention and wear problem on the highways of Texas was to make personal observations of how the markers were performing. These observations were to be quantitative with the results to be used as a guide for further study.

Quantitative observations of this nature are relatively simple but somewhat subjective. Missing markers are easy to see and count in daylight. Undamaged markers are not quite so easy to see, but upon close inspection there would be little disagreement between reasonable observers as to which were damaged and which were not. Similarly there would be little disagreement during night inspections as to which of the markers were reflecting and which were not.

The difficulties arise during daylight inspections when it is necessary to evaluate the markers as "Effective" or at night as "Reflectivity Unimpaired". These determinations require judgement and reasonable people might reach different conclusions.

DALLAS - SAN ANTONIO STUDY

In March, 1977, a systematic two year study of the retention and durability of RPMs was initiated by the SDHPT at three select locations, one in Dallas and two in San Antonio. The one location in Dallas was on a six-lane divided highway (SH183 from Mockingbird Lane to near International Place), and the markers were placed on both the inside and outside lane lines. The two San Antonio locations (IH 10 from Fredericksburg Road southeast to IH 35, and IH 35 from the Stockyards south to IH 10) were both four-lane divided highways, and the markers were placed only as lane lines. While not always symmetrical in numbers, each type of marker was placed so as to be exposed to traffic in each direction at each test site. Seven different Type II-CR markers were selected for evaluations. They were:

1. Stimsonite RPM, manufactured by Amerace-Esna.
2. Stimsonite RPM with pressure sensitive adhesive backing.
3. New type Ray-O-Lite RPM with air-gap reflector, manufactured by Ray-O-Lite.

4. Old type Ray-O-Lite RPM with solid reflector.
5. Ray-O-Lite RPM with pressure sensitive adhesive backing. These markers also have air-gap reflectors.
6. Old type Permark low intensity reflectance RTB, manufactured by Ferro Corporation (Model P-17).
7. New type Permark high intensity reflectance RTB manufactured by Ferro Corporation (Model P-117).

Twelve and 24 months after the test markers were placed, counts were made of those judged to be missing, nonreflective, 25% reflective, 50% reflective and 75% reflective. It was assumed that all the others were undamaged. The types numbered 2, 3, and 5 performed poorly and, except as temporary markers for construction areas, are not currently used by the Department. The markers numbered 1, 4, 6 and 7 are still being used and the performance of each of these will be considered further.

The documents and data originally published by the Department are included as Appendix C.

To get a broad overview of the results, the performance of the RPMs (both the Stimsonite and Ray-O-Lite) and of the RTBs (Permark) were first plotted as a function of the number of vehicles passing in the adjacent two lanes (see Figures 17 and 18, respectively). Because the ADT at each test site was different this required the calculation of a weighted ADT appropriate for all the sites pooled together. Table 4 illustrates how this calculation was made. The average traffic in the two adjacent lanes at all the test sites were found to be 33,300 vpd (or 12.15×10^6 vpd).

Three different results were plotted as the average traffic in adjacent two lanes. They included 1) the percent of markers remaining in place, 2) the percent of markers undamaged, and 3) the percent of markers effective. The results numbered 1) and 2) are straightforward and reflect actual numbers counted on the roadway. The percent of the original markers remaining in place is shown by the top, heavy, solid curve, and the percent of the markers still undamaged is shown by the lower, lighter, solid curve. The number of markers effective, however, is more subjective. The effective markers take into account 1) the number of missing markers and 2) the reduction of reflectivity of the remaining markers. The reflectivity is standardized across all markers. These results are shown plotted on the graphs as a broken line. A perusal of Figure 17 and 18 indicates that the retention of the RTB

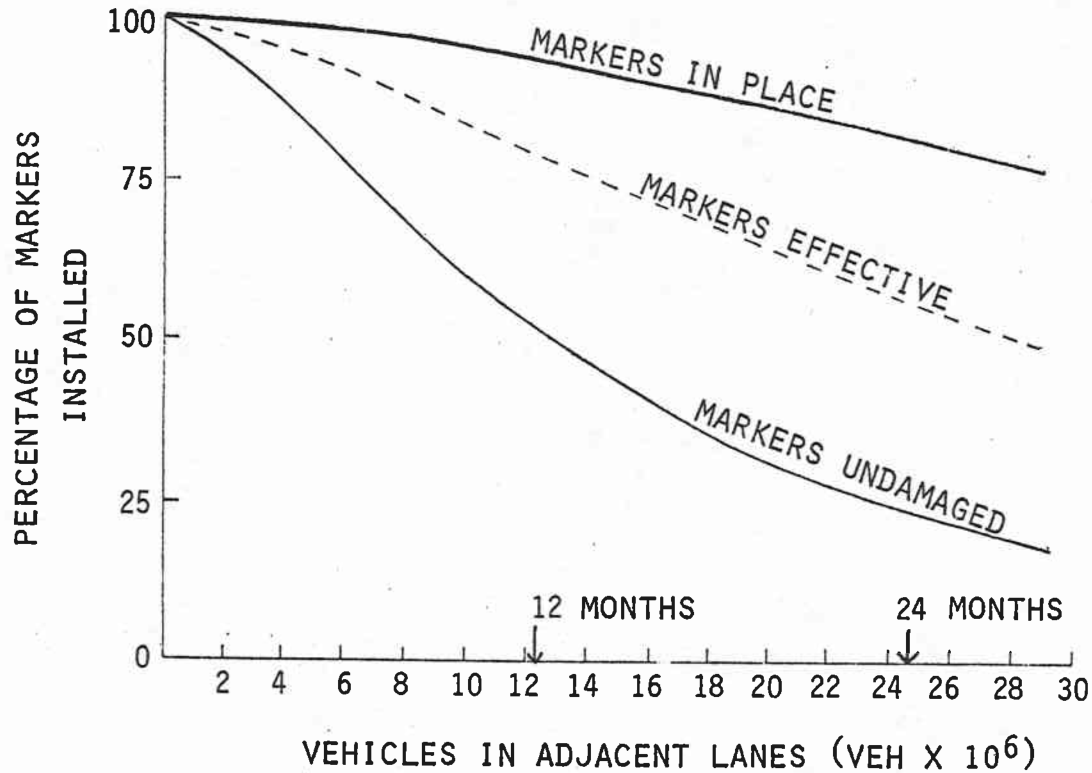

Figure 17. Curves Showing the Deterioration of RPMs (Both Stimsonite and Ray-O-Lite) Observed in the 1977 Dallas - San Antonio Study. The Average Daily Traffic in the Two Lanes Adjacent to the Markers was Assumed to be 33,300 VPD.

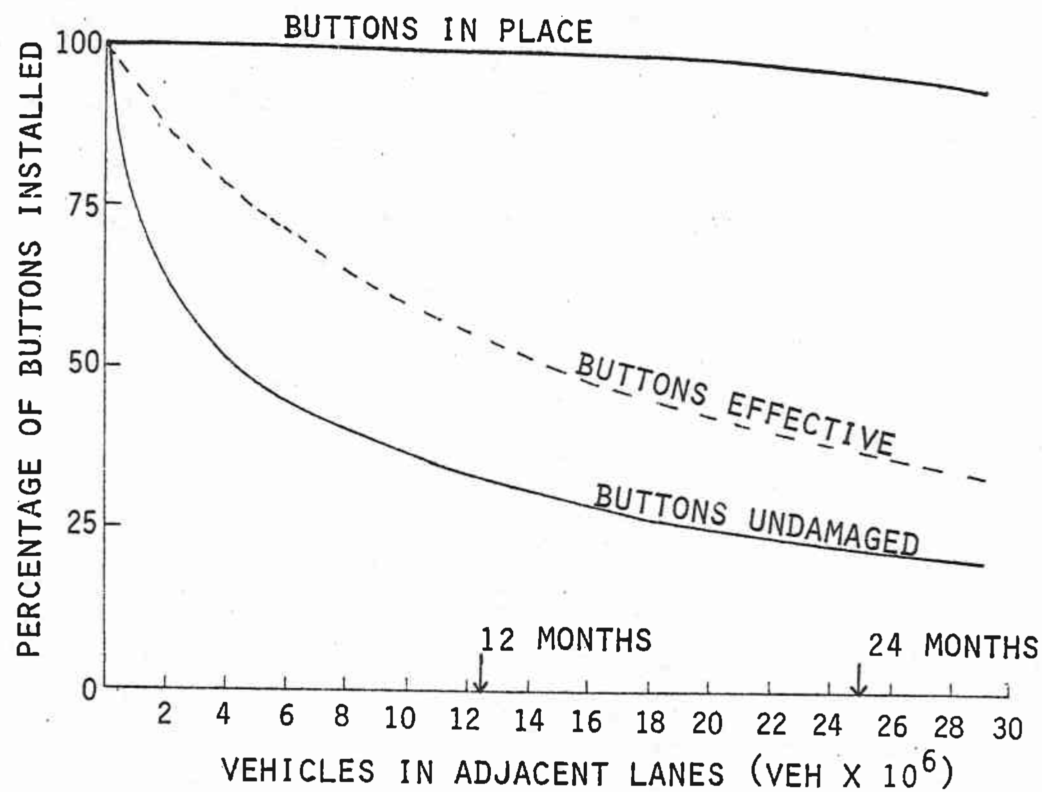

Figure 18. Curves Showing the Deterioration of RTBs (Permark P-17 and P-117) Observed in the 1977 Dallas - San Antonio Study. The Average Daily Traffic in the Two Lanes Adjacent to the RTBs was Assumed to be 33,300 VPD.

Table 4. 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)	Product Markers x Two Lane ADT
San Antonio						
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
Dallas						
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

$$\text{Weighted Average Daily Traffic} = \frac{7.95 \times 10^6}{239} = 33{,}300 \text{ vpd}$$

overall average in adjacent two lanes divided by the number of markers.

is better than that of the RPM but that the RPM performed better in terms of effectiveness.

RELATIVE PERFORMANCE OF MARKER TYPES

It is rare that different types and makes of markers are installed at the same time and location. But, because of the technical interest of a few SDHPT engineers it has occurred in several 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, each over a three mile segment of IH 10 east of San Antonio. Each of the markers were TY II-CR and were used to supplement the lane lines in both directions of the four-lane asphaltic concrete 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 18,500 vpd in both directions. The observations were made in July 1982. Approximately 4.22×10^6 vehicles had traveled down the two lanes on each side of the markers since they were installed. The data were taken from a moving automobile both during the day and at night.

The results of these observations are shown plotted against the summary curves from the Dallas - San Antonio study in Figure 19 for the 947s, Figure 20 for the 88s and Figure 21 for the P-117s. It is readily 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 demonstrates the conclusion, confirmed by other observations, that the RTBs are retained considerably better than the RPMs.

These data indicate the rather poor performance of all RPMs found on many of the asphalt concrete pavements in Texas. It is an extensive and expensive

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

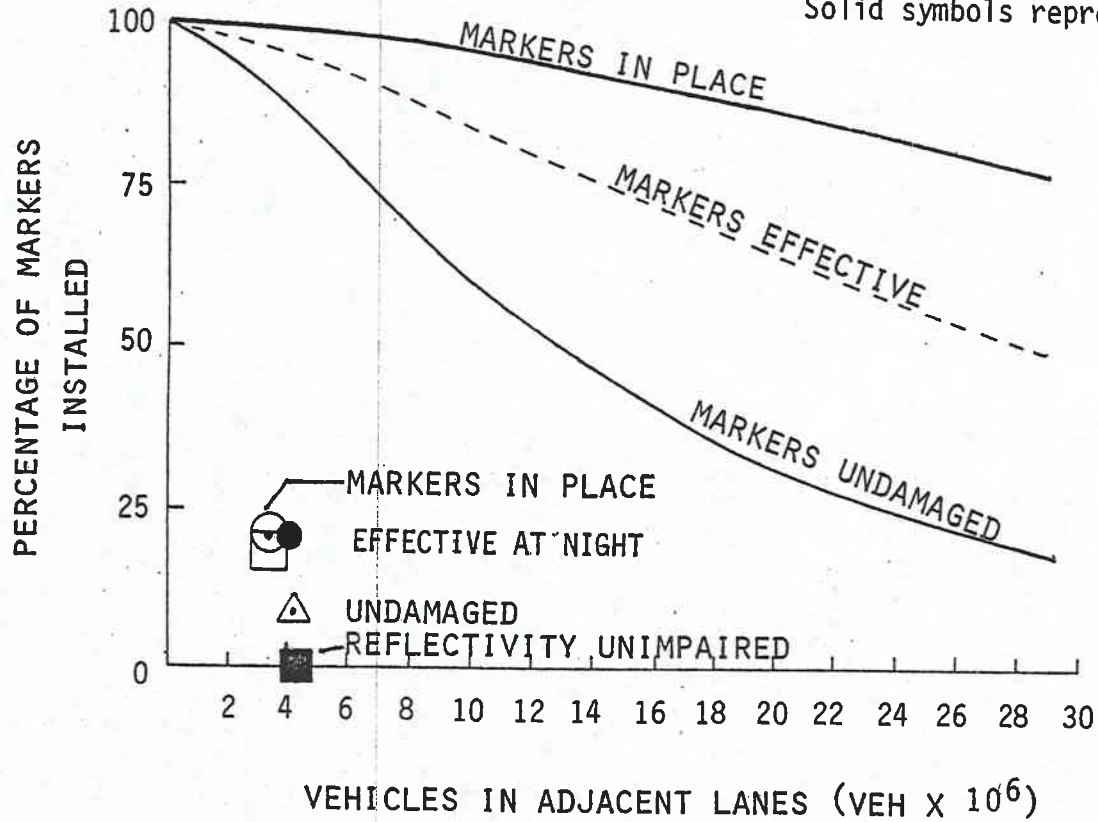

Figure 19. Observed Conditions of RPMs on IH 10 East of San Antonio (Both Directions) Compared to RPM Performance Reported in the 1977 Dallas - San Antonio Study.

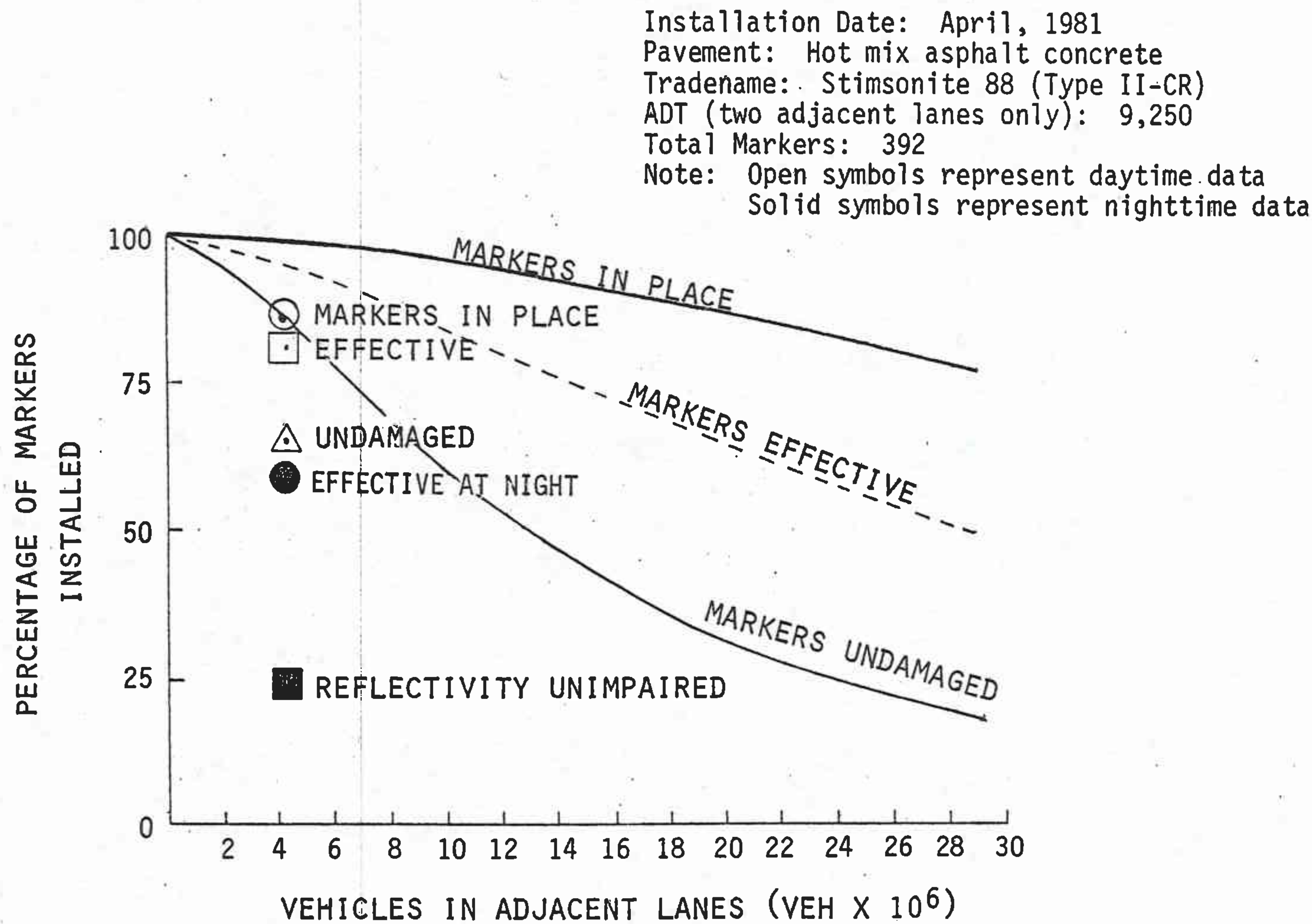

Figure 20. Observed Conditions of RPMs on IH 10 East of San Antonio (Both Directions) Compared to RPM Performance Reported in the 1977 Dallas - San Antonio Study.

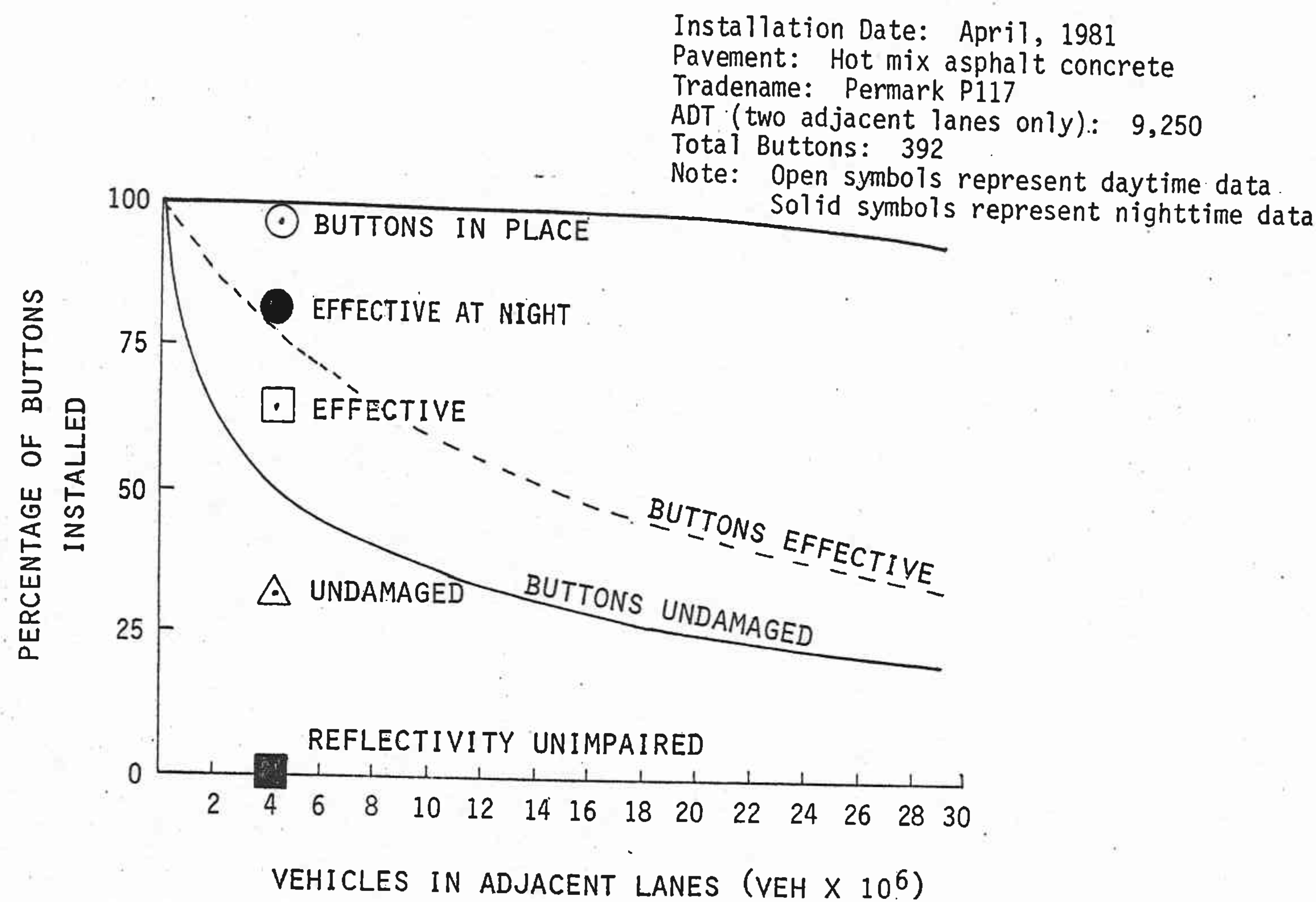

Figure 21. Observed Condition of RTBs on IH 10 East of San Antonio (Both Directions) Compared to RTB Performance Reported in the 1977 Dallas - San Antonio Study.

problem. However, the next section shows data from IH 10 northwest of San Antonio, which shows that markers on asphalt are not always such a serious problem.

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

These markers were placed by the same contractor that did the test markers east of San Antonio.

The results of a count of the performance of these markers is shown in Figure 22 and 23 for the RTBs and RPMs, respectively. This count was over an eleven-mile segment of the test section near Boerne, it involved more than 700 markers in each direction, and it represents by far the largest sample that was counted. It is readily apparent that the performance of these markers is superior even though the total traffic experienced has been small. Tentatively this is attributed to the difference in the properties of the two hot mix asphalt concrete pavements.

The types of markers were retained well so the superiority of the RTB retention properties over the corresponding RPM properties is not so obvious. However, the susceptibility of the reflecting element of the RTBs to early damage is obvious.

The most striking conclusion that can be drawn from this data is that when good retention is observed there is a parallel improvement in the resistance to breakage and wear. This conclusion was found universally to be valid when comparing marker performance on asphalts.

RPM PERFORMANCE ON ASPHALT CONCRETE

District 14 count of RPMs on SH 71 near the entrance to Bergstrom Air Force Base again reflects their poor performance on some asphalts. These results, (first for eastbound four lanes (west) of the Bergstrom Main Gate and

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

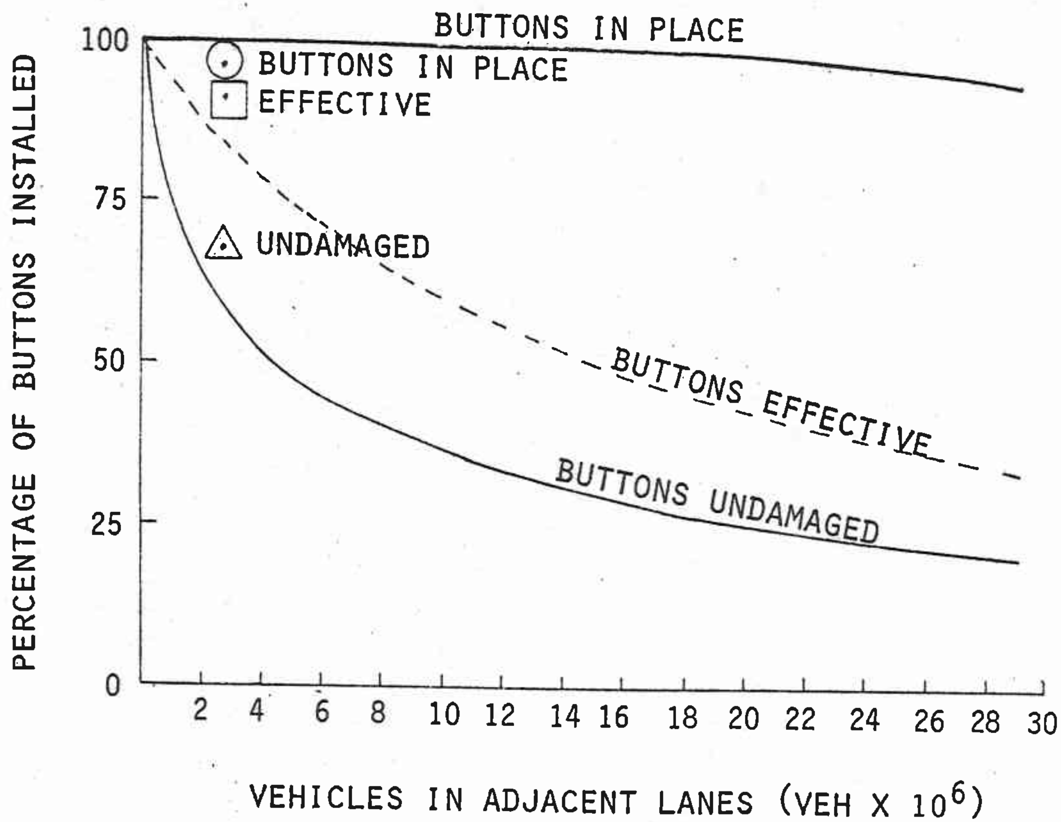

Figure 22. Observed Condition of RTBs on IH 10 Northwest of San Antonio (Westbound) Compared to RTB Performance Reported in the 1977 Dallas - San Antonio Study.

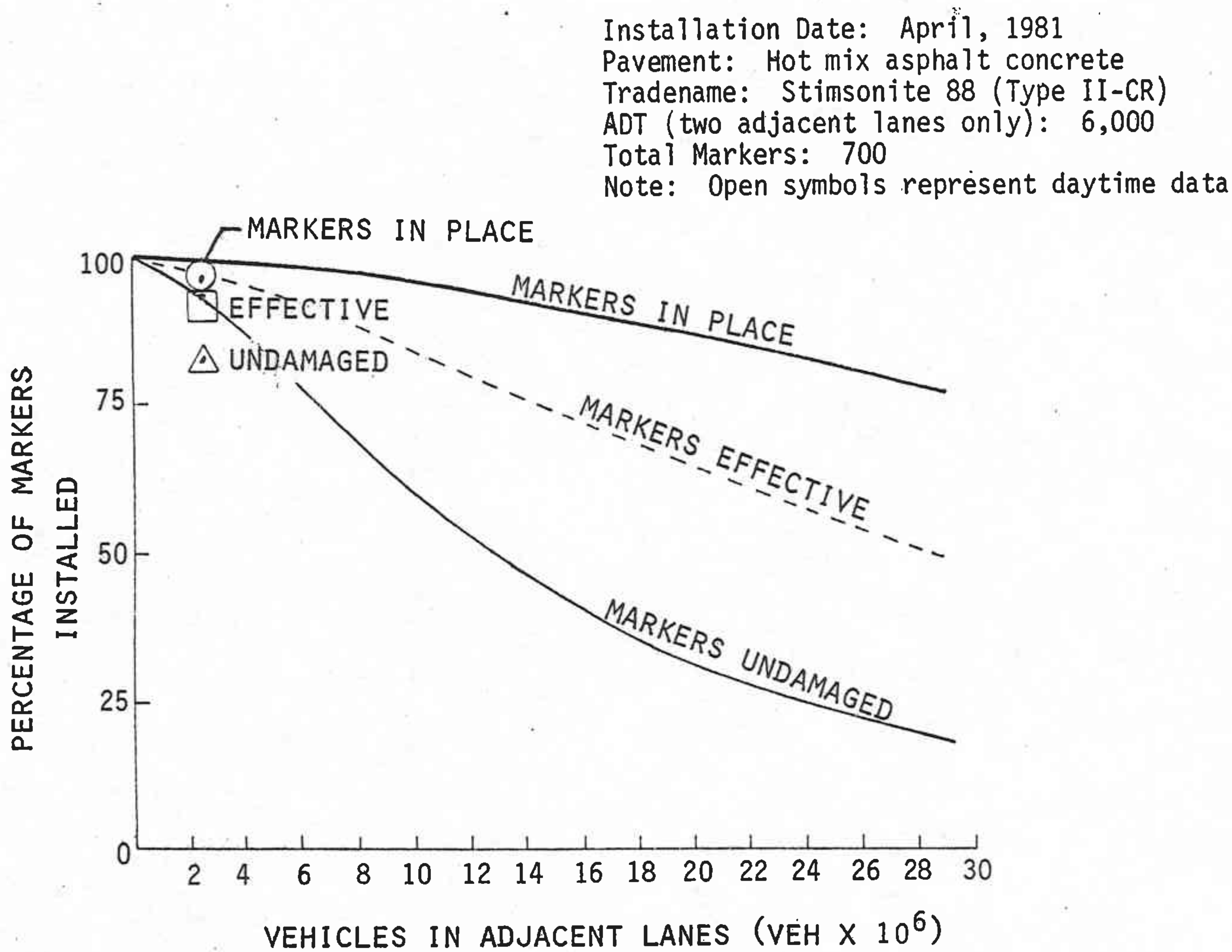

Figure 23. Observed Condition of RPMs on IH 10 Northwest of San Antonio (Eastbound) Compared to RPM Performance Reported in the 1977 Dallas - San Antonio Study.

second for the eastbound two lanes (east) of the Main Gate), are shown in Figure 24 and 25, respectively. The RPMs were all installed at about 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 percent of those remaining were judged ineffective. The observation that low effectivity occurs parallel with poor retention on asphaltic pavements is a recurring one.

The erratic behavior of asphalt concrete is again shown by the points plotted in Figures 26 and 27. These data, collected by District 14, shows the performance of RPMs on the eastbound and westbound lane lines of US 290 east of Austin. The traffic counts of both lanes were made in August, 1978, and both lines of RPMs were placed in June, 1979.

In the eastbound direction more than three times as many markers are missing than westbound. This could be due to the trucks being either loaded or empty. While a comparable number of RPMs were judged effective in both directions the number rated as damaged in the eastbound direction was nearly double that of the westbound.

This type of erratic and unexplainable behavior is more characteristic of asphalt pavements than those of Portland cement concrete.

RPM PERFORMANCE ON PORTLAND CEMENT CONCRETE

To provide an indication of the overall performance of the 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 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, one lane line at a time, and, as would probably be expected, the outside line showed slightly more distress than the inside line. In Figure 28 the combined results for all lane lines in both directions are shown.

It is interesting, and informative, that 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 while 35% of the RPMs are missing, only 2% were attributed to pavement failures. The raw data are reported in detail in Appendix E. The

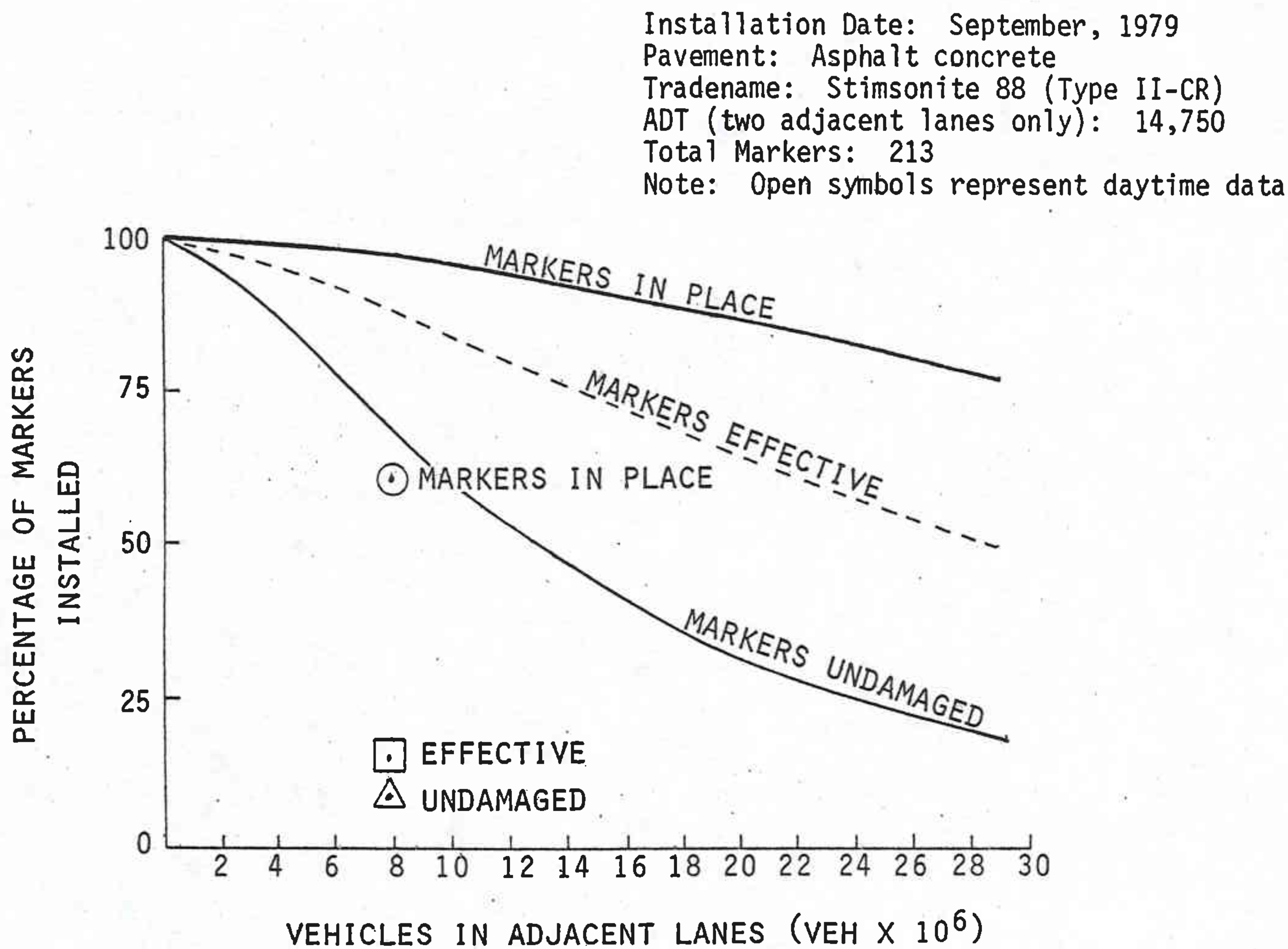

Figure 24. Observed Condition of RPMs on SH 71 West of the Bergstrom Main Gate (Eastbound) Compared to RPM Performance Reported in the 1977 Dallas - San Antonio Study.

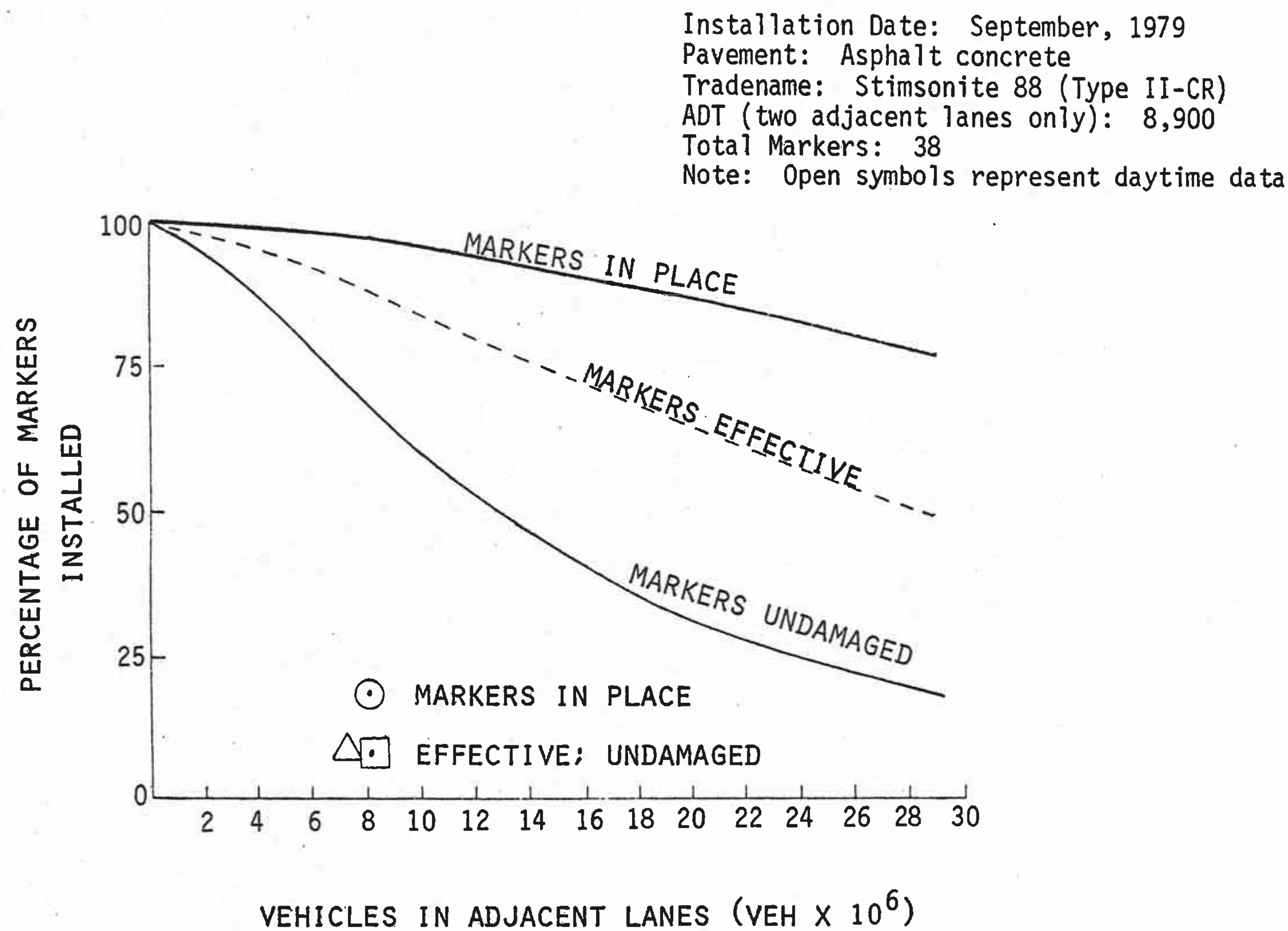

Figure 25. Observed Conditions of RPMs on SH 71 East of the Bergstrom Main Gate (Eastbound) Compared to RPM Performance Reported in the 1977 Dallas - San Antonio Study.

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

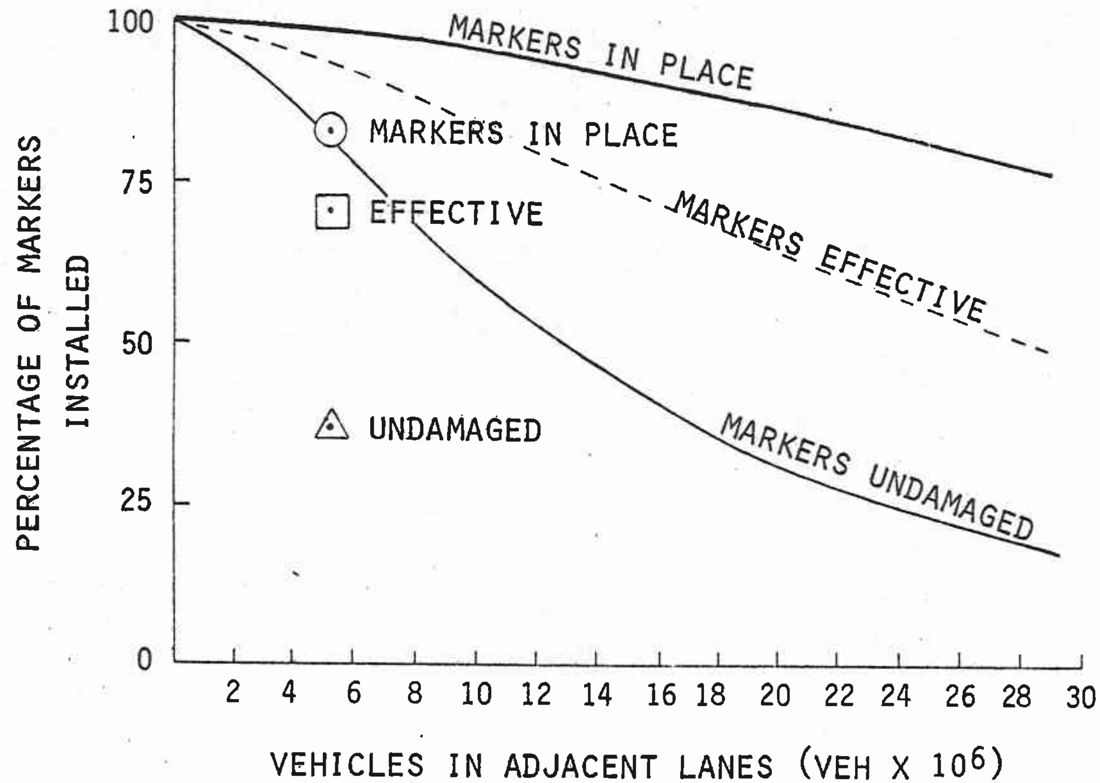

Figure 26. Observed Consitions of RPMs on U.S. 290 East of Austin (Eastbound) Compared to RPM Performance Reported in the 1977 Dallas - San Antonio Study.

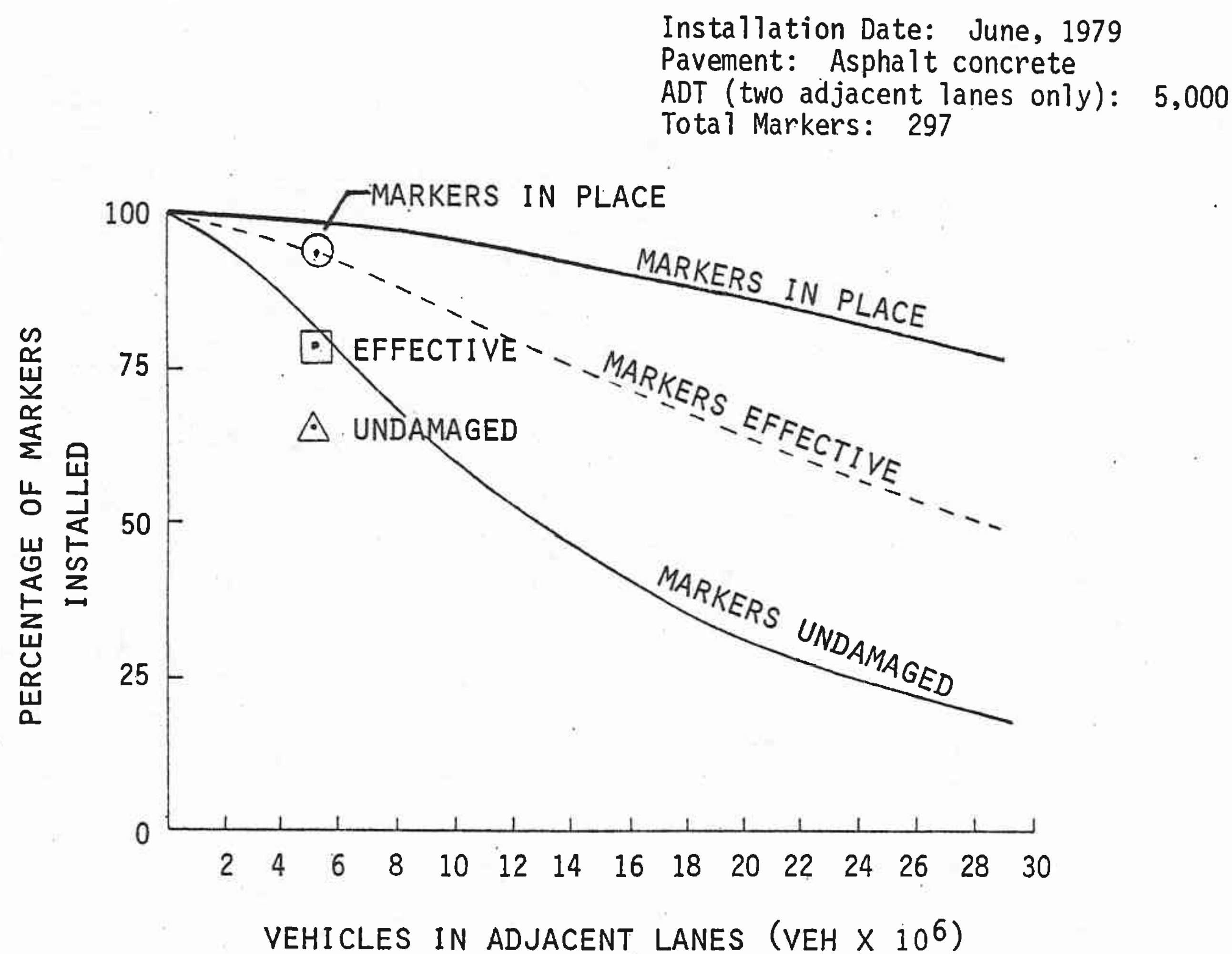

Figure 27. Observed Condition of RPMs on U.S. 290 East of Austin (Westbound) Compared to RPM Performance Reported in the 1977 Dallas - San Antonio Study.

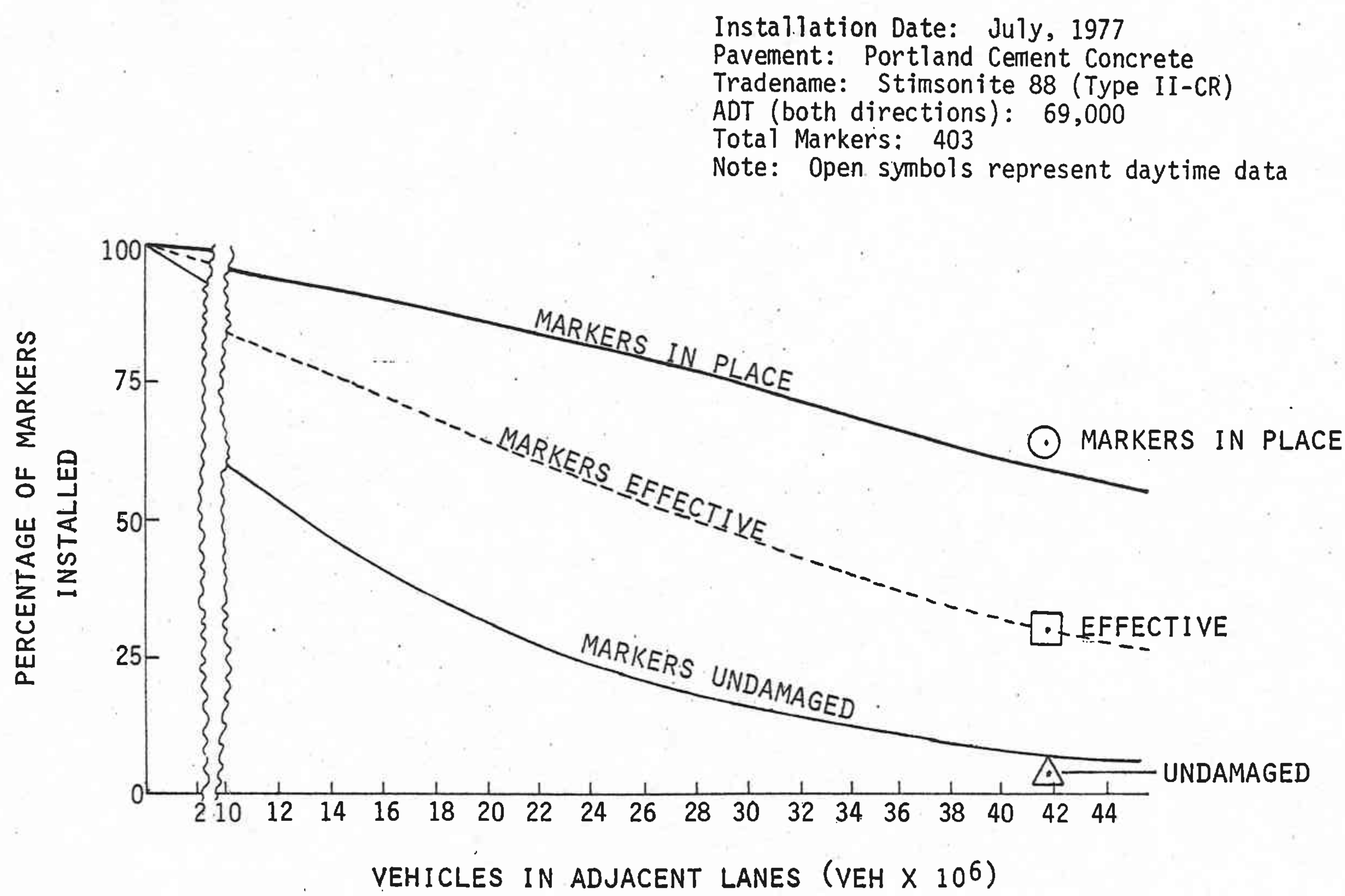

Figure 28. Observed Condition of RPMs on IH 10 West of Houston (Both Directions) Compared to RPM Performance Reported in the 1977 Dallas - San Antonio Study.

remaining 33% was judged to be about equally divided between marker-to-epoxy failures and epoxy-to-pavement failures.

SUPERIOR RTB PERFORMANCE

District 14 produced an example of superior RTB performance on lower and upper levels of IH 35 in Austin. The RTBs were used to form the lane line stripes; in this instance Type II-CRs for the lead RTB and three Type I-C equally spaced to form the remainder of the 10 foot stripe. Figure 29 shows the results for Type IIs, Figure 30 for Type Is on the upper level concrete pavement, Figure 31 for the Type IIs and Figure 32 for the Type Is on the lower level asphalt pavement.

In all instances the RTB retention performance was superior, though the Type IIs did not fare as well as the Type Is. This could have been due to the inherent fragility of the two-way RTBs compared to those reflecting in only one direction. It is suspected that the two-way, especially the round ones (P-117), are more susceptible to fracturing than the one-way. 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 RTBs could almost be labeled incredible, especially those on Portland cement concrete. After the passage of eight years and 80 million vehicles more than 87% were judged effective and 74% undamaged. Less than 1% were missing. The low percentage of truck traffic (5.4%) is undoubtedly a mitigating parameter. Nonetheless this was by far the most impressive marker performance observed during the project.

So it is not impossible to make the markers, especially RTBs, give long and satisfactory service.

MARKERS IN URBAN AREAS

The urban area performance of raised markers is especially critical because of the high cost and, more importantly, the safety risks associated with their maintenance. Generally the urban markers are outperforming those on more lightly traveled roads of the state at least in terms of surviving a number of hits.

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

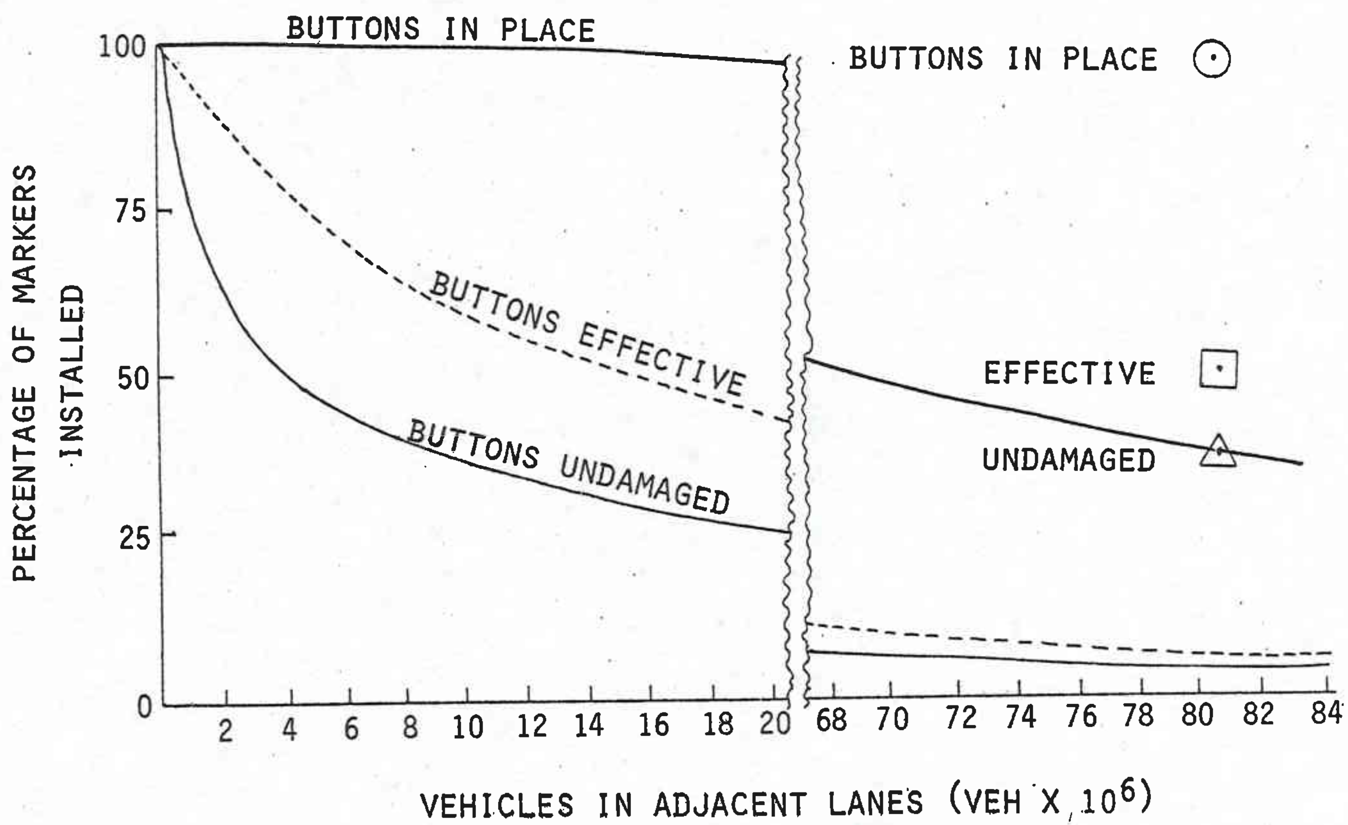

Figure 29. Observed Condition of RTBs on IH 35 Upper Level in Austin (Northbound) Compared to RTB Performance Reported in the 1977 Dallas - San Antonio Study.

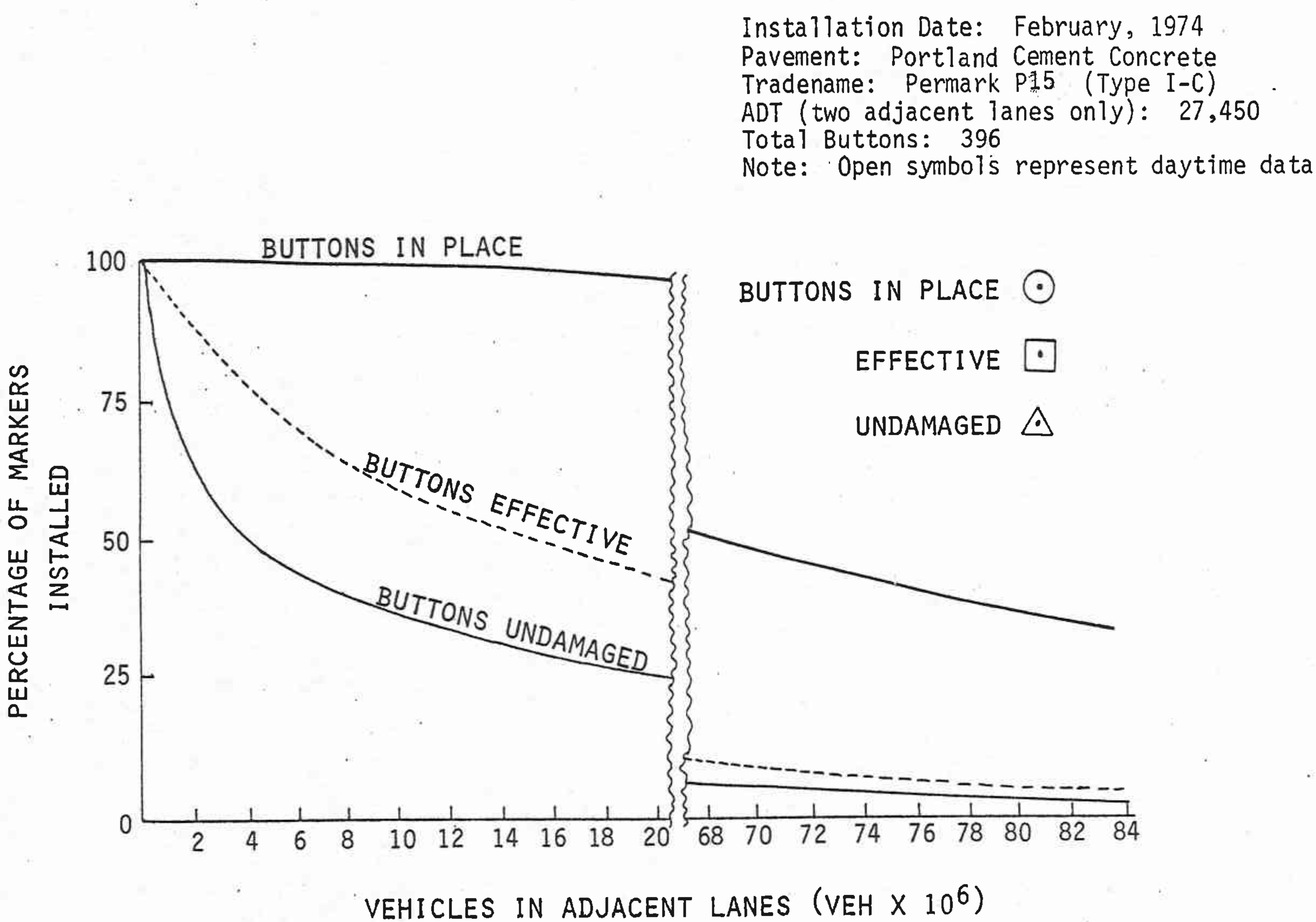

Figure 30. Observed Conditions of RTBs on the IH 35 Upper Level in Austin (Northbound) Compared to RTB Performance Reported in the 1977 Dallas - San Antonio Study.

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

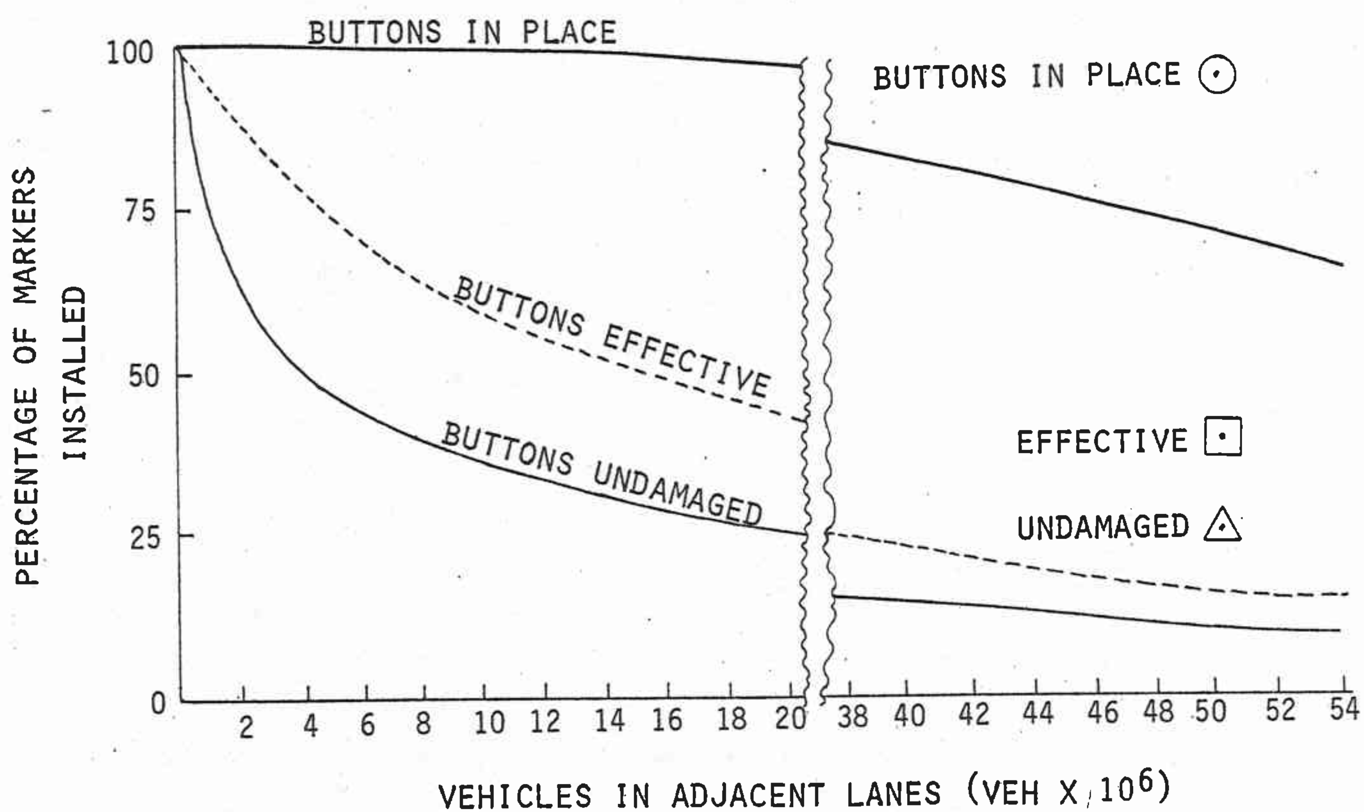

Figure 31. Observed Condition of RTBs on IH 35 Lower Level in Austin (Southbound) Compared to RTB Performance Reported in the 1977 Dallas - San Antonio Study.

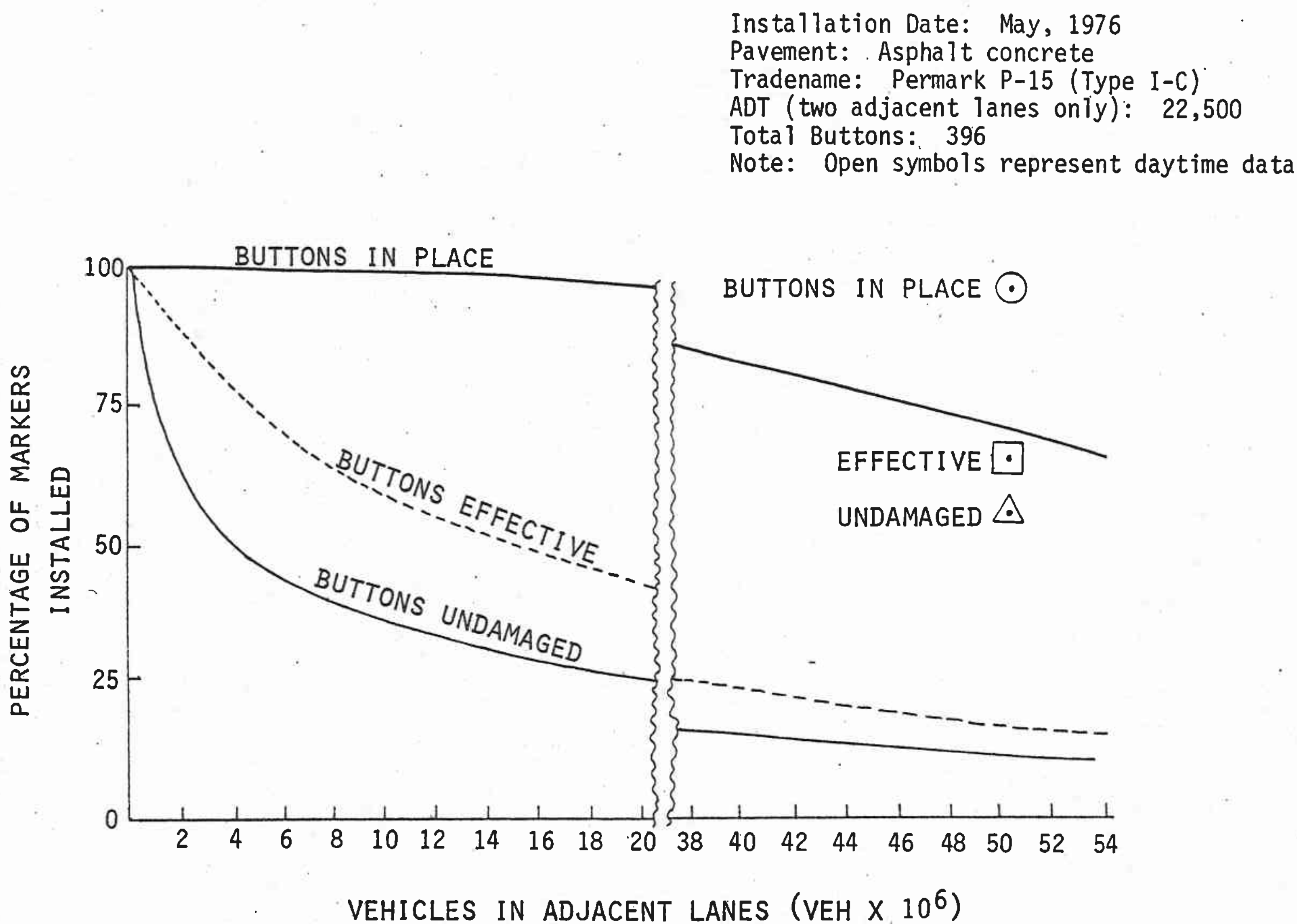

Figure 32. Observed Condition of RTBs on IH 35 Lower Level in Austin (Southbound) Compared to RTB Performance in the 1977 Dallas - San Antonio Study.

Data was taken concerning the performance of RPMs on IH 45 in downtown Houston between the intersection with Allen Parkway and IH 10. On the four southbound lanes both Stimsonite 88s and Ray-O-Lites were installed in June, 1980. The four northbound lanes have only Stimsonite 88s which were installed in June, 1981. Figures 33 and 34 reflect these findings. The markers were found to be performing better than those from the earlier Dallas-San Antonio Study.

SUMMARY OF RPM AND RTB OVERALL PERFORMANCE

RPM (4x) and RTBs have about equal loss rates as indicated in Figure 35a. The mean rates are not statistically significantly different as indicated in Figure 35b. This contrast is equally valid for asphaltic concrete and portland cement concrete. Retention on Portland cement concrete is significantly better than for asphaltic concrete. The observed mean loss percentage per million vehicles in the two adjacent lanes is 4 to 5 percent on asphaltic concrete and one percent or less on Portland cement concrete.

The 2x4 RPMs on asphaltic concrete exhibited a significantly higher loss rate than the other two marker types. The average was 19 percent per million vehicles in the two adjacent lanes, and the 90 percent confidence interval is very small (see Figure 35b). Even from the limited data available, there can be little doubt the rate of loss of the 2x4 RPMs is dramatically higher than the other marker types. These data suggest that the 947 markers are not retained as well as the 88s or RTBs.

Figures 36a and 36b present the retention properties of both RPMs and RTBs on both portland cement concrete and asphalt concrete, respectively. RPMs performance on PCC is good, however, the performance on AC is very poor. Virtually all of the RPM will be removed from the road surface with 50 million vehicles using the facility. The data used to develop these figures were the counts of RPMs and RTBs made during the study period and did not take into account the 1976-77 study performed by the Texas SDHPT. These figures categorize effectiveness by retention and reflectivity. The reflectivity curve was developed using sites in which photometric readings were obtained. The PCC sites were to be in the Houston area however it was not possible to stop traffic to obtain the photographs or photometric readings. The effectiveness levels used were those developed during the study. Figure 36a when compared

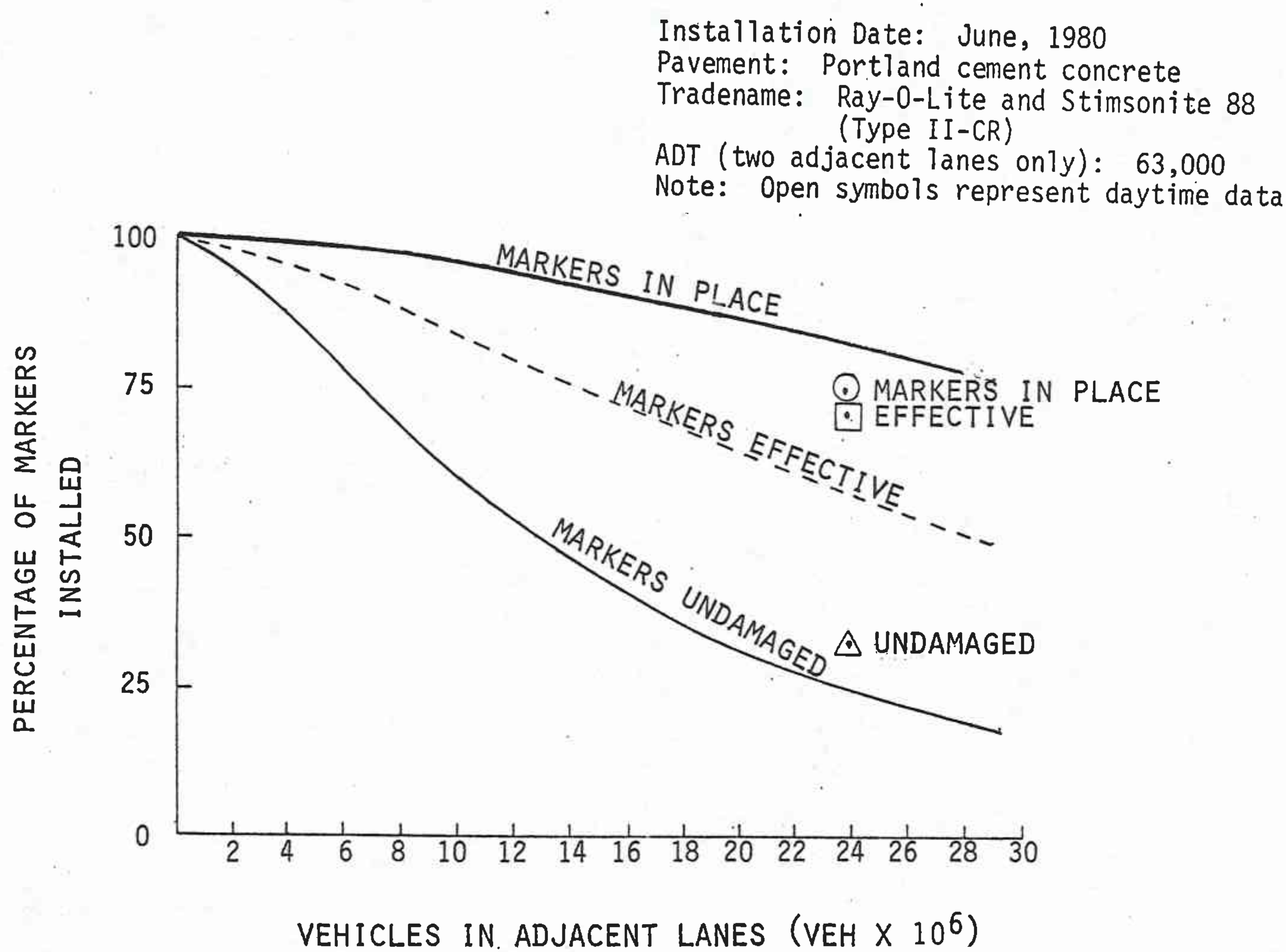

Figure 33. Observed Condition of RPMs on IH 45 in Downtown Houston (Southbound) Compared to RPM Performance Reported in the 1977 Dallas - San Antonio Study.

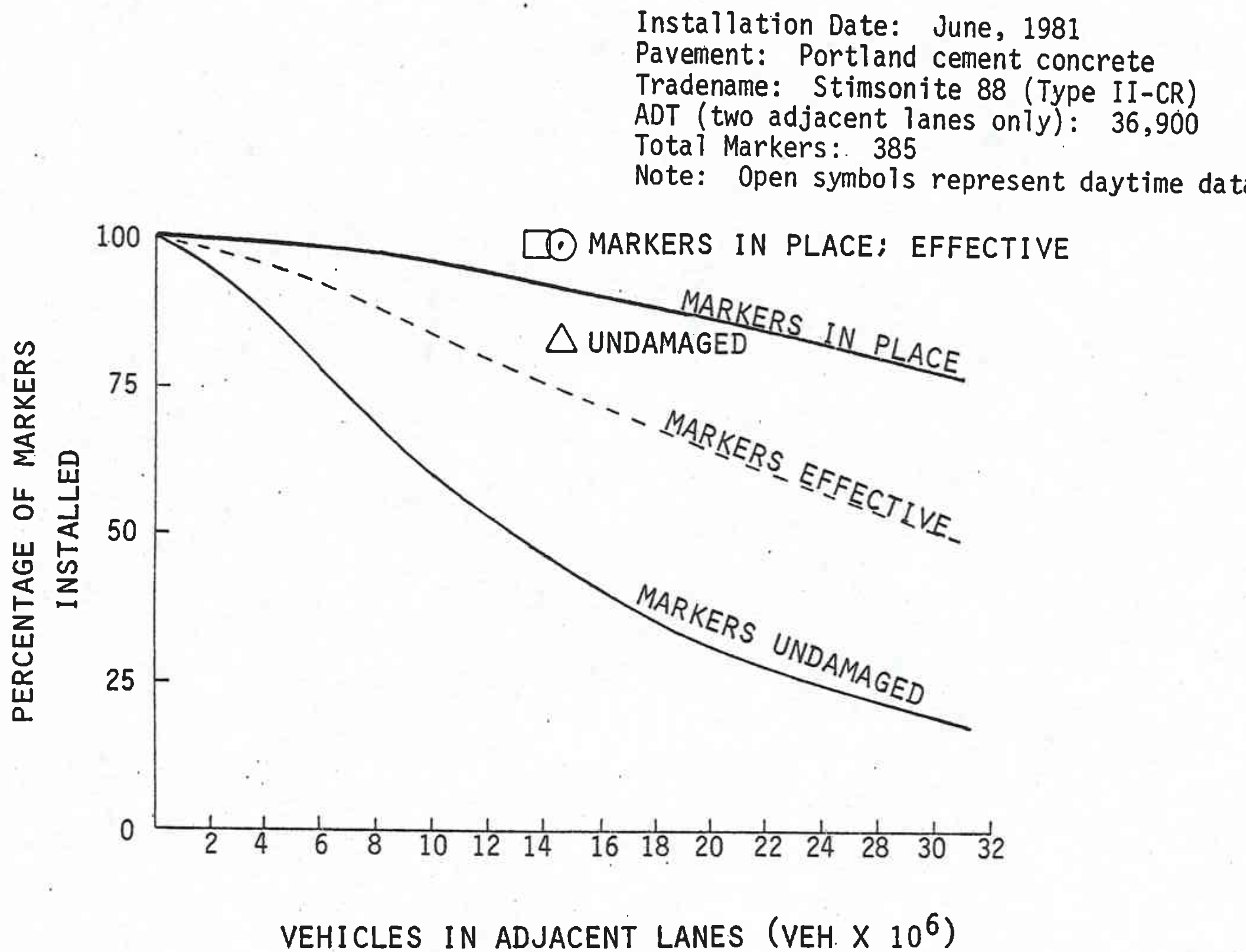

Figure 34. Observed Condition of RPMs on IH 45 in Downtown Houston (Northbound) Compared to RPM Performance Reported in the 1977 Dallas - San Antonio Study.

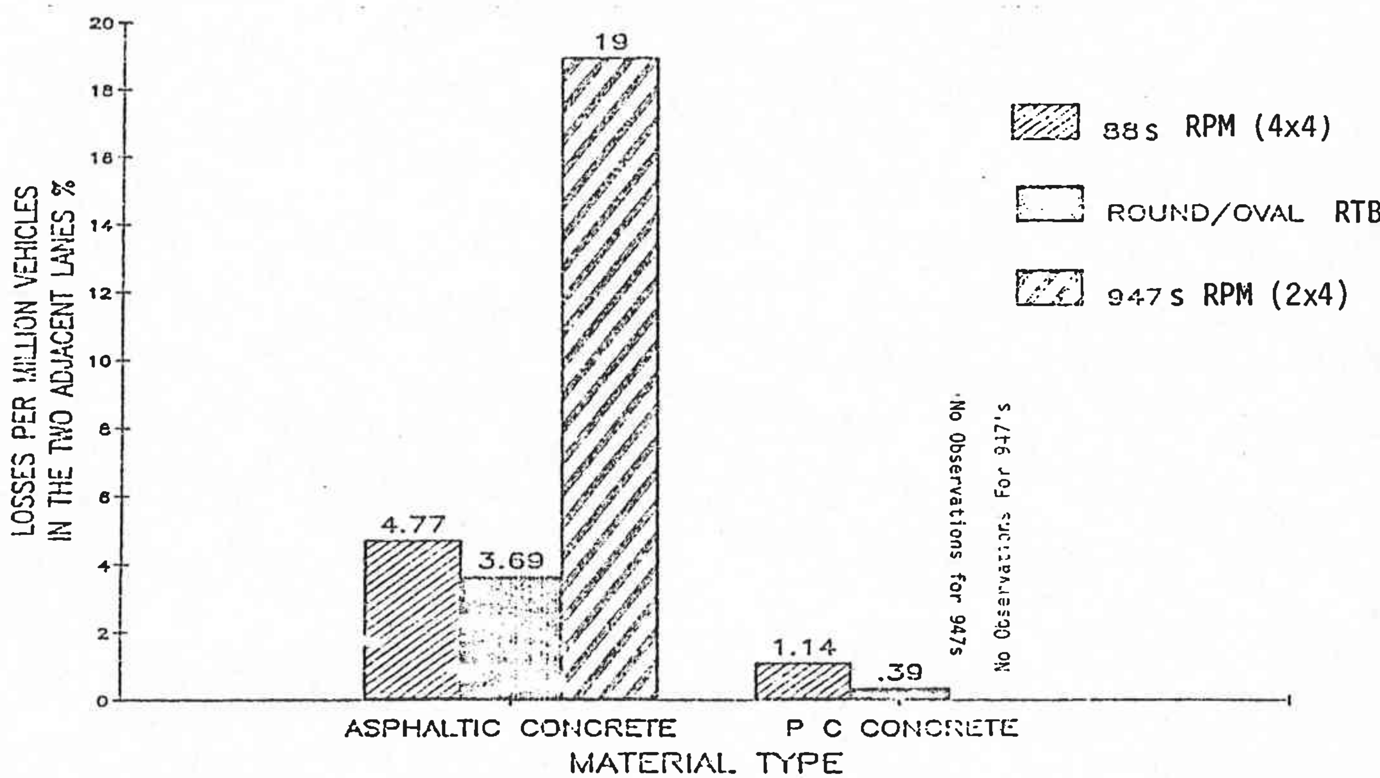

Figure 35a. Average Percentage Losses per Million Vehicles in the Two Adjacent Lanes.

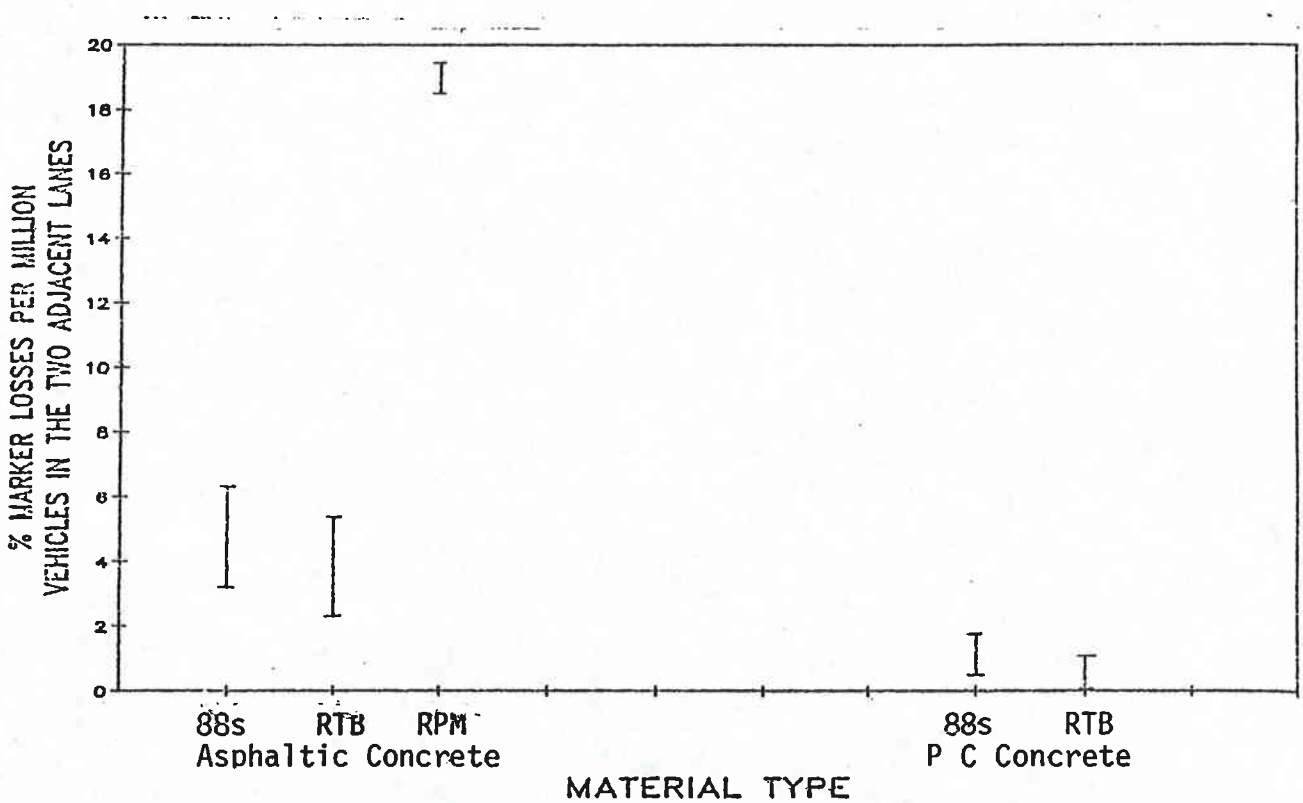

Figure 35b. 90% Confidence Intervals on Mean Losses per Million Vehicles in the Two Adjacent Lanes.

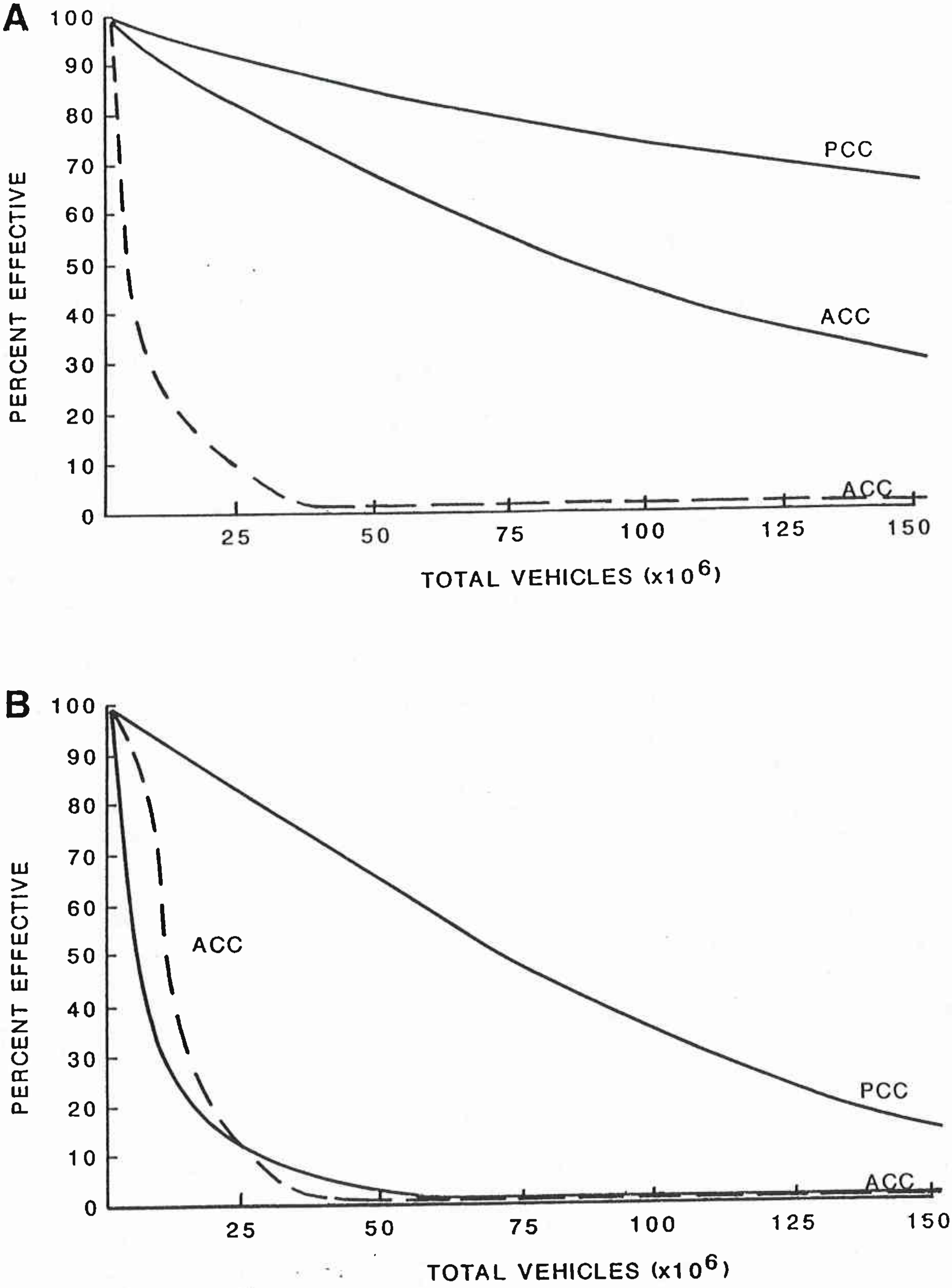

Figure 36. Effectiveness of Both Reflective Traffic Buttons (a) and Pavement Markers (b) on Portland Cement Concrete (PCC) and Asphaltic Concrete (ACC), with respect to both marker retention and retroreflectivity.

to Figure 36b points out the relatively poorer performance of the RPMs than RTBs on both PCC and ACC pavements.

The RTB curves indicate that on both PCC and ACC the RTBs remain effective longer than RPMs. The length of time is based on the total volume of traffic passing the markers. In both figures it becomes apparent that markers on PCC remain effective longer than those on ACC. The reflectivity curve for RTBs point out most appropriately the loss of effectiveness of that marker being the low level of reflectivity initially and some loss of buttons at a later time. The RPM reflectivity curve indicates that the markers initial loss of effectiveness is not due to reflectivity, its reflectivity curve shows a higher level of effectiveness on ACC than the retention curve. This most appropiately points out that the RPMs initial problem is due to retention and not reflectivity.

TIRE-MARKER IMPACTS

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. The total volume of traffic passing through a pattern of raised pavement markers is a function of time, generally increasing with time. However, the retention of the markers is most dependent on the number of impacts to which the marker is subjected.

Traffic volume is the best indicator of whether or not to expect a large loss rate of effectivity. The second factor contributing to the loss of effectiveness is the location of the markers. If they are in a high weave area a higher loss rate is expected. This implies that the primary factor contributing to both losses and marker damage is the actual number of tire hits.

One additional factor that has an influence on the effectiveness of the markers is the percentage of trucks in the traffic stream. It is intuitively clear that trucks are more damaging to the markers than automobiles, but no attempt to assign an equivalency was made.

ESTIMATING NUMBER OF HITS

A simple method was devised to estimate the number of markers hit as a fraction of the total traffic passing in the two adjacent lanes. The method is appropriate only for straight and level stretches of highways and is apt to be in gross error for any other highway conditions.

Sample counts were made on both four lane divided and two-lane, two-way highways. The samples were all taken in District 17 near Bryan, Texas. The typical ADT's for the roads surveyed were 10,000 vehicles per day for the four lane highways and 3,000 vehicles per day for the two-lane, two-way highways. The counts were conducted by observing the total traffic passing and the number striking a specific marker. These counts were made in fifteen-minute intervals throughout the twenty-four hour day. The conclusions are based on about ten total hours of such counts.

As a direct result it was concluded that about 1.5 percent of the traffic strikes a lane-line marker and 0.5 percent a center-line (yellow) marker on four-lane divided highways. These percentages are of the total traffic headed in one-direction i.e., in two lanes only. On two-lane, two-way highways the count showed 1 percent of the total traffic striking the centerline markers.

These factors were used to make the calculations shown in Table 5.

FORCES ON RAISED TRAFFIC MARKERS

The preliminary observations completed to date indicate that the primary mode of failure of RPMs on asphalt concrete is a tension or shear failure within the paving material. The asphalt fractures beneath the marker and adhesive. A small crater one-half to one-inch deep is produced upon ejection of the marker. The displaced markers, including the adhesive pad and a mass of asphalt, becomes a loose object bouncing around on the roadway until it inadvertently sticks in an unwanted location or is knocked to the shoulder.

Failure Analysis

The driving forces responsible for expelling the RPM are thought to be combinations of shear and tension. Pure compression of the marker into the pavement is not thought to present a serious loading condition for this mode of failure. The compressive strength of most asphalts is adequate to support markers under normal automobile wheel loads.

Forces that cause markers to be torn from the pavement come from tire impacts that tend to twist, slide, and/or rock the marker. These loadings subject the pavement to forces more likely to cause failure of the asphalt than would pure compression.

The factors which are expected to influence the forces on markers included the height, shape, slope, bond area, tire pressure, tire width or "footprint", contact location across tread, and vehicle speed. These factors and their interrelationships are discussed below.

Factors Influencing Impact Forces on Markers

The height of the marker influences impact forces both directly and indirectly. The higher the marker, the greater the proportion of the wheel load it receives as the tire passes over it. Work performed by Bonse and Kuhn (1) on embedded load cells which protrude above the plain of the roadway can

Table 5. Calculation of Number of Hits

Tangent Sections Only

Lane Lines 1.5%

4-Lane Divided

Divided Center Lines

0.5%

2-Way Traffic

Center Lines 1.0%

Estimate Hits	Highway Type	Total Adjacent Lanes ($x10^6$)	Percent Hits	Vehicles Number of ($x10^6$)
Austin I35	4-Lane	56.67	1.5	850.0
Austin US290	4-Lane	5.48	1.5	82.2
Austin US290	4-Lane	5.48	1.5	82.2
Brownfield US82	4-Lane	4.76	1.5	71.4
College Station TX 6	4-Lane	1.86	1.5	27.9
Corrigan US287	4-Lane	0.66	1.5	9.9
Diboll US 59	4-Lane	2.05	1.5	30.8
Lubbock I27	Ramp	0.14	1.0	1.7
Huntsville US75	4-Lane	3.64	1.5	54.6
Huntsville US190	4-Lane	9.86	1.5	147.8
Lufkin TX7E	2-Lane (1250 vpd)	0.41	1.0	4.1
Lufkin US287(NW)	4-Lane	1.74	1.5	26.1
Port Lavaca	2-Lane	4.50	1.0	45.0
Port Lavaca	4-Lane	5.11	1.5	76.7
San Antonio I37	4-Lane	5.11	1.5	76.7
San Antonio I10E	4-Lane	8.03	1.5	120.4
San Antonio I10W	4-Lane	3.07	1.5	46.1
Victoria Loop 175	2-Lane	7.41	1.0	24.1
Lufkin TX71N	2-Lane	0.68	1.0	6.9
Nacogdoches Loop 224	4-Lane	3.72	1.5	55.8
Nacogdoches TX21	2-Lane	1.28	1.0	12.8
San Antonio I35S	4-Lane	5.11	1.5	76.7

be applied to the marker problem. Results of their work is shown in Figure 37.

Marker height has an indirect effect on the influence that tire pressure has on the forces induced on markers. When the marker is being impacted by the center of the tire tread, the influence of tire pressure is enhanced by marker height. Figure 38 shows how an embedded load cell responded to both height and pressure. Impacts under a side wall are influenced less by tire pressure and marker height. This is due to the way in which forces are distributed across a pneumatic tire. Tielking and Schapery (2) have shown that the force under the tire side wall can be twice the force under the mid-tread area. The mid-tread has the flexibility to deform over obstacles. Variations of marker height of a centimeter or so would not be expected to increase the vertical force under low to normal inflation pressures. As inflation pressures are increased, the tire becomes more rigid, and the mid-tread region is less able to locally deform. More of the weight of the vehicle is transmitted to the marker as the pressure increases up to the point where the tire is rigid enough to be completely raised off the pavement by the protrusion. At this point, the entire wheel load is applied to the marker and the pavement beneath.

Figure 39 through 42 show the influence of tire pressure and point of contact on the forces delivered to the marker. In Figure 39, a low to normal pressure tire is shown impacting the marker at the mid-tread of the tire. The tire bridges over the marker, allowing the high forces under each side wall to contact the pavement. This reduces the force on the marker. In Figure 40, a low to normal pressure tire impacting a marker under a side wall is seen to be able to deform sufficiently again to bridge over the marker. Marker forces are reduced by this distributed load. Figure 41 shows a direct mid-tread impact of a marker by a high pressure tire. The tire is seen supported by the marker, thereby applying the tire axle load to the marker and pavement. Figure 42 shows the same conditions from a side view. Figure 43 shows a marker impact by the edge of a high pressure tire. The tire is totally supported by the marker. The condition shown in Figure 42 can cause the marker to rotate about both vertical and horizontal axis, thereby producing large shearing and tensile forces in the pavement. Further, a tire edge impact where the tire side wall is above the marker will produce the most severe loading condition.

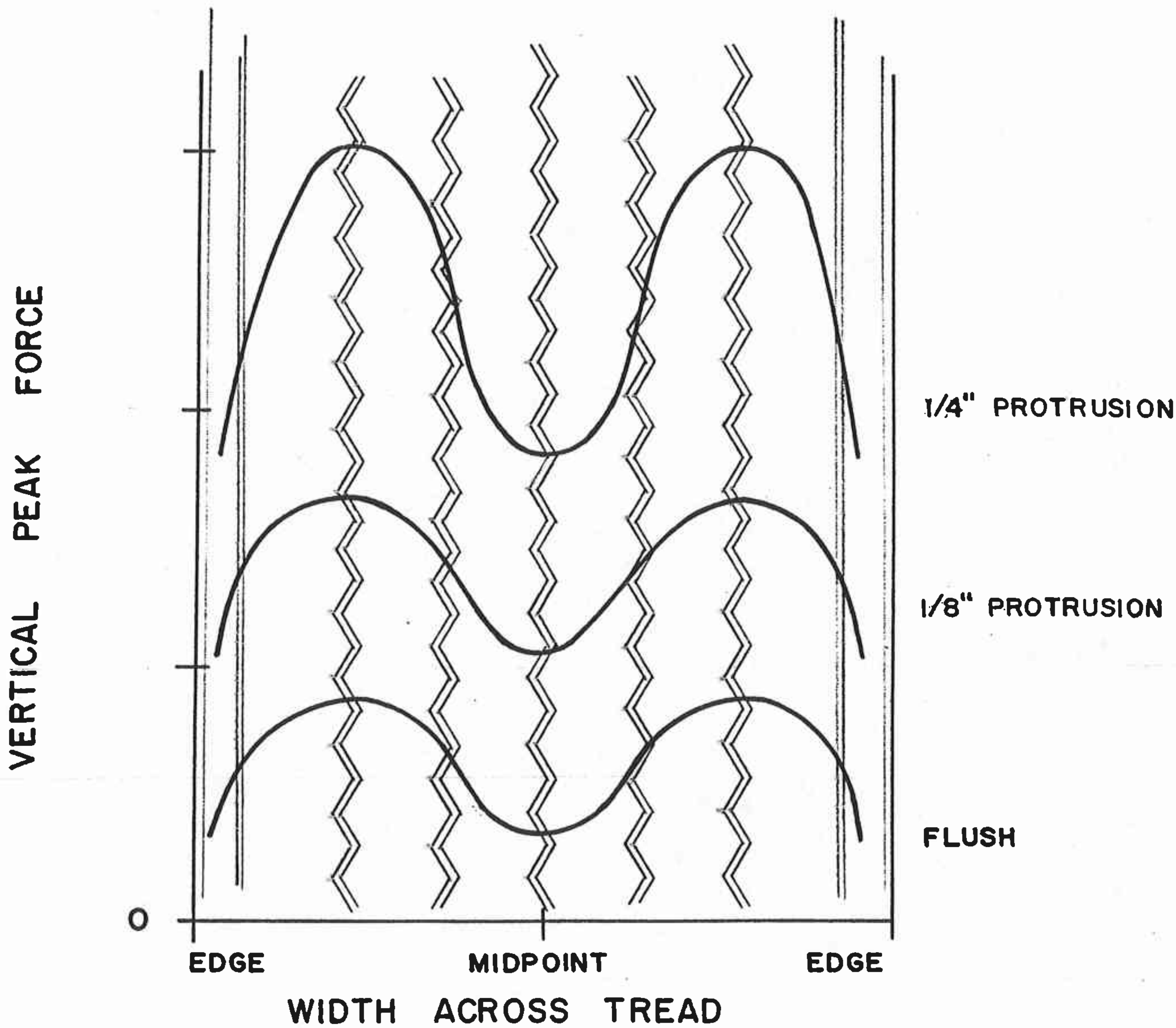

Figure 37. Influence of Protrusion Height on the Maximum Vertical Forces Distributed Across the Tread. Adapted from Bonse and Kuhn (1).

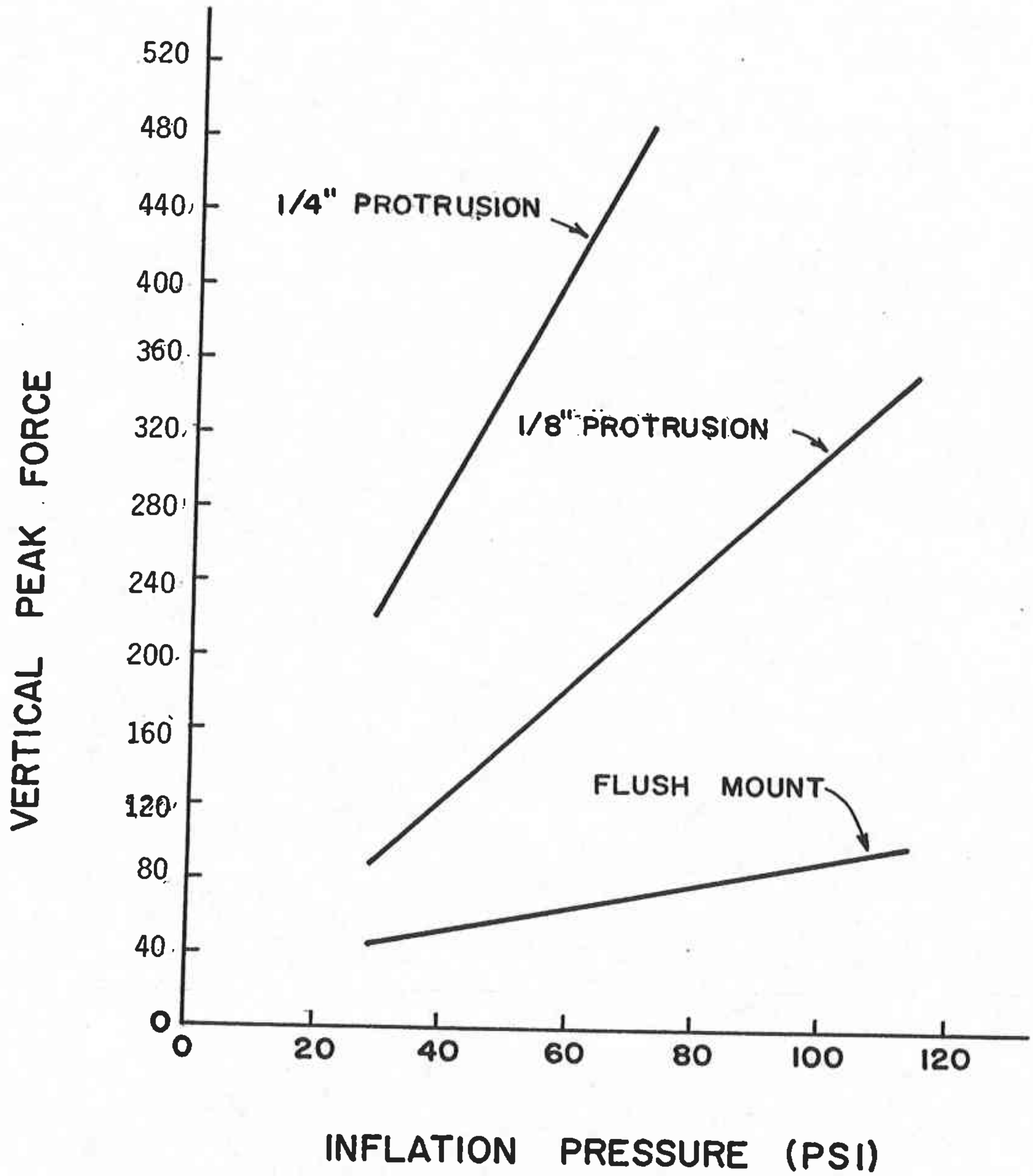

Figure 38. Vertical Peak Force Versus Inflation Pressure Where Height of Load Cell Above Pavement is Shown as a Parameter.

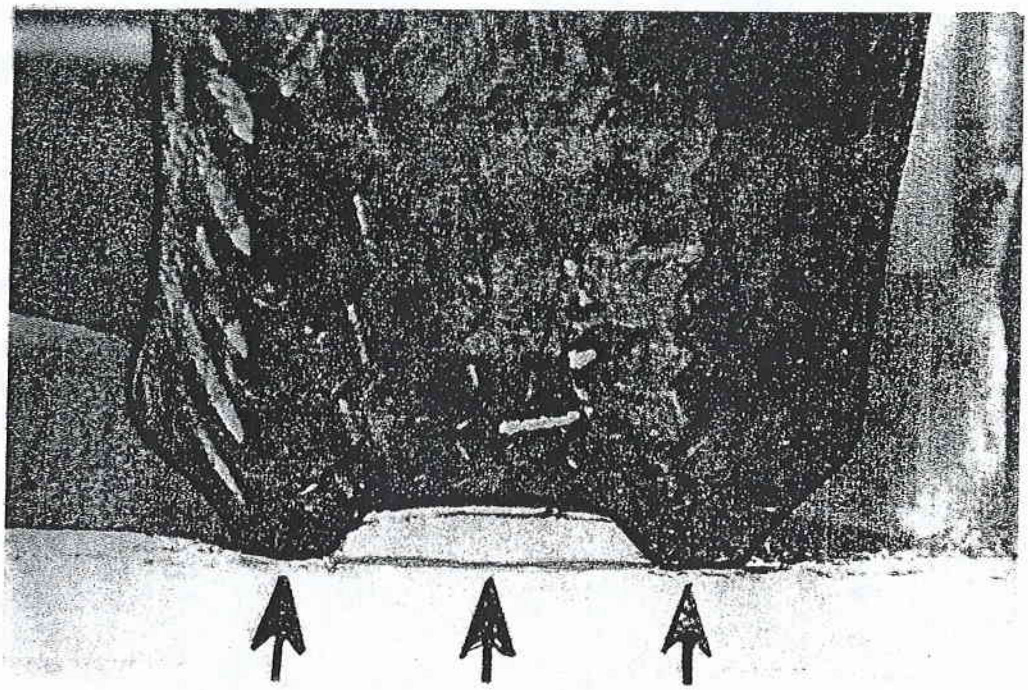

Figure 39. Mid-Tread Impact of a Marker by a Low to Normal Pressure Tire. Arrows Show Points of Load Transfer to the Pavement.

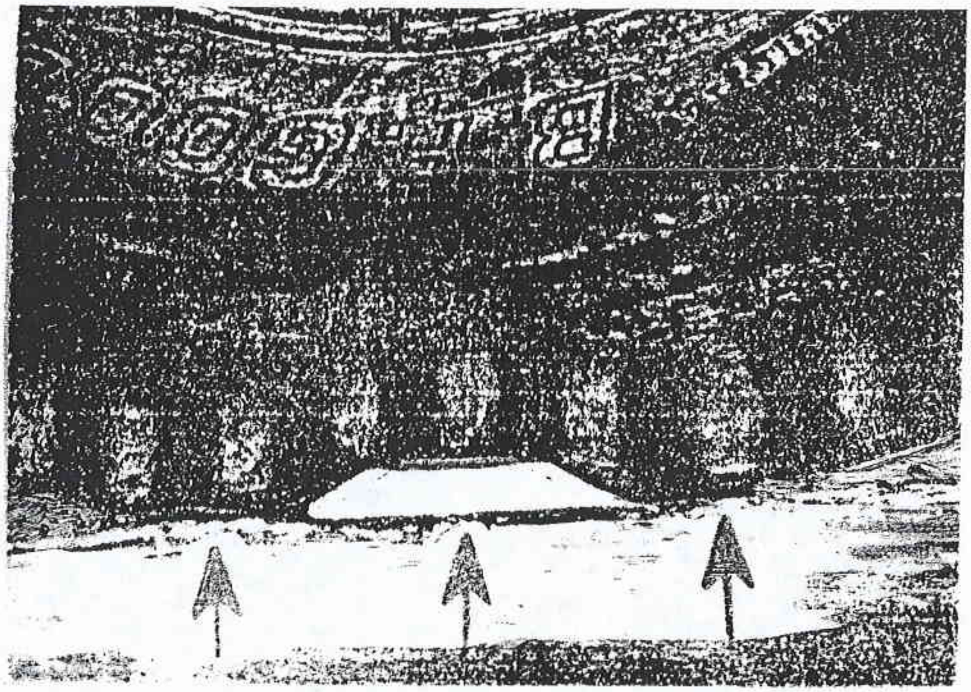

Figure 40. Sidewall Impact of a Marker by a Low to Normal Pressure Tire. Arrows Show Points of Load Transfer to the Pavement.

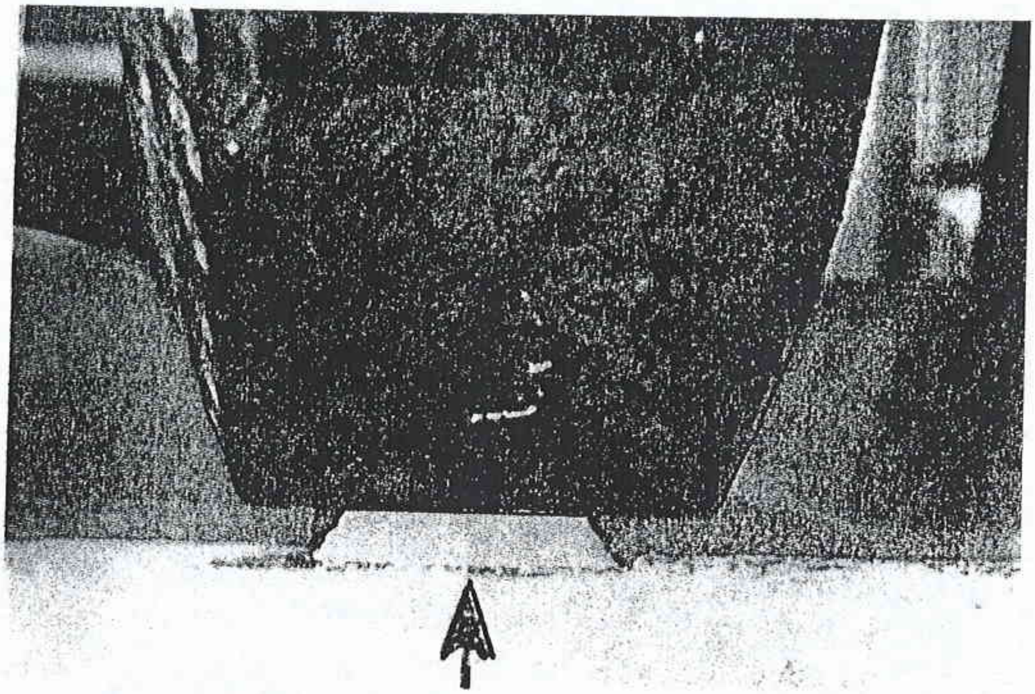

Figure 41. Mid-Tread Impact of a Marker by a High Pressure Tire. Arrows Show Points of Load Transfer to the Pavement.

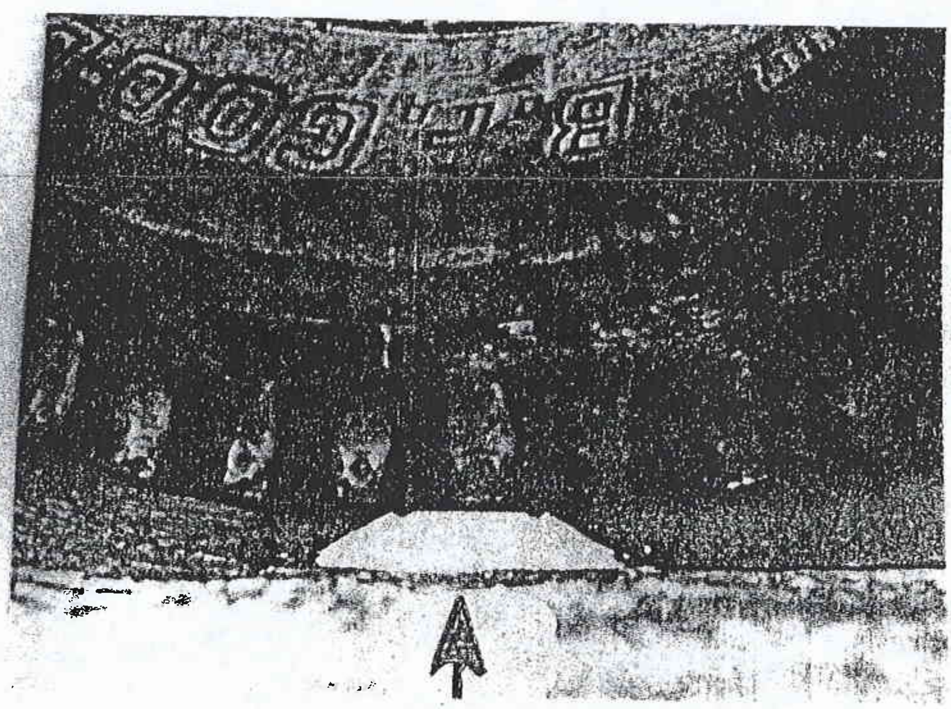

Figure 42. Sidewall Impact of a Marker by a High Pressure Tire. Arrows Show Points of Load Transfer to the Pavement.

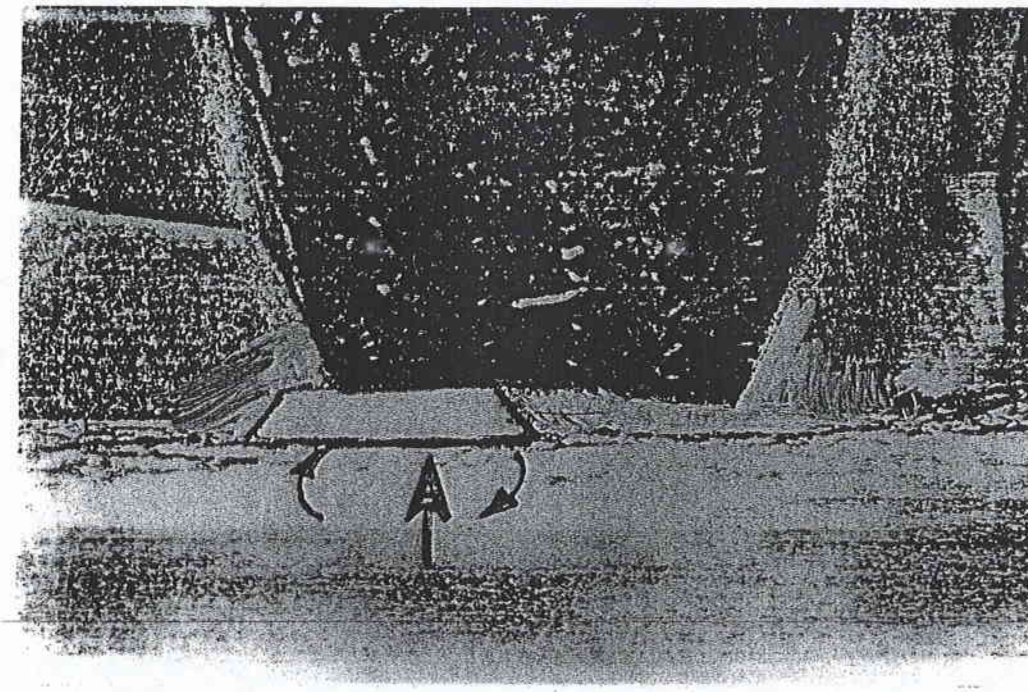

Figure 43. A Longitudinal View of the Marker Shown in Figure 42 of the Sidewall Impact by High Pressure Tire. Arrows Show Points of Load Transfer to the Pavement.

Although not addressed in the literature the most damaging type of impact occurs when the tread under the side wall strikes a glancing blow on the more vertical (lateral) side (non-reflective) of a marker. Here, the maximum force available from the tire is imposed on the marker in a manner which would tend to displace the marker laterally, twist it about it's vertical axis, and rotate it about its longitudinal (traffic direction) axis. All these motions produce forces which the pavement is least able to withstand. The higher the marker, the greater these lateral and twisting forces will be. The more abrupt the transition from flat pavement to pavement marker, the more severe these forces will be. In this sense, a smoothly contoured low profile marker with a large bond area to the pavement would have the best chance for retention. In contrast, a tall marker with near vertical sides and small bond area to the pavement would be more likely to fail.

Stresses Within The Pavement

All three types of stress, tension, compression, and shear, are apt to be induced in the pavement under a marker. Compression stresses will predominate. That is good because that is the type of stress paving materials can best support. However, the application of a purely compressive load to a marker can cause the marker to punch into the pavement thereby causing shearing stresses. For any applied load the smaller the bond area between the marker and the pavement, the greater will be the shearing stress. If the pavement material is weak, the marker may become submerged.

Two other loadings are believed to be more critical. Anytime the resultant downward force on a marker passes outside the center third of the bonded area between the marker and the pavement, it can be expected that the adhesive at the opposite edge of the marker will be subjected to simple tension. This will manifest itself by a tendency for the marker to roll about an axis in the bonded plane. While the tensile stress is usually small, it is clear that tension is the type of stress the adhesive and paving material are least capable of resisting.

The other type of stress, perhaps the most important, is the shear stress caused by loads which are not directly vertical. Horizontal components may be induced because of the shape of the marker or because of vehicle accelerations (or decelerations). These accelerations may be induced by speeding up, turning, or slowing a vehicle. The resulting horizontal components will cause sliding tendencies on curved surfaces cupped under the marker. Such sliding is exactly analogous to sliding failures of sloping soil, such as embankments and dams.

Influence of Speed

Kinetic energy increases with vehicle speed, stopping distances increase with speed, and so do the forces of impact when the vehicle rams an obstacle. These factors suggest that vehicle speed must influence the forces on raised markers.

A study of the dynamics of the problem alters some of these calculations. Automobile tires respond more elastically than viscoelastically and as such have very little increase in stiffness with increasing rates of localized deformation. The tire exerts essentially the same down force on the marker regardless of speed. Although no measurements are reported in the literature, lateral forces may be found to be influenced by vehicle speed. The loading suspected as being most severe is a glancing blow to the nearly vertical side (parallel to traffic), such as would be experienced during a turning-passing maneuver.

Influence of Tire Pressure

The stiffness of the tire depends upon inflation pressure. The stiffer the tire, the less deformation the marker can cause in the tire, and the more axle weight is imposed upon the marker. Measurement by Bonse and Kuhn (1) of the forces on a load cell embedded in the road surface showed the tire pressure to be one of the most important factors in increasing the dynamic forces exerted by moving vehicles. Further, this effect of pressure has been found to be essentially linear; but, remember that the forces also increase with marker height, thus magnifying the pressured effect.

Following the lead of Tielking and Schapery (2), Figure 44 shows the influence of tire pressure on the forces acting on the pavement as a function of the location across the tread.

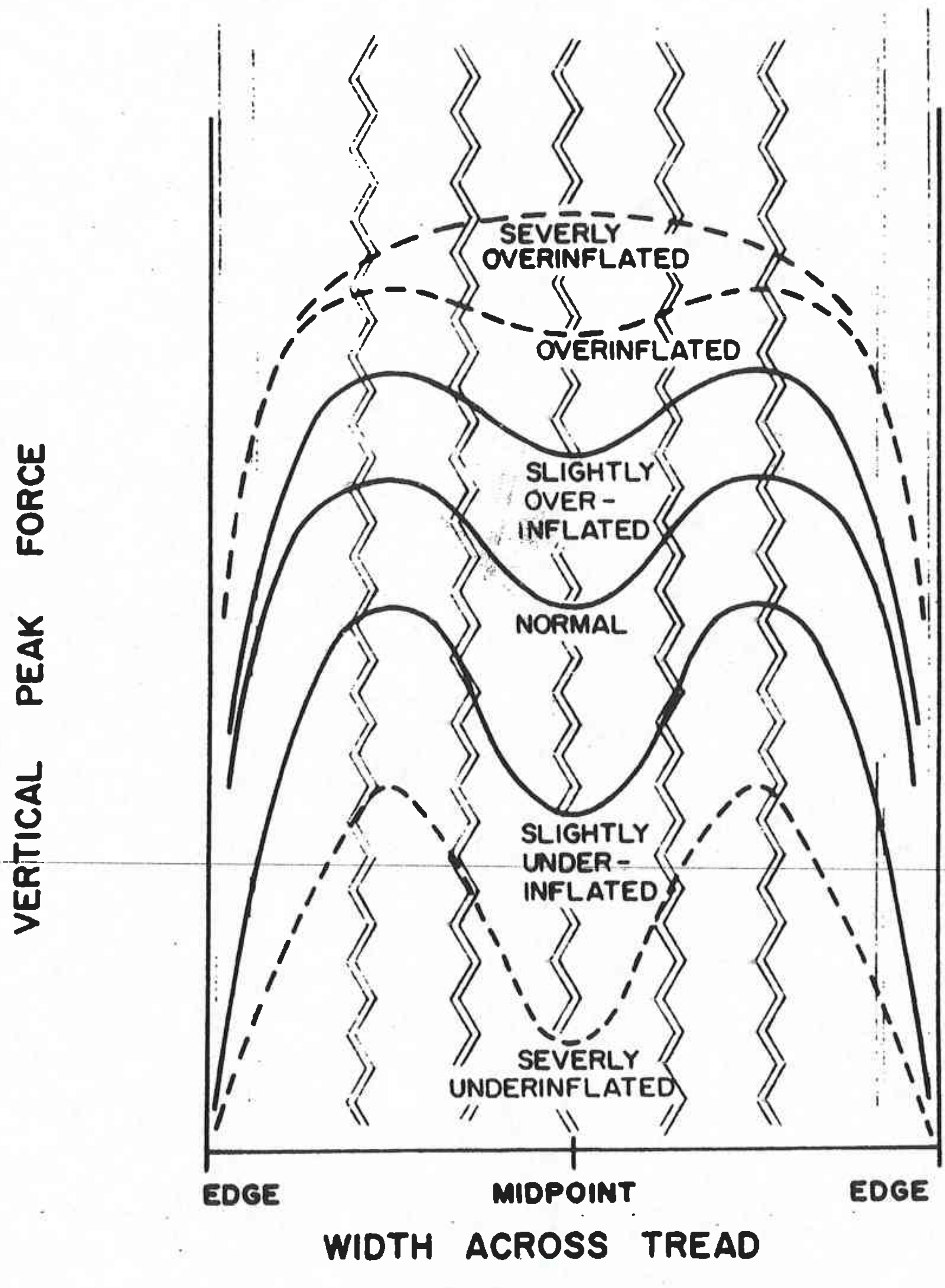

Figure 44. Estimated Influence of Inflation Pressure on the Vertical Force Shown as a Function of Width Across Tread.

PULL UP-TEST

Finding a test of asphalt pavement that would indicate the material's ability to retain the reflective markers was an early and continuing goal. To this end a device was built to pull up (or out) RPMs that had been epoxied to the pavement. But, the problem of gripping the RPMs with enough strength to assure they could be pulled from the road was never solved. Figure 45 shows a metal plate bonded to the top of a RPM illustrating one attempt at solving the problem.

So, an alternate technique of bonding 4 x 4 and 2 x 4 inch aluminum plates directly to the pavement was tried. A 3/4 inch hole was drilled and tapped in the top of the 1/2 inch thick plate. A threaded rod was screwed into the plate to test the pavements resistance to tension.

The apparatus used to perform the direct tension test can be described as a hydraulic arm mounted in a vertical steel frame and connected to a hydraulic pump. The arm was connected to the special bolt that screwed into the hydraulic ram. The hydraulic pump causes the ram to contract, pulling the aluminum plate upwards, thus causing a failure in either the epoxy or the pavement. The maximum force was then recorded.

During the first tests, it was observed that temperature played a significant role in the way that the simulated RPMs failed. Never was a failure of the epoxy itself nor of the epoxy-to-aluminum bond observed. However, some failures were deemed to be epoxy-asphalt bond failures even though more often than not some bits of pavement material adhered to the epoxy surface after the failure.

Three types of failure modes were characterized as follows:

Failure A — Failure was of the pavement-to-epoxy bond. Failure was characterized as abrupt.

Failure B — Failure medium was the pavement (asphalt). The asphalt under the RPMs exhibited a slow ductile failure mode. It can be described as sluggish, like removing a piece of "bubble gum" from the pavement. Unlike A, the B failure type removed a great volume of asphalt from the pavement. The removed sample would resemble a dome with an edge angle varying from

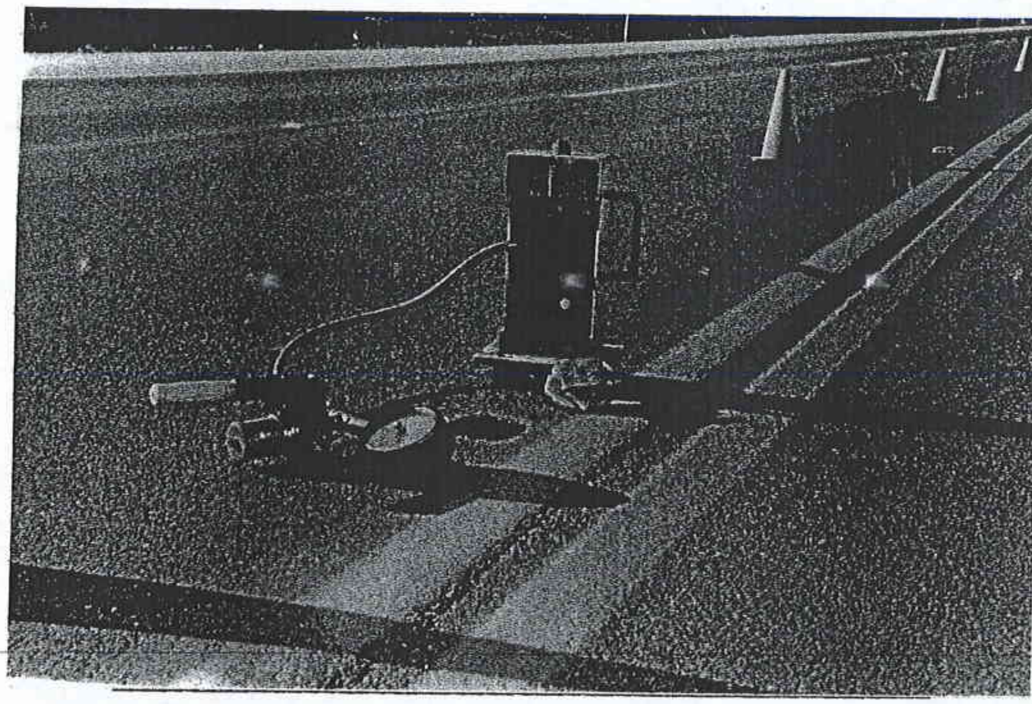

Figure 45. Marker Pull-Up Testing Device. (Note the Plate Bonded to the Top of Our Existing Marker).

20 to 45 degrees. The slower the failure the higher the angle and, as a rule the greater the volume of asphalt.

Failure C Failure mode was a combination of A and B.

Three testing sites were chosen for the direct tension test study. Several factors were considered such as proximity to College Station, service life of existing RPMs, and in situ conditions. The sites were:

Site 1 FM 2818, near the intersection with FM 60
Asphalt: T-340

Site 2 Highway 21, near the TAMU Research Center
Asphalt: T-340

Site 3 Highway 30, 15 miles south of College Station
Asphalt: T-340

To evaluate the importance of temperature on the strength and mode of failure the tests were run at several temperatures at each site. Tables 6, 7 and 8, indicate the increasing tensile strength with decreasing temperature that was observed. More importantly perhaps is the pronounced change in the mode of failure.

The loss rates observed at the three sites are not well defined because neither the traffic count nor the RPM losses are carefully documented. Nevertheless, an estimate of each was made using the best data available. They are shown in Table 9.

Table 9 indicates that the loss rate at Site 2 (TX 21) is considerably lower than the other two sites. A glance at the Figure 46 shows that the pull up strength at this site was found to be considerably below that for the other two sites. From this it might be concluded that the loss rates on pavements with low observed pull up strengths, and with high temperatures will exhibit the best retention.

But, there is a complicating factor. In discussions with the highway engineers of Texas and in statewide observations it was determined that the loss rates increase during the spring and fall seasons. This is most pronounced during the spring. Since these seasons are times of transitions from one temperature to another there is a question as to whether low pull up strength alone is a good indicator of the best pavements for marker retention.

Table 6. Results of the Direct Tension Tests At Site 1.

Pull-Out Stress (psi)	Pull-Out Force (lbs)	Temperature Degrees Fahrenheit	Type of Failure
1000	16000	77	B
1100	17600	77	B
1300	20800	77	B
1500	24000	71	B
1500	24000	71	B
1600	25600	71	C
2600	41600	64	C
2900	46400	64	C
3100	49600	64	C
2500	40000	56	A
2600	41600	56	A
2600	41600	56	A
3300	52800	45	A
3400	54400	45	A
3400	54400	45	A
3750	60000	38	A
4000	64000	38	A
4000	64000	38	A

Table 7. Results of the Direct Tension Test at Site 2

Pull-Out Stress (psi)	Pull-Out Force (lbs)	Temperature Degrees Fahrenheit	Type of Failure
800	12800	74	B
1200	19200	74	B
1400	22400	74	B
1500	24000	61	B
1600	25600	61	B
1800	28800	61	B
1600	25600	50	A
2000	32000	50	A
2200	35200	50	A
2200	35200	39	A
2400	38400	39	A
2400	38400	39	A

Table 8. Results of the Direct Tension Test at Site 3

Pull-Out Stress (psi)	Pull-Out Force (lbs)	Temperature Degrees Fahrenheit	Type of Failure
2100	33600	77	B
2200	35200	77	B
2200	35200	77	B
2600	41600	59	B
2700	43200	59	B
3000	48000	59	B
3400	54000	47	A
3500	56000	47	A
3500	56000	47	A
3600	57600	39	A
3700	59200	39	A
3800	60800	39	A

Table 9. Marker Loss Rates Life and Number of Hits Sustained by Site

	ADT (vpd)	Markers Remaining (Percent)	Marker Life (Month)	Hits (1000)	Loss Rate (%/10^4 Hits)
Site 1	10,000	40	18	41	14.6
Site 2	7,000	88	24	38	3.1
Site 3	10,000	70	12	27	11.1

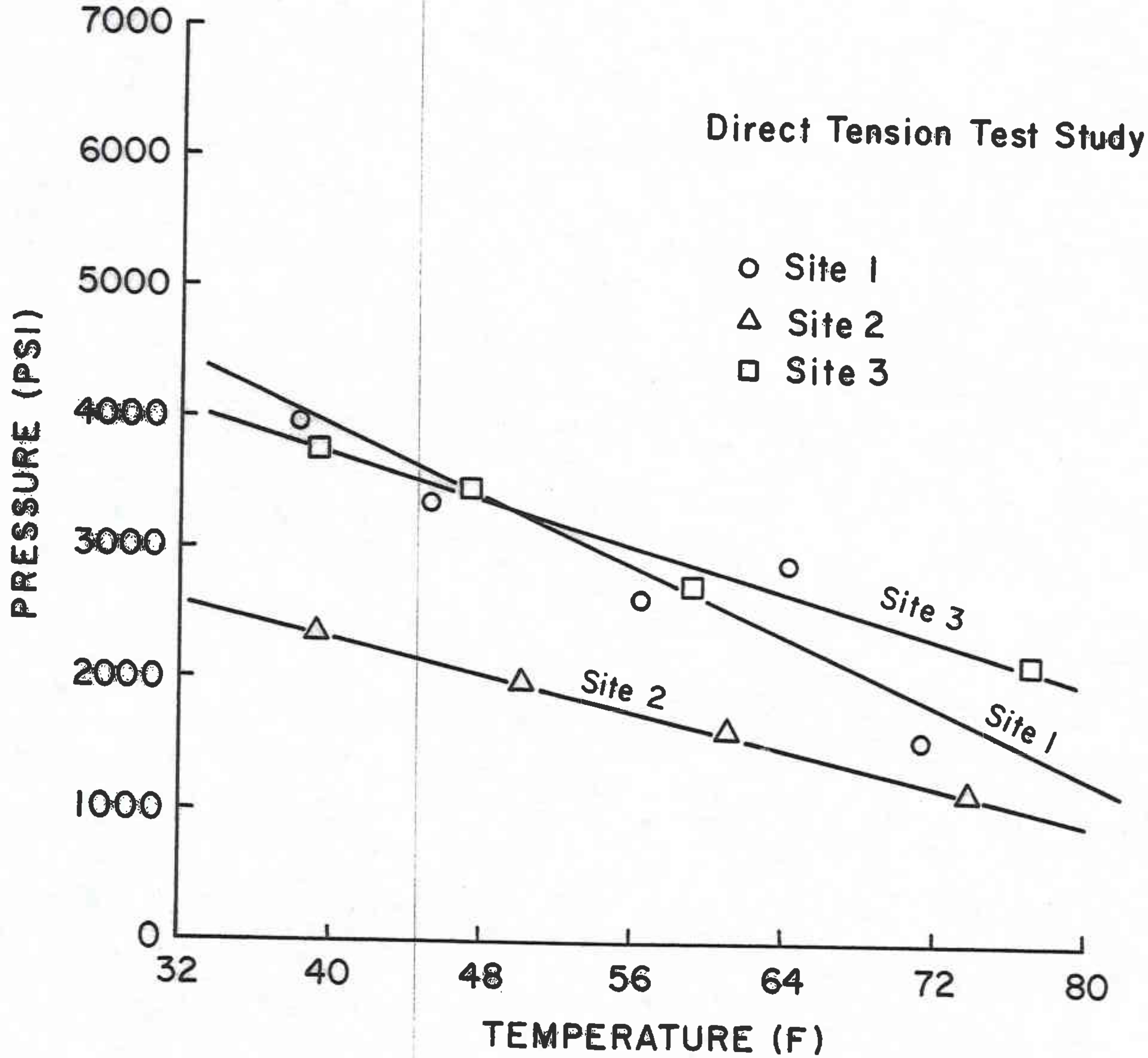

Figure 46. Strengths Observed in Pull-Up Tests as a Function of Temperature.

ASPHALT PROPERTIES

Sample cores were extracted at twenty-two locations across the State. The locations were selected to represent a variety of climatic and traffic conditions as well as different marker loss rates. The conventional cores were 4-inches in diameter and usually about 1-inch thick. A minimum of four cores were extracted at each site giving about 88 test specimens.

The trailer mounted coring machine is shown in Figure 47. The sample cores were extracted, tagged and bagged in polyethelene bags after which they were returned to the materials laboratory at TTI for testing.

Asphalt Unit Weights

The unit weights of the asphalt were measured by weighing the core samples both in air and submerged in water. Using the formula:

$$\rho = (0.036\ \text{lb/in}^3)\left[\frac{W_{air}}{W_{air} - W_{water}}\right]$$

where,

W_{water} = weight submerged in water

W_{air} = weight in air, and

= unit weight of the asphalt in lb/in^3.

the unit weights were calculated.

The values obtained are summarized in Table 10.

At first glance one might suppose that loss rates are inversely proportional to the unit weight of the asphalt. Highways observed to have retained markers well: Austin IH 35 and Diboll US 59 showed asphalt unit weights of 0.0634 lb/in^3 and 0.0638 lb/in^3 respectively; while those showing excessively rapid loss rates, College Station TX 6 and Lufkin TX 7 W, had unit weights of 0.0816 lb/in^3 and 0.0915 lb/in^3. However, when all the data were plotted no trends were apparent. This can be seen in Figure 48.

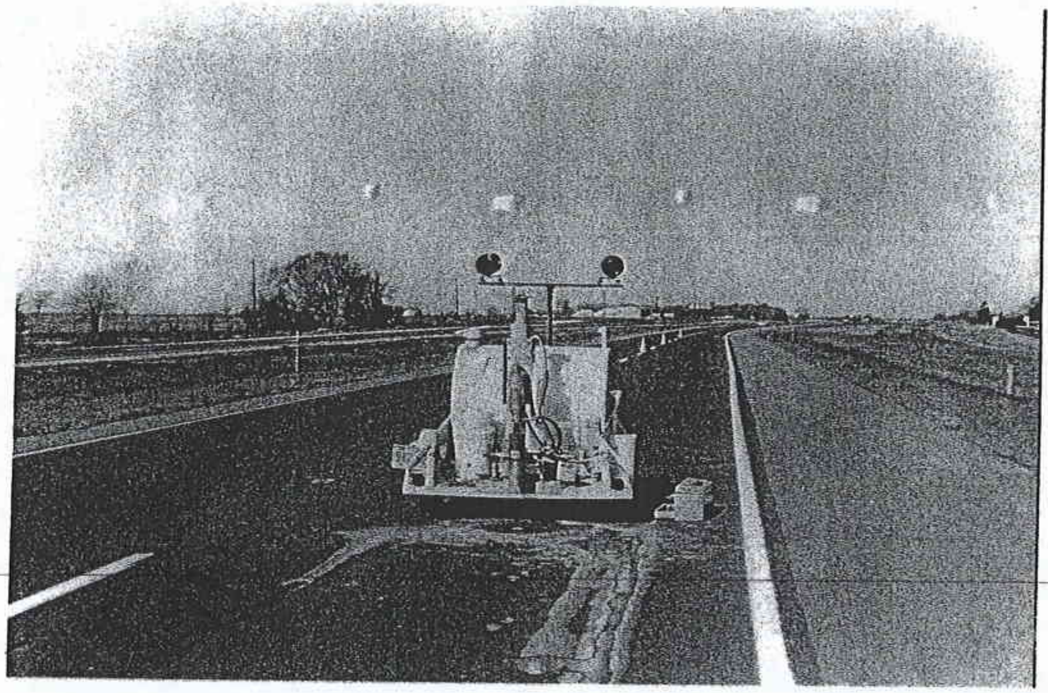

Figure 47. Coring Machine Used to Extract Asphalt Pavement Samples.

Table 10. Measured Asphalt Densities Compared to Marker Loss Rates.

Location	Type Asphalt	Type Marker	Time in Place (Years)	Measured Density lb/in^3	Loss Rate %lost/10000
Austin IH 35	T-340	Ceramic	6.9	0.0634	0.31
Austin US 290 EB	T-340	Plastic 4x4	3.0	0.0782	1.83
Austin US 290 WB	T-340	Plastic 4x4	3.0	0.0789	0.61
Brownfield US 82	Reclaimed Rejuvinate	Plastic 4x4	2.5	0.0768	3.78
College Station TX 6	T-340	Plastic 4x4	1.0	0.0816	25.00
Corrigan US 287	Sealcoat	Plastic 4x4	0.9	0.0815	1.12
Diboll US 59	T-340	Plastic 2x4	0.9	0.0638	0.0
Huntsville US 75	T-340	Plastic 2x4		0.0830	7.69
Huntsville US 190				0.0853	6.76
Lufkin TX 7W	Sealcoat	Plastic 2x4	0.9	0.0915	26.09
Lufkin TX 7E				0.0833	2.43
Lufkin US 287	Sealcoat	Plastic 2x4	0.9	0.0804	0.38
Nacadoches Loop 224				0.0516	0.00
Nacadoches TX 21				0.0708	9.40
Port Lavaca TX 316	T-340	Plastic 2x4	2.8	0.0843	7.11
Port Lavaca TX 238	Sealcoat	Plastic 4x4	2.8	0.0728	0.0
San Antonio IH 35	T-340	Plastic 4x4	2.0	0.0785	9.00
San Antonio IH 37				0.0689	7.82
San Antonio IH 10E	Sealcoat	Plastic 4x4	2.0	0.0699	1.58
San Antonio IH 101W	Sealcoat	Ceramic and Plastic 4x4	1.4	0.0803	0.0
Victoria Loop 175	Sealcoat	Plastic 4x4	3.0	0.0739	9.58

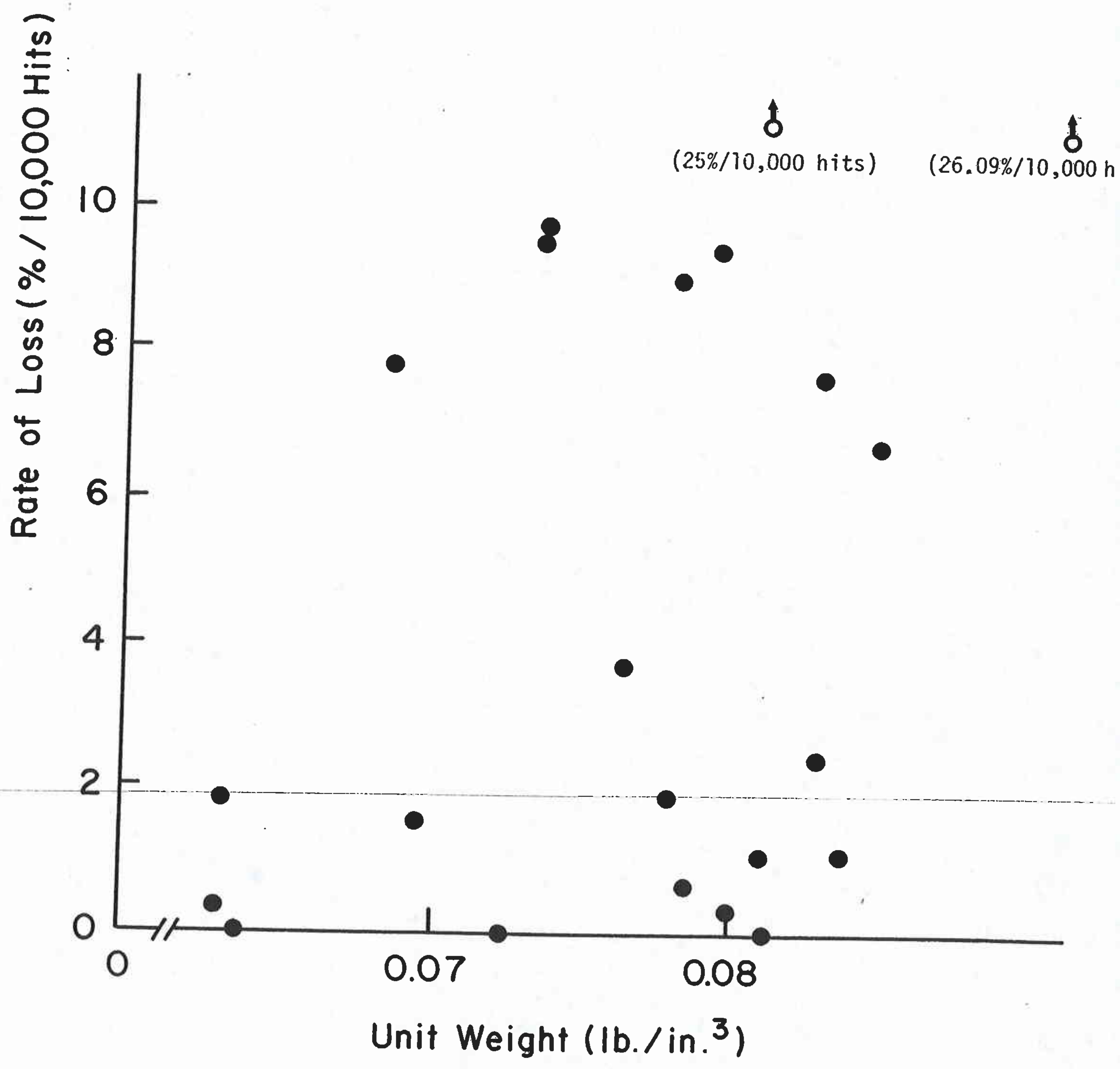

Figure 48. A Plot of the Loss Rates Observed vs. the Measured Asphalt Unit Weights.

INDIRECT TENSION TESTS

When one compresses a circular cylinder by applying equal and opposite line loads at each end of a diameter a tensile stress is generated perpendicular to the diameter. For materials that are weak in tension, compared to their compressive strength, these kinds of tests are termed "indirect tension tests". The fact that direct tensile test coupons are hard to machine in these kinds of materials and the coupons are then difficult to grip and fail have assisted in the indirect tension test to be widely used.

Table 11 summarizes some of the results obtained from the more than sixty indirect tensile tests that were completed. Both a maximum tensile stress and a measured corresponding strain were recorded. Further, a toughness, in inch-pounds (in-lbs), was recorded indicative of the energy absorbed by the sample until the maximum tensile stress was obtained.

Table 12 compares the indirect tensile strength and toughness with the observed loss rate in percent per 10,000 hits. A study of the Table and Figures 49 and 50 where the indirect tensile strength and the toughness are plotted vs. the observed loss rates indicates there is little correlation. So the conclusion was drawn that marker retention is not a strong function of either the asphalt strength or toughness.

Core Sample Statistical Analysis

Core samples were taken from twenty locations across Texas. Four cores from different sections of the roadway were removed at each location. These cores were approximately 6-8 inches in height. Thirteen variables were studied with respect to each sample. These 14 variables were:

1. Lift Height (inches)
2. Top Lift Height (inches)
3. Roadway Surface Composition (T292, T340, Sealcoat)
4. Weight of Core in Air (Grams)
5. Weight of Core in Water (Grams)
6. Density
7. Tensile Strength at Failure (PSI)
8. Traffic (Vehicles)
9. Time (Years)
10. Percent Marker Loss (%)
11. Maximum Stress (PSI)

Table 11. Summary of Results of Indirect Tension Tests on 4 inch Diameter Cores

Location	Core Thickness	Maximum Stress psi	Corresponding Strain in/in	Toughness
IH 35 Austin	1.02	147.5	0.0034	11.3
US 290 Eastbound Austin	1.23	152.9	0.0021	7.1
US 290 Westbound Austin	1.37	130.7	0.0018	4.9
US 82 Brownfield	1.37	217.8	0.0066	28.3
TX 6 College Station	0.89	214.6	0.0024	10.5
US 287 Corrigan	1.44	147.7	0.0061	18.2
US 59 Diboll	1.655	166.8	0.0040	11.1
US 75 Huntsville	1.32	183.7	0.0039	48.2
Spur 346 Port Lavaca	1.33	174.2	0.0034	13.1
IH 35 San Antonio	1.31	91.7	0.0100	16.8
IH 10 E San Antonio	0.74	125.2	0.0037	8.7
Loop 287 NW Lufkin	1.47	123.8	0.0129	27.4
Loop 224 Nacogdoches	1.64	195.0	0.0080	17.7
TX 21 Nacogdoches	1.37	162.1	0.0055	16.5
US 190 Hunstville	1.18	183.7	0.0062	20.6
IH 27 (Ramp) Lubbock	1.01	158.1	0.0055	17.8
TX 7 W Lufkin	1.53	137.8	0.0038	30.0
TX 7 E Lufkin	1.08	52.0	0.0081	8.0
IH 10 NW San Antonio	1.37	125.0	0.0053	16.0
Loop 175 Victoria	1.55	79.7	0.0024	3.5

Table 12. Observed Asphalt Properties Compared to Loss Rates

Location	Asphalt	% Remaining	Est. No. of Hits	Age (yrs)	Indirect Tensile Strength (psi)	Toughness (in-lb)	% Lost 10000th
Austin US 290E	T340	85	82000	3.0	152.9	7.1	1.83
Austin US 290W	T340	95	82000	3.0	130.7	4.9	0.61
Brownfield US 82	Reclaimed Rejuvenated	73	71500	2.5	217.8	28.3	3.78
College Station TX6	T340	30	27900	1.0	214.6	10.5	25.09
Huntsville US75	T340	58	54600	3.0	183.7	48.2	7.69
Huntsville US 190	T340	0	147800	3.0	183.7	20.6	6.77
Port Lavaca TX316	T340	95	45000	2.8	174.2	13.1	1.11
Port Lavaca TX238	Seal	100	76600	2.8	186.5	5.4	0.00
Victoria Loop 175	Seal	77	24000	3.0	79.7	3.5	9.58

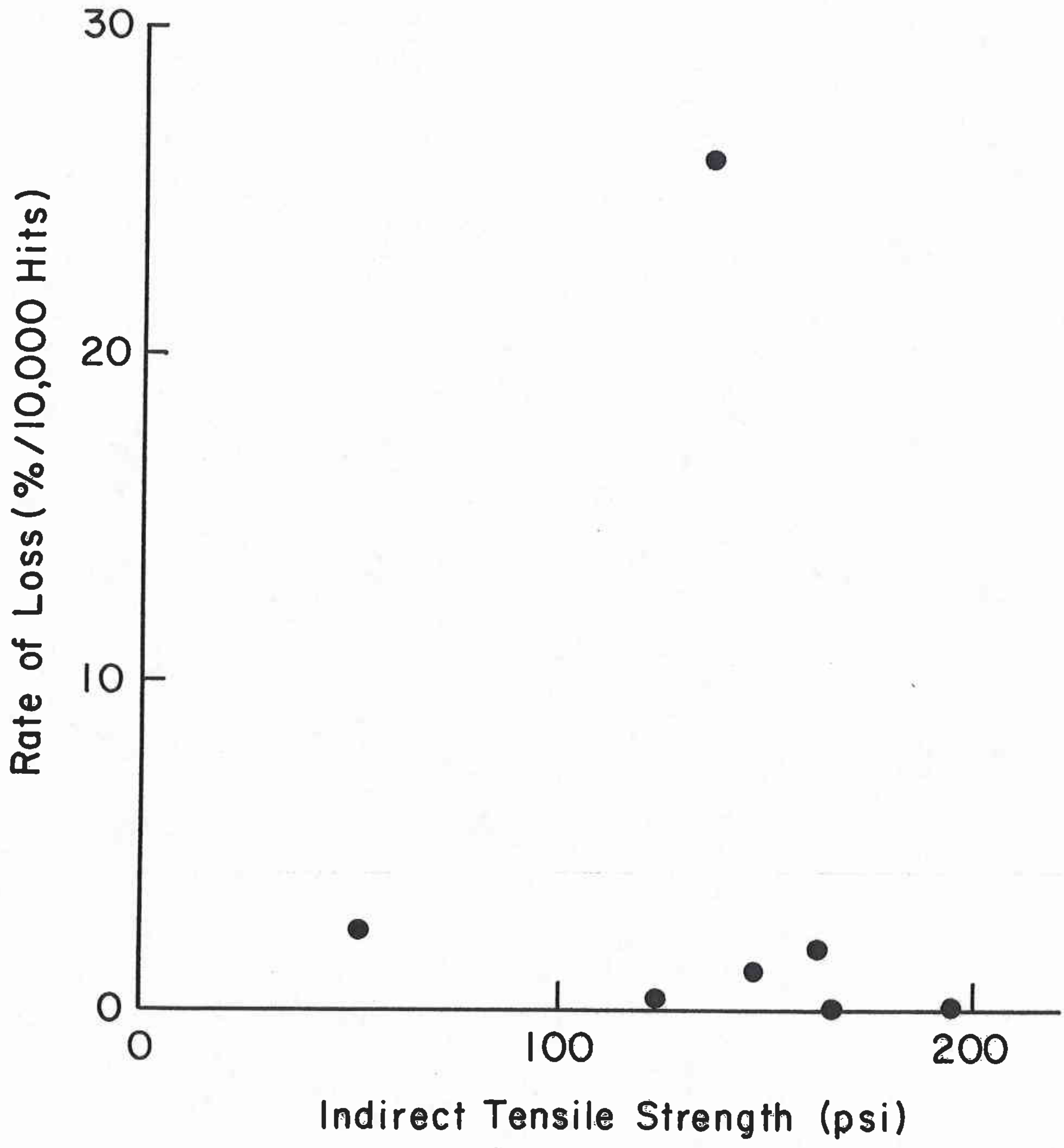

Figure 49. A Plot of the Observed Loss Rates vs. the Indirect Tensile Strength of the Asphalt.

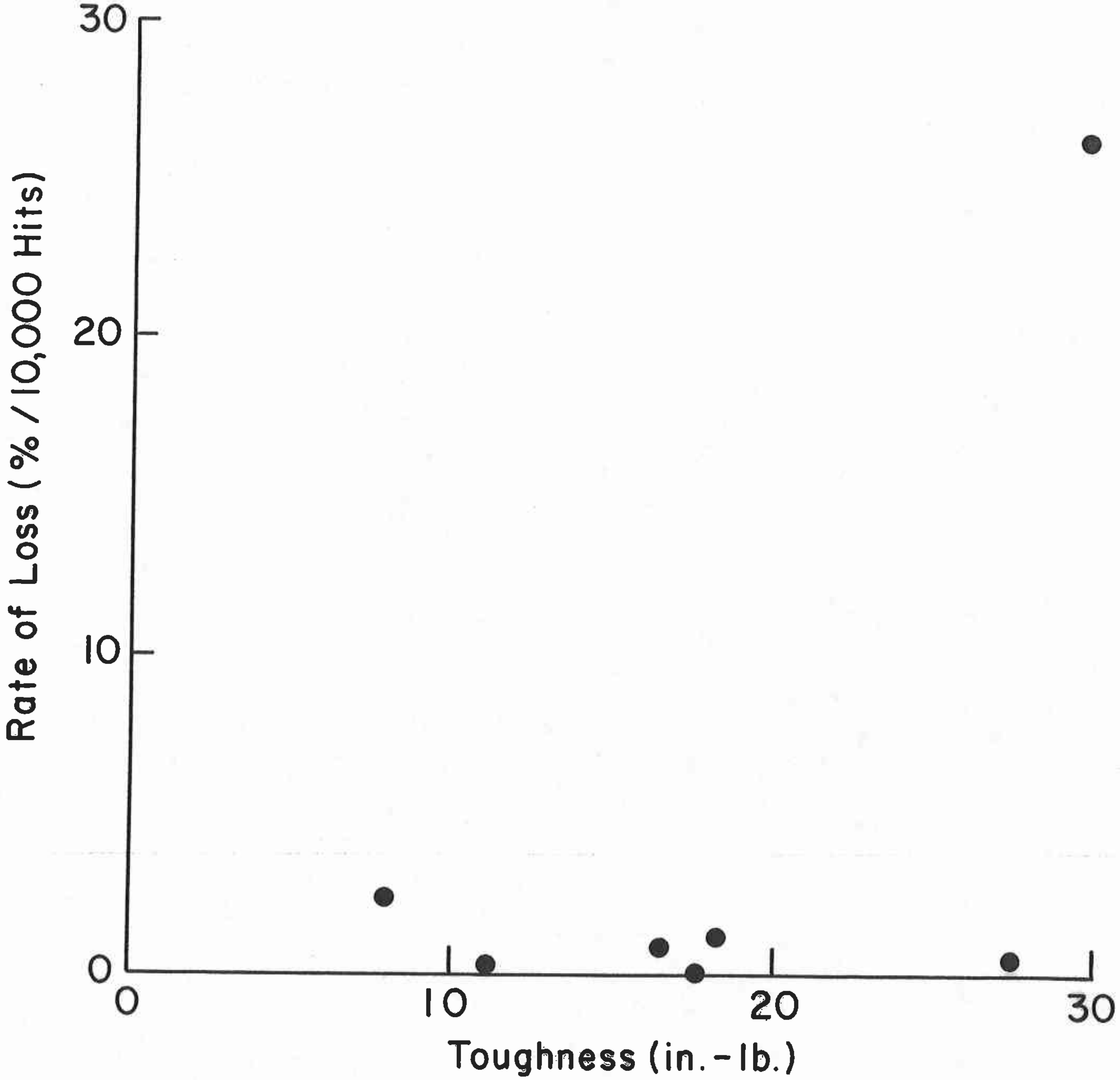

Figure 50. A Plot of the Observed Loss Rates vs. the Toughness Measured for the Asphalt.

12. Strain (in/in)

13. Toughness (in-lbs)

14. Marker Type (2x4, 4x4, Ceramic)

Appendix D, lists the locations and corresponding data for these test cores.

A statistical analysis was performed on the data to determine which variable contributed the most to marker loss. Table 13, presents the results of the multiple linear regression using all variables. The overall accuracy of the model is R=.85 which accounts for the majority of the error. This level of accuracy is to be expected with this many variables. Those variables accounting for the majority of the error are:

1.	Lift Height	-.181
2.	Top Lift	-.396
3.	Weight in Air	-.431
4.	Weight in Water	-.382
5.	Tensile Strength	.153
6.	Traffic	.171
7.	Time	.286
9.	Toughness	-.274
10.	Marker Type	.280

Following each variable is the associated amount of error explained by that variable. A regression model using these 10 variables instead of the original 14 variables reduced the accuracy of the model from R=.85 to R=.75 as indicated by Table 14. This means the other four variables accounted for approximately .10 of the total error.

Plots of the variables, similar to those in Appendix E, indicated that some variables may not be linear. Specifically, top lift, weight in air, and density appear to be curvilinear which may mean that a model with squared terms would be more appropriate. Therefore a statistical analysis using 16 variables, in which three were squared, was performed. The results of this analysis is presented in Table 15. The correlation coefficient increased from R=.85 to R=.86 indicating a slight increase in model accuracy due to the exponential terms.

These models indicate the complexity of the RPM loss problem. In order to develop a simple test which would indicate which asphalts would retain markers, a model with fewer variables to account for the majority of the

Table 13. Model With All Variables Included

Dependent Variable: 12 Loss | 26 Valid Cases

Coeff of Determination	.716847	Estimated Constant Term:	-845.575
Multiple Corr Coeff:	.846668	Standard Error of Estimate:	13.7190

Analysis of Variance for the Regression:

Source of Variance	Degrees of Freedom	Sum of Squares	Mean of Squares	F Test
Regression	13	5717.86	439.836	2.33692
Residuals	12	2258.54	188.212	
Total	25	7976.41		

Variable	Regression Coefficient	Standardized Coefficient	Correlation With Dependent
3 Lift Ht	1.97932	.270552	-0.180848
4 Top Lift	209.750	3.54908	-0.395915
5 Material Type	-7.52693	-0.165283	5.664E-002
6 Wt Air	-0.169353	-1.50630	-0.431134
7 Wt Air	-0.688262	-3.82197	-0.382409
8 Density	10702.0	3.44048	- 6.067E-002
9 Tensile	4.650E-002	0.122179	0.152959
10 Traffic	10.9773	1.46682	0.170821
11 Time	1.04147	4.096E-002	0.286463
13 Stress	7.904E-002	0.187583	0.156599
14 Strain	67.9057	4.613E-002	- 4.153E-002
15 Tough	0.644996	-0.271966	-0.273899
16	-18.1615	-0.374113	0.280337

Table 14. Model With All Significant Variables Set.

Dependent Variable: 12 Loss — 26 Valid Cases

Coeff of Determination	.577473	Estimated Constant Term:	39.8009
Multiple Corr Coeff:	.759916	Standard Error of Estimate:	14.9894

Analysis of Variance for the Regression:

Source of Variance	Degrees of Freedom	Sum of Squares	Mean of Squares	F Test
Regression	10	4606.16	460.616	2.05007
Residuals	16	3370.25	224.683	
Total	29	7976.41		

Variable	Regression Coefficient	Standardized Coefficient	Correlation With Dependent
3 Lift Ht	-2.82513	-0.386164	-0.180848
4 Top Lift	44.9863	0.761194	-0.395915
6 Wt Air	-0.720258	-6.40628	-0.431134
7 Wt Wtr	1.03492	5.74700	-0.382409
10 Traffic	-2.52249	-0.337061	0.170821
11 Time	17.3486	0.682410	0.286463
13 Stress	-5.495E-003	-1.304#-002	0.156599
15 Tough	-0.463815	-0.195570	-0.273899
16	4.60953	9.495E-002	0.280337

Table 15. **Model With All Variables Included**

Dependent Variable: 12 Loss   30 Valid Cases

Coeff of Determination .744122   Estimated Constant Term: -380.806
Multiple Corr Coeff: .862625   Standard Error of Estimate: 11.6124

Analysis of Variance for the Regression:

Source of Variance	Degrees of Freedom	Sum of Squares	Mean of Squares	F Test
Regression	13	6274.42	482.647	3.57922
Residuals	16	2157.55	134.847	
Total	29	8431.97		

Variable	Regression Coefficient	Standardized Coefficient	Correlation With Dependent
3 Lift Ht	-0.569551	-8.120E-002	-8.878E-002
4 Top Lift	614.50100	10.8755	-0.352466
5 T Lift Sq	-199.45000	-8.34837	-0.363445
6 Wt Air	-0.687280	-6.21553	-0.361387
7 Wt Air Sq	3.326E-004	3.26538	-0.359135
8 Density	-708.61400	-.257028	5.556E-002
9 Density Sq	40876.50000	2.34586	5.260E-002
10 Traffic	5.24628	0.740423	0.223880
11 Time	11.75000	0.474783	0.241137
13 Stress	0.183009	0.424277	0.129781
14 Strain	100.26900	6.666E-002	-1.483E-002
15 Tough	-2.00073	-0.840149	-0.214887
16 Marker Type	-24.3993	-5.42384	0.297778

error, must be found. Table 16 presents a model with 6 variables. These six variables accounted for the majority of the total error. The overall accuracy of this model was R=.54 which is very low. This means that a simple test to determine the pavements ability to retain markers is not possible using the data collected in this project.

Table 16. Model With Best Six Variables

Dependent Variable: 12 Loss — 60 Valid Cases

Coeff of Determination	.292682	Estimated Constant Term:	-36.3446
Multiple Corr Coeff:	.541001	Standard Error of Estimate:	16.1326

Analysis of Variance for the Regression:

Source of Variance	Degrees of Freedom	Sum of Squares	Mean of Squares	F Test
Regression	6	5707.77	951.295	3.65516
Residuals	53	13793.8	260.261	
Total	59	19501.6		

Variable	Regression Coefficient	Standardized Coefficient	Correlation With Dependent
4 Top Lift	176.14600	2.74505	-0.315194
5 T Lift Sq	-78.60120	-3.06063	-0.331723
6 Wt Air	-0.209916	-1.67796	-0.242479
7 Wt Air Sq	1.731E-004	1.54000	-0.252385
13 Stress	0.123965	0.284880	0.284004
16 Marker Type	-10.762200	-.310026	-0.140375

ADHESIVE EVALUATION FOR PAVEMENT MARKERS ON ASPHALT

During the first year of this research project it was determined that the retention of RPMs on the roadway was the biggest problem associated with the markers. The markers sustain a number of hits depending on the length of time they are on the road, the average daily traffic (ADT) and the location, whether the markers are on tangents or curves (centerlines or lanelines). The 4x4 RPM on asphalt roads were dislodged from the road in great numbers, for example in a relatively short period of time (up to 80 percent in 1.5 years). The loss of markers is due primarily to their inability to repeatedly absorb the total force imposed on them and transmit it to the pavement. For some reason, yet to be determined, environmental and material related factors create a fracture in the pavement around the epoxy pad holding the markers to the surface. After several hundred hits the RPM along with the adhesive and some asphalt is freed from the roadway. To eliminate this problem one or all three of the following solutions could be employed:

1. Strengthen the roadway surface
2. Redesign the marker to reduce impact forces
3. Use an adhesive that better absorbs shock forces.

The studies conducted during the course of this research project have not fully defined the variables contributing to the lack of strength of the asphalt. There is evidence that (1) moisture and (2) freeze-thaw interaction reduce the strength of the pavement and encourage RPM loss. Marker shape has a significant impact on marker retention. RTBs are retained on the road longer than RPMs due to their shape. The primary objective of this study did not include the design/redesign of the marker shape. The Technical Advisory Committee (TAC) felt that this was an industry role and not that of the SDHPT. It was determined during the first two years of the project that rapid set epoxy (Type I) did not become brittle after it cured. To some degree it remained compliant thus being able to absorb more force than the other epoxy formulations used by the Department.

Based on these facts the TAC determined that an epoxy study would be appropriate. The study would be conducted in the Bryan/College Station area on asphaltic concrete roads using rapid-set epoxies.

In the Corpus Christi area, Stimsonite installed RPMs using a bituminous material called "Bitumen". This test served as an extension to the Bryan/College Station test.

DESCRIPTION OF TESTS

Test Materials

The test consisted of using four different manufacturer's type I epoxy in five test conditions. The types and manufacturer of the epoxies were:

1. Type I Ring Manufacturing Company
2. Type M (Black Magic) - Miracle
3. Type I Epoxy Industries
4. Type I Ferro Corporation

These four types of epoxies were placed in five test conditions. The five test conditions were:

1. Regular application of Ring Manufacturing Type I Epoxy
2. Regular application of Type M (Black Magic) Epoxy
3. Regular application of Epoxy Industries Type I Epoxy
4. Regular application of Ferro Corporation Type I Epoxy, and
5. Twice the circumference of the normal application with the Type I Epoxy from Epoxy Industries.

Various types of RPMs and RTBs were used in this study. They are as follows:

1. Stimsonite 88 Type II-CR
2. American Clay P15A without Studs Type I-C
3. American Clay P7A with studs
4. Stimsonite 947 Type II-CR
5. American Clay P15 without studs Type I-C
6. American Clay P117 without studs Type II-CR

The various types of epoxies and test conditions were randomized at each location. The RPMs were placed first at one test site and the RTBs were placed first at the second test site. The randomized order will be discussed in the description of each test site.

Test Sites

Two tests sites consisting of 4,000 linear feet of lane line markers were established in District 17, near Bryan/College Station. Markers were placed 80 feet apart between existing lane line markers.

The first site was on Texas 21 approximately 2.5 miles west of FM 2818. This section is a four lane divided highway with a moderate amount of truck traffic. The ambient temperature during installation ranged from 59_F to 62_F. At this location five RTBs were placed immediately preceding five RPMs. The American Clay P15 markers with studs were used, however, one P117 with studs and five P7As were used for comparison. Approximately 2,000 linear feet of lane line markers were installed in the following order:

1. Type M (Black Magic) - Miracle
2. Type I Epoxy Industries - Applied with twice the circumference
3. Type I Epoxy Industries
4. Type I Ferro Corporation
5. Type I Ring Manufacturing

The second site was on FM 2818 near the FM 60 underpass. The ambient temperature ranged from 55_F to 57_F. Five Stimsonite 88s (RPMs) were placed immediately preceding five American Clay P15A (RTBs). The last three RTBs were P7As. Approximately 2,000 linear feet of lane line markers were placed in the following order:

1. Type I Ferro Corporation
2. Type I Ring Manufacturing
3. Type M (Black Magic) - Miracle
4. Type I Epoxy Industries - Applied with epoxy twice the normal circumference.
5. Type I Epoxy Industries

This site was selected because it is characterized with a high volume of passenger vehicle traffic and heavy oil field truck traffic. Both of these sites were known to be poor marker retainers.

Test Results

Since the initial installation three test counts of the markers have been performed. These counts were conducted after about 7 days, 60 days, 90 days and 8 months. Figures 51 through 60, illustrate the percent of markers

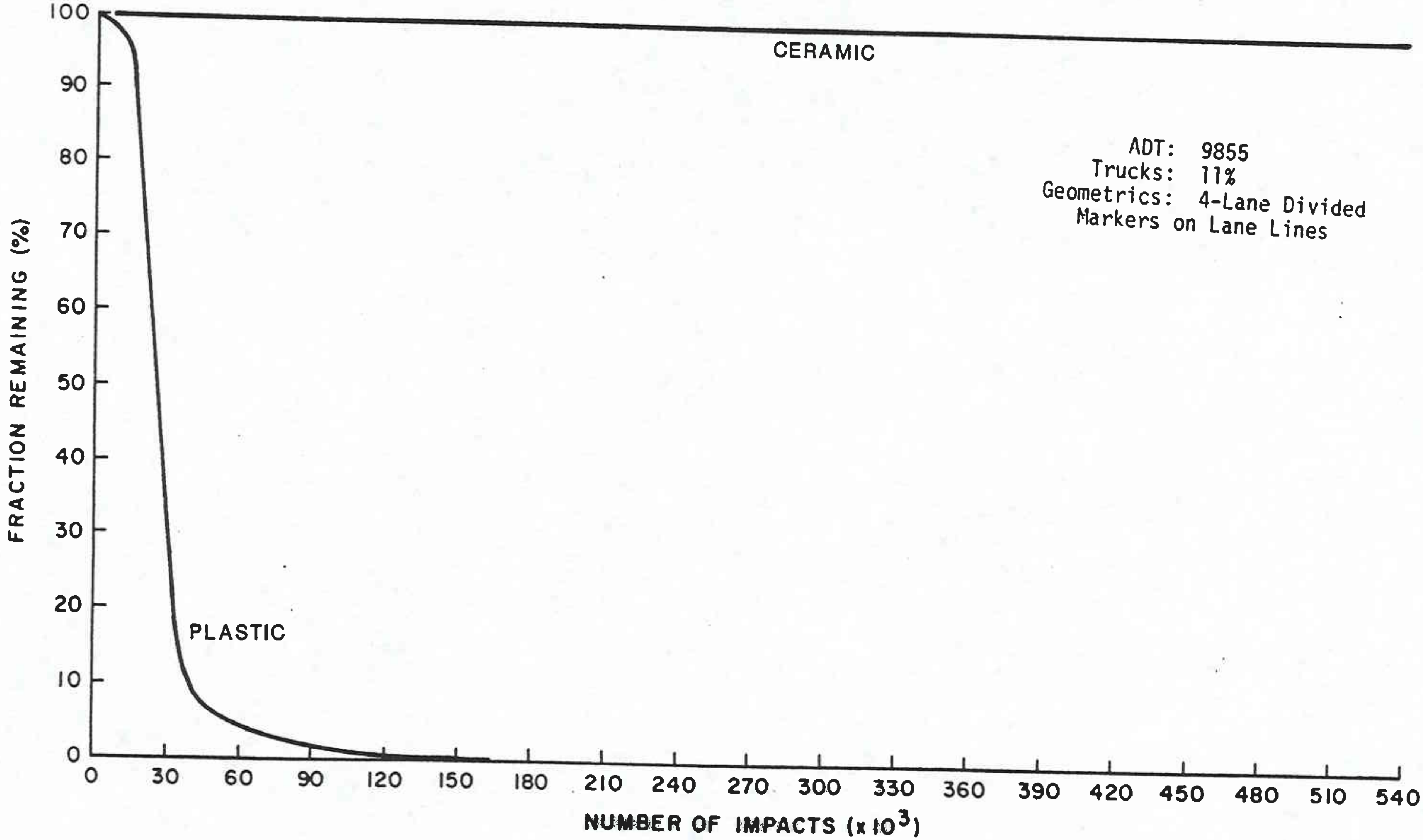

Figure 51. Texas 21 - Test Section #1 (Type M - Black Magic)

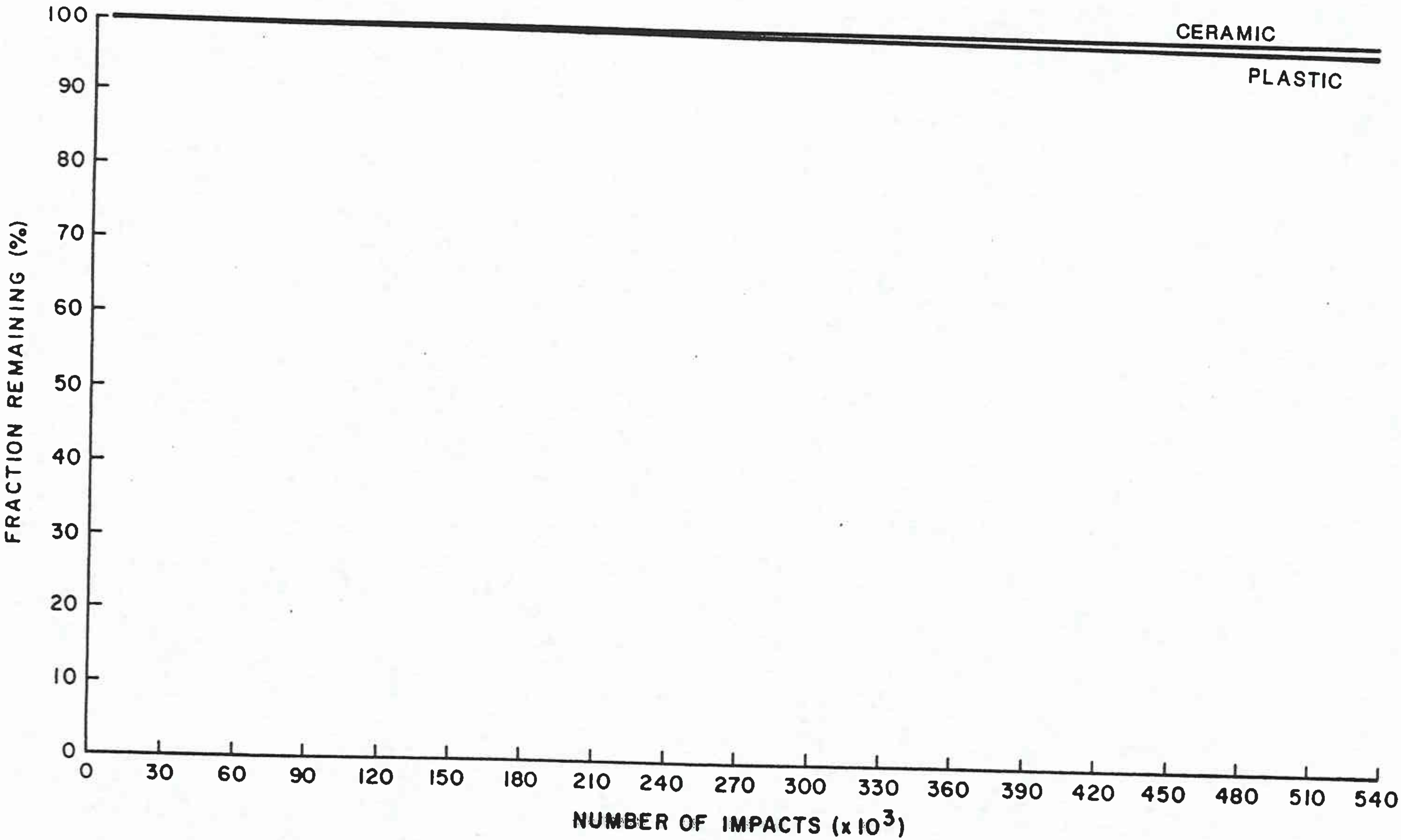

Figure 52. Texas 21 - Test Section #2 (Type I - Epoxy Industries) Applied Twice Normal Circumference.

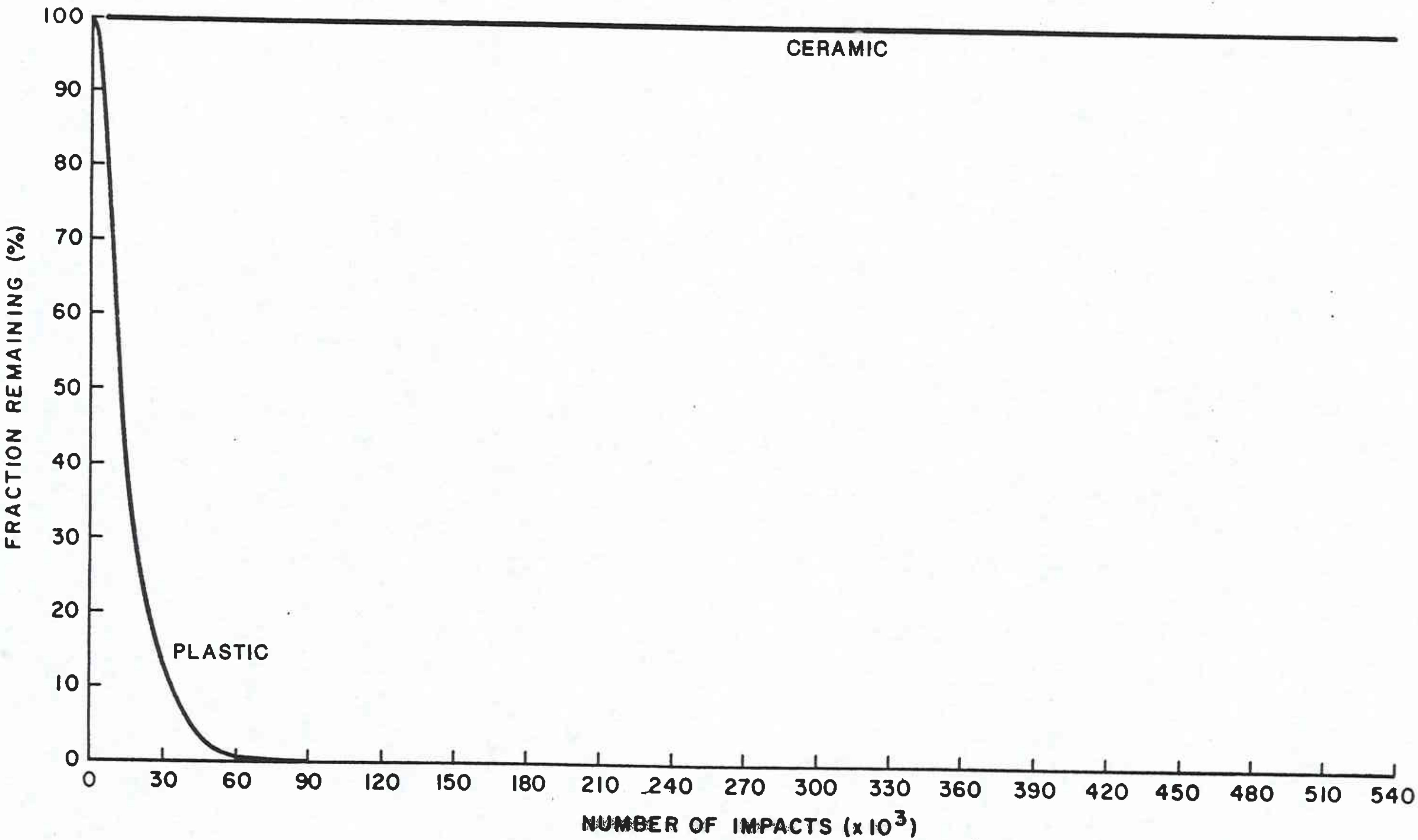

Figure 53. Texas 21 - Test Section #3 (Type I - Epoxy Industries)

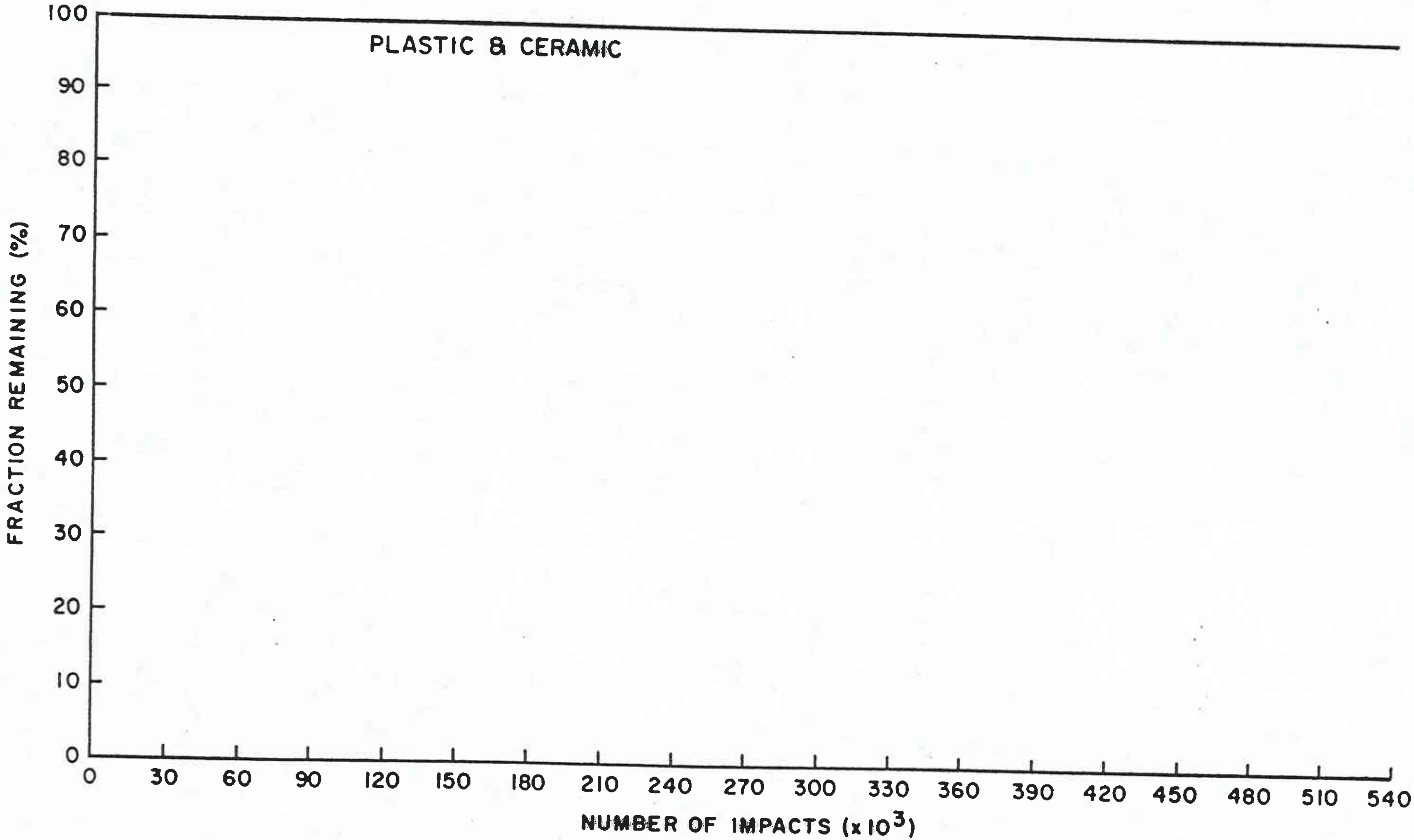

Figure 54. Texas 21 - Test Section #4 (Type I - Ferro Corporation).

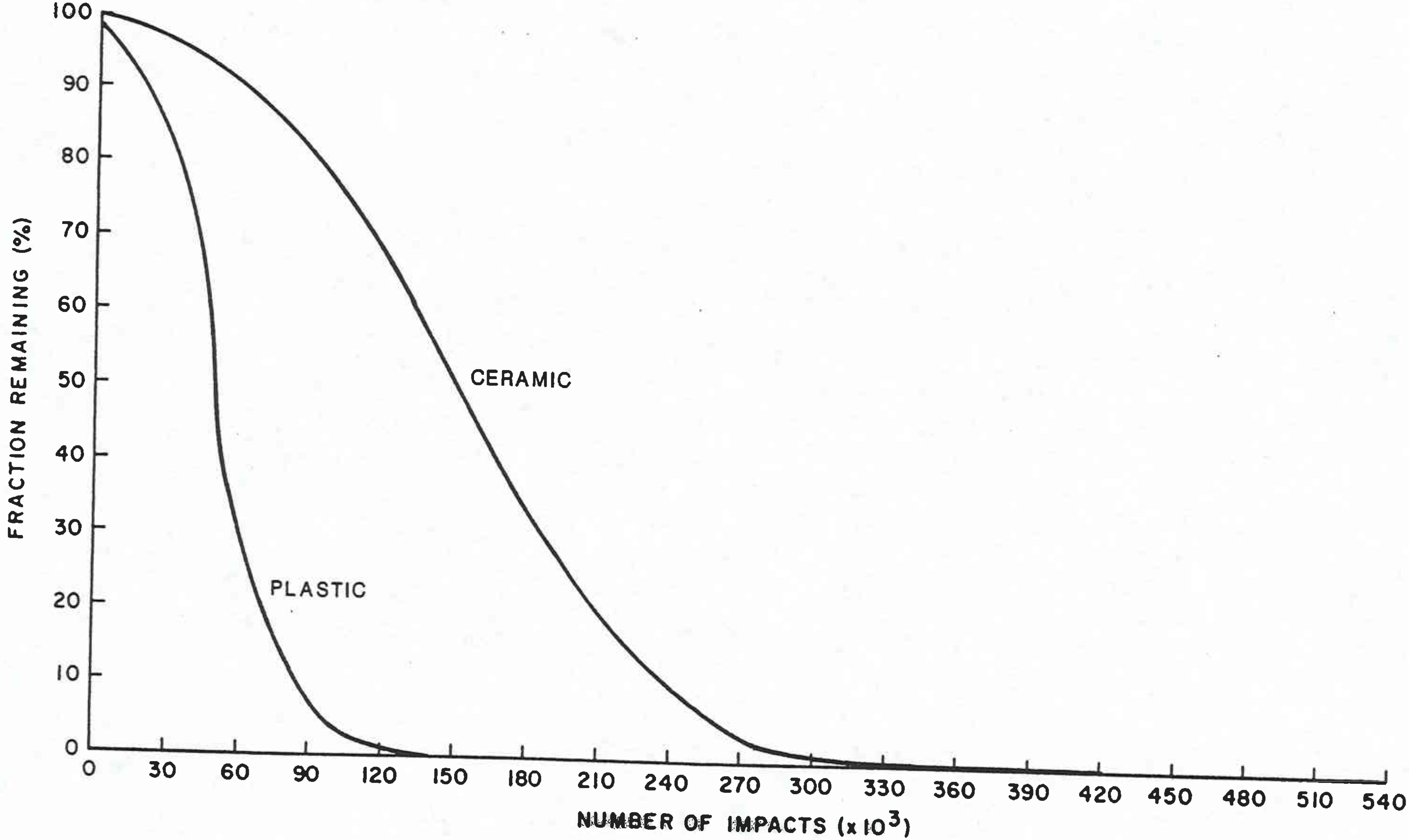

Figure 55. Texas 21 - Test Section #5 (Type I - Ring Manufacturing).

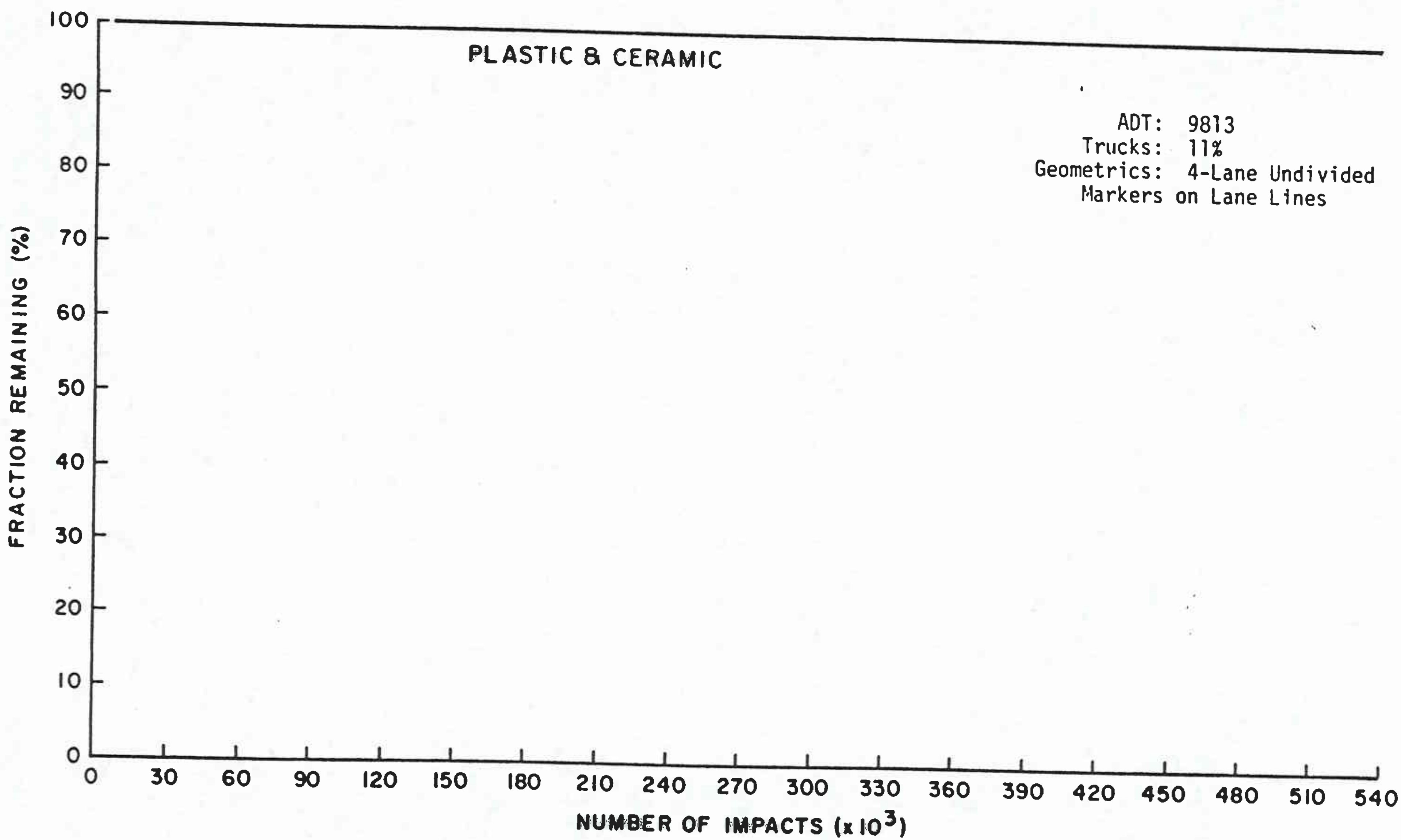

Figure 56. FM 2818 - Test Section #1 (Type I - Ferro Corporation).

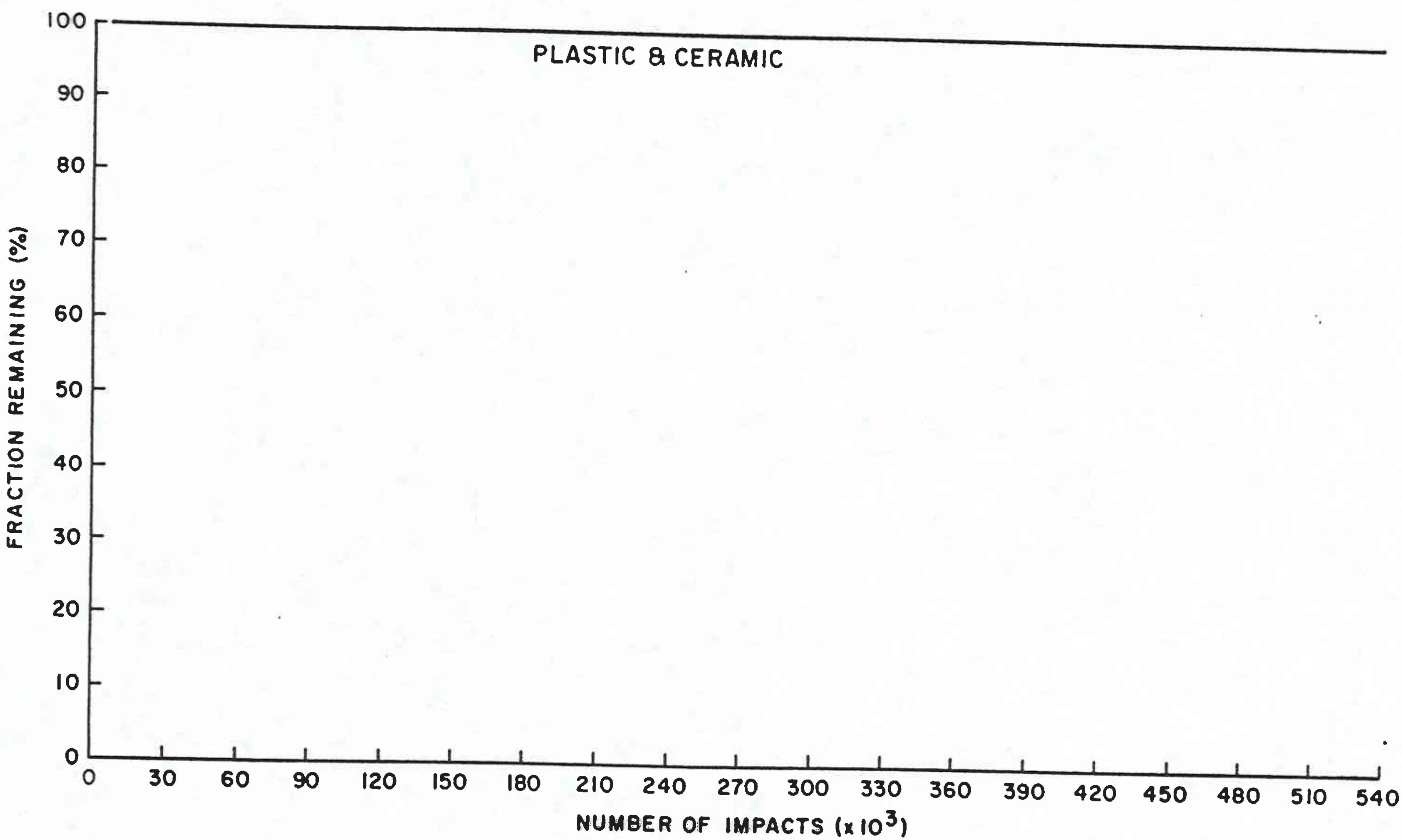

Figure 57. FM 2818 - Test Section #2 (Type I - Ring Manufacturing).

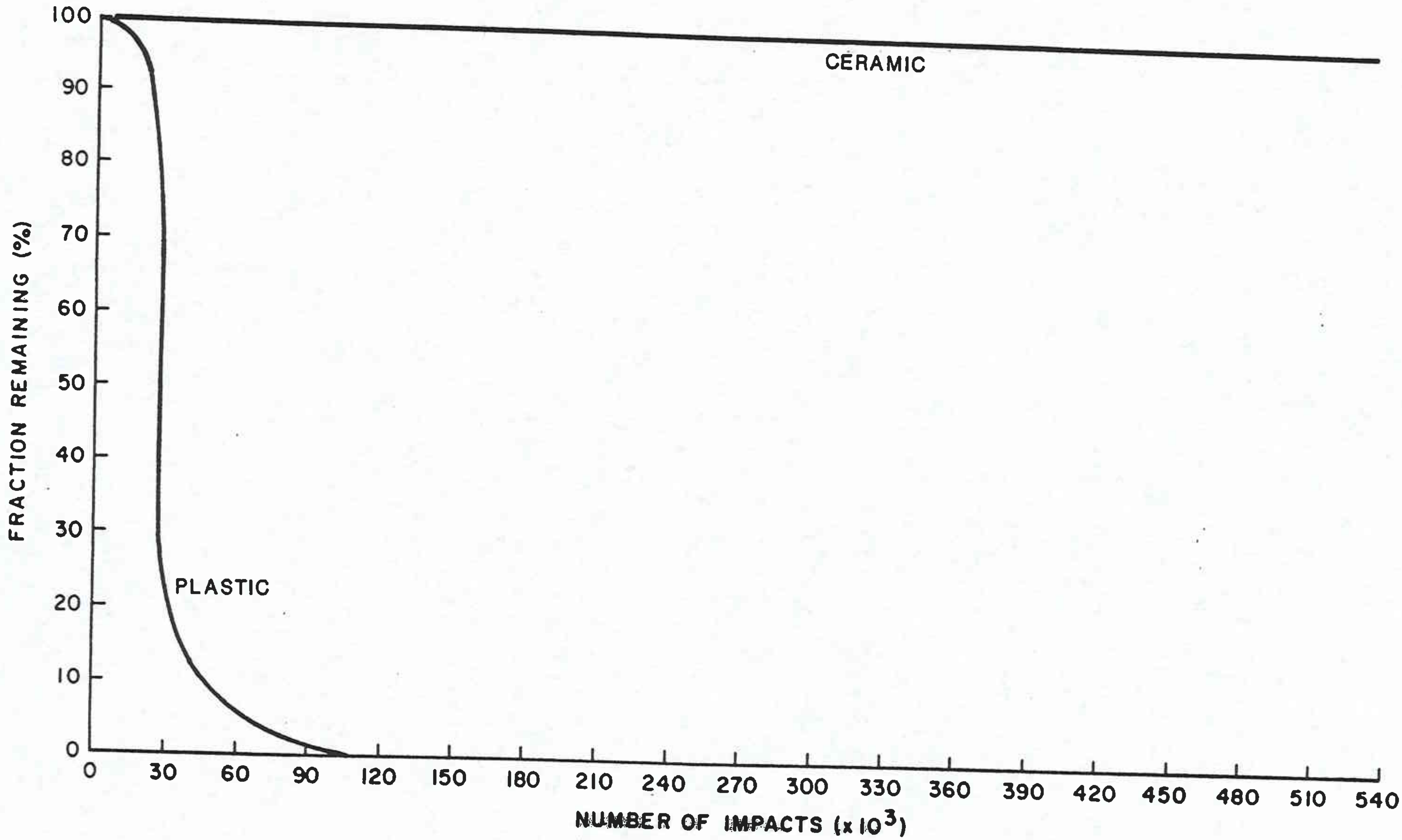

Figure 58. FM 2818 - Test Section #3 (Type M - Black Magic).

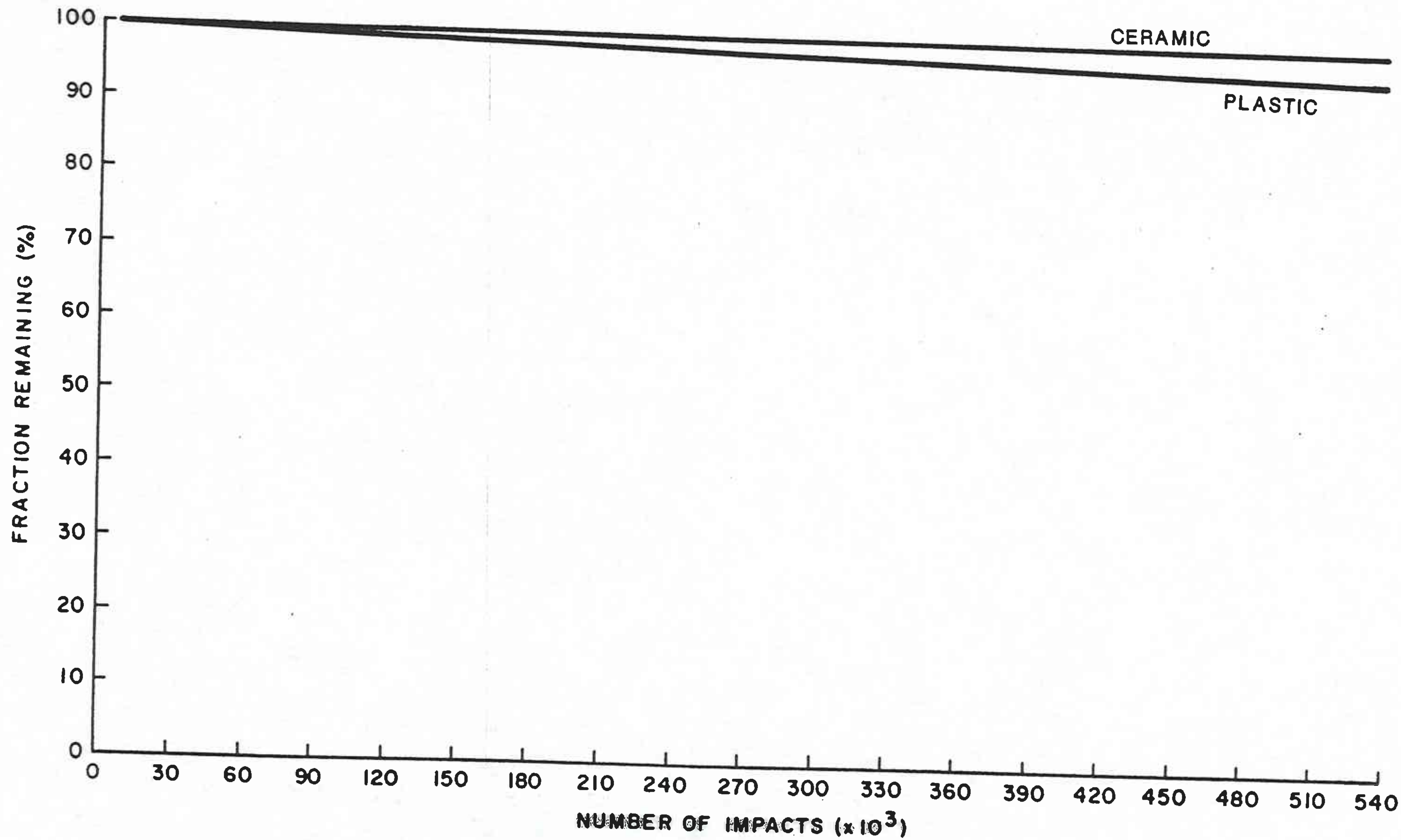

Figure 59. FM 2818 - Test Section #4 (Type I - Epoxy Industries Twice Normal Circumference).

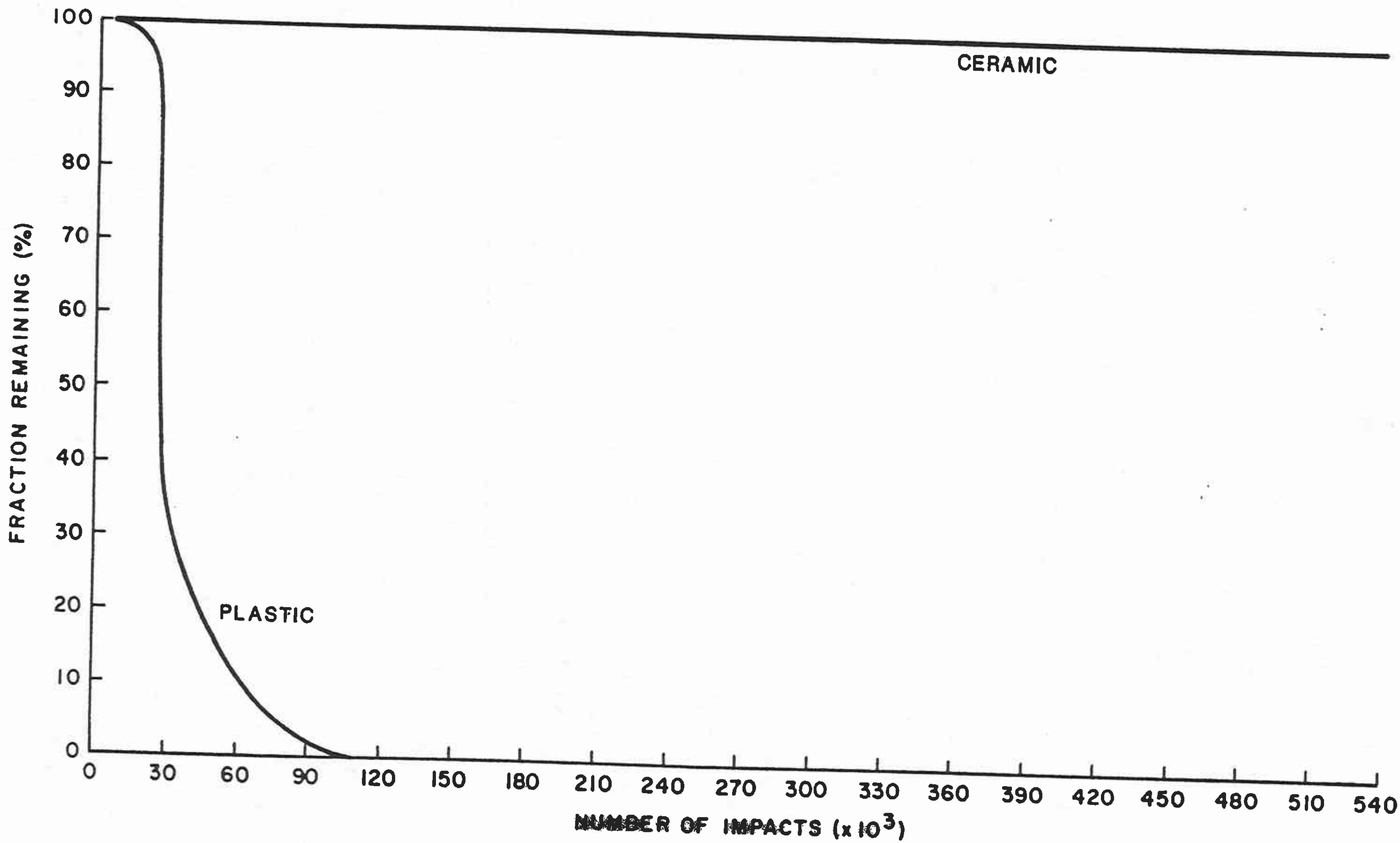

Figure 60. FM 2818 - Test Section #5 (Type I - Epoxy Industries).

remaining at each of the sites by marker type and test section. Comparing both sites without regard to either marker type or epoxy, the test site on Texas 21 has lost more markers (5) than on FM 2818. Both sites carry approximately the same traffic (9,000 VPD). The other major difference is that the Texas 21 site has 2x4 RPM whereas the FM 2818 sites has 4x4 RPMs. Four of the five missing markers are plastic. All of the missing 2x4's are in test section 1. The epoxy in this section is the Miracle Type M - Black Magic. The corresponding test section on FM 2818 (#3) has not lost any markers. The one missing RTB was located in test section #5 which used the Ring Manufacturing Type I epoxy. The three counts from which these figures were drawn were made within the first three months after installation. Periodically counts will be made over remaining life to determine loss rates by marker type and epoxy type. District 17 is reconstructing portions of FM 2818 near the test site. Unusual wear may occur because of this construction activity.

BITUMEN EPOXY STUDY

Test sections of markers were installed in District 16 during July 1984 440 Low-Profile (2x4) RPMs were installed using a bituminous adhesive, 340 Low-Profile RPMs and 500 RTBs using Texas Type II epoxy. These markers were installed on Texas 358, Texas 44 and Farm-to-Market 881. Texas 358 is a 4-lane divided facility with an ADT of 36,000 vehicles. Texas 44 is a 4-lane divided with an ADT of 14,000 with a section of 2-lane with an ADT of 15,000. Farm-to-Market 881 is a 2-lane facility with an ADT of 9,000.

The adhesive appears to be performing satisfactorily as illustrated in Figure 61. Those RPMs installed with bitumen have incurred a 2 percent loss in 10 months compared to a 17 percent loss for those RPMs installed with regular Texas epoxy. Appendix F, presents the physical characteristics of the bitumen adhesive. Numerically, 9 RPMs installed with bitumen are missing, whereas 58 RPMs installed with Texas Epoxy are missing. This indicates a significant loss reduction due to the type of adhesive.

A cost analysis was performed for comparison and is presented in Table 17. The Texas Epoxy is contained in two one gallon containers. One container is hardener and the other is resin. The combined cost for both containers is

Table 23. Calculation of the Fraction of RTBs to be Replaced Assuming Biannual Maintenance. The Present Worth of a Ten-Year Service Life is Also Shown.

Year After Installation	Loss Rate (per 2 yr)	Year 2	Year 4	Year 6	Year 8	Year 10
2	0.627	0.627	0.393	0.366	0.368	0.368
4	0.191		0.191	0.119	0.111	0.112
6	0.102			0.102	0.063	0.059
8	0.045				0.045	0.028
10	0.018					0.018
	Required Replacement	0.627	0.584	0.587	0.587	0.585
	Present Worth (Dollars)	1186.64	921.41	765.41	632.57	521.00

Net Present Worth = $6,027.03 (per 1,000 Markers)

= $ 397.78 per line mile @ 80 ft c/o

Table 24. Calculation of the Fraction of RPMs to be Replaced Assuming a Five Year Maintenance Cycle. The Present Worth of a Ten-Year Service Life is Also Shown.

Year After Installation	Loss Rate (per 5 yr)	Year 5	Year 10
5	0.824	0.824	0.678
10	0.137		0.137
	Required Replacement	0.824	0.815
	Present Worth (Dollars)	1120.49	688.14

Net Present Worth = $3,808.63 (per 1,000 Markers)

= $ 251.37 per line mile @ 80 ft o/c

Table 25. Calculation of the Fraction of RTBs Replaced Assuming a Five Year Maintenance Cycle. The Present Worth of a Ten-Year Service Life is Also Shown.

Year After Installation	Loss Rate (per 5 yr)	Year	
		5	10
5	0.879	0.879	0.772
10	0.105		0.105
	Required Replacement	0.879	0.877
	Present Worth (Dollars	1178.91	730.34

Net Present Worth = $3,909.25 (per 1,000 Markers)
= $ 258.01 per line mile @ 80 ft o/c

CONCLUSIONS

There is a great deal of evidence that the real cost of installing and maintaining the reflective pavement markers may be higher than was originally anticipated, primarily because of the rapid loss rates that were observed. While epoxy failures, marker breakage, poor installation techniques, reflector loss, and punch through failures (marker submergement) were all observed to be major modes of failure, by far the most important one is the loss of RPMs due to failures within asphalt paving. The largest portion of the effort reported was the attempts to characterize and ultimately to predict the probability of this type of failure.

1. While installation guidelines, published earlier, emphasized the importance of installation techniques, it is a readily apparent conclusion that improper installations are not the major cause for RPM loss in Texas. This conclusion is not intended to imply that moisture and temperature at the time of installation are not important. They are, and if the markers are installed with the pavement surface too wet, either asphalt or Portland cement concrete, they are apt to disappear quickly, primarily due to epoxy-to-pavement failure.
2. So far as retention is concerned, there is evidence that the RTBS, especially those with studded bases, are the best performers. The 2x4 RPMs are the poorest.
3. Marker loss rates on all pavement surfaces are clearly a strong function of the number of hits by tires. While there is evidence that trucks are more damaging than autos the equivalency was not established. Any measures that can be taken to protect the markers from hits will increase their time of retention on the pavement.
    a. Shape appears to be a primary factor in retaining markers. Shape is probably the primary factor accounting for the superior performance of the RTBS.
    b. Markers used in lane lines receive about twice as many hits as those in the centerlines, on four-lane divided highways, and hence disappear, and wear, at a significantly faster rate.

4. One early conclusion was that seal-coat surfaces retain markers better than does asphalt concrete. When losses are compared to the number of hits this conclusion was found not to be valid. The fact that seal-coats are often used on lightly traveled roads probably accounts for the earlier misconception.
5. A valid relationship between conventional asphalt concrete and retention rates was not established.

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APPENDIX A

CUMULATIVE DISTRIBUTION FACTOR

CUMULATIVE DISTRIBUTION FACTOR

To reasonably and consistently represent the multiple observations of missing markers, these observations were mathematically fitted to an expression for an ogive (S-shaped) curve. Often these curves are called cumulative distribution factors. The expression used was

$$PR = \frac{100\%}{(1+\frac{n}{N})}^{K}$$

where

PR = the percentages fraction remaining
N,K = arbitrary constants available to best fit the observations
n = number of hits, the independent variable

The physical significance of N is that it is the number of hits (or vehicles in adjacent lanes) when one-half of the markers are missing. The corresponding significance of K is that it influences the maximum slope of the ogive curve, that is to say, the rate at which the markers are disappearing. K's larger than one give a "slope of zero at the origin while K's smaller than one give a negative slope of infinity.

The fact that this expression is a cumulative distribution function means that the derivative is a probability density function. The area under the density function equal to unity (100%) and has properties of a conventional statistical distribution.

APPENDIX B

VALID REGRESSION MODELS FOR AVAILABLE PAVEMENT MARKER DATA

VALID REGRESSION MODELS FOR AVAILABLE PAVEMENT MARKER DATA

1. Permark on Portland Cement Concrete - All Data

   % Pavement Failures = 3.06 - 0.04 (Traffic) Plot A

   R^2 = 0.93 p = 0.04 N = 4

   % Pavement FAilures = 4.49 - 0.046 (Time) Plot B

   R^2 = 0.93 p = 0.04 N = 5

2. 88s on Asphaltic Concrete

   % Reflectivity Lost = 47.12 + 16.12 (Traffic) Plot C

   R^2 = 0.91 p = 0.0002 N = 7

3. Permark on Portland Cement Concrete

   % Missing Marker = - 3.47 + 0.34 (Time) Plot E

   R^2 = 0.81 p = 0.04 N = 5

   % Reflectivity Lost = 4.35 + 1.94 (Time) Plot F

   R^2 = 0.82 p = 0.03 N = 5

4. Permark on Portland Cement Concrete

   No Valid Cases Existed

5. 88s on Portland Cement Concrete

   % Epoxy Failure = - 8.93 + 0.70 (Time) Plot G

   R^2 = 0.97 p = 0.02 N = 5

6. 88s on Portland Cement Concrete - All Data

   % Epoxy Failure = - 8.93 + 0.70 (Time) Plot J

   R^2 = 0.97 p = 0.002 N = 4

   % Epoxy Failure = - 18.86 + 1.245 (Traffic) Plot K

   R^2 = 0.97 p = 0.002 N = 5

   % Reflectivity Lost = - 12.44 + 1.39 (Time) Plot L

   R^2 = 0.97 p = 0.000 N = 6

   % Broken Markers = 8.76 + 0.90 (Time) Plot M

$R^2 = 0.91$ $p = 0.012$ $N = 5$

7. 88s on Asphaltic Concrete - All Data

% Pavement Failure = - 29.44 + 14.87 (Traffic) - 1.06 (Time)

Traffic Time

$R^2 = 0.80$ $p = 0.01, 0.27$ $N = 8$ Plots D_1
Plots D_2

Where:

Time = Time in months since markers were placed on the road.

Traffic = Traffic in the adjacent two lanes since markers were placed.

Trucks = Percent trucks in the traffic stream at the location.

```
              40.0000                                                  90.0000
                 40          50          60          70          80         90
                 -+-----------+-----------+-----------+-----------+-----------+
0       2.00000  +
5       1.83333  +
        1.66667  +
P       1.50000  +
V       1.33333  +         1
T       1.16667  +
F       1.00000  +
A      0.833333  +         1
I      0.666667  +
L      0.500000  +
       0.333333  +
       0.166667  +
        0.00000  +                                                 2
                 -+-----------+-----------+-----------+-----------+-----------+
                 40          50          60          70          80         90
              40.0000                                                  90.0000

TOTAL POINTS PLOTTED:4                 1 TRAFFIC
```

PLOT A

```
              10.0000                                             100.000
                 10    20    30    40    50    60    70    80    90   100
                 -+-----+-----+-----+-----+-----+-----+-----+-----+-----+
0       70.0000  +
6       65.0000  +
        60.0000  +        1
R       55.0000  +
E       50.0000  +
F       45.0000  + 1                                                   1
L       40.0000  +
O       35.0000  +
S       30.0000  +                                     1
T       25.0000  +
        20.0000  +
        15.0000  +
        10.0000  +                                     1               1
                 -+-----+-----+-----+-----+-----+-----+-----+-----+-----+
                 10    20    30    40    50    60    70    80    90   100
              10.0000                                             100.000

TOTAL POINTS PLOTTED:6                 2 TIME
```

PLOT B

```
MISSING VALUE TREATMENT: LISTWISE

                2.00000                                               9.00000
                  20      30      40      50      60      70      80      90
                  -+-------+-------+-------+-------+-------+-------+-------+
O       100.000    +
6       90.0000    +                                                 1
        80.0000    +                                                1
R       70.0000    +
L       60.0000    +
O       50.0000    +
S       40.0000    +
T       30.0000    +
        20.0000    +                  1      2
        10.0000    +
        0.00000    +      2           1
                  -+-------+-------+-------+-------+-------+-------+-------+
                  20      30      40      50      60      70      80      90
                2.00000                                               9.00000

TOTAL POINTS PLOTTED:8                1 TRAFFIC
```

PLOT C

```
MISSING VALUE TREATMENT: LISTWISE

                2.00000                                               9.00000
                  20      30      40      50      60      70      80      90
                  -+-------+-------+-------+-------+-------+-------+-------+
O       90.0000    +
5       80.0000    +                                                1
        70.0000    +
P       60.0000    +
V       50.0000    +
T       40.0000    +
F       30.0000    +                                               1
A       20.0000    +
I       10.0000    +                 1      1
L       0.00000    +      2          1      1
                  -+-------+-------+-------+-------+-------+-------+-------+
                  20      30      40      50      60      70      80      90
                2.00000                                               9.00000

TOTAL POINTS PLOTTED:8                1 TRAFFIC
```

PLOT D_1

```
MISSING VALUE TREATMENT: LISTWISE

             10.0000                                                        40.0000
                10                   20                   30                     40
                -+--------------------+--------------------+--------------------+
O        90.0000 +
5        80.0000 +                                          1
         70.0000 +
P        60.0000 +
V        50.0000 +
T        40.0000 +
F        30.0000 +                                          1
A        20.0000 +
I        10.0000 +          1                                       1
L        0.00000 +          3                                       1
                -+--------------------+--------------------+--------------------+
                10                   20                   30                     40
             10.0000                                                        40.0000

TOTAL POINTS PLOTTED:8                    2 TIME
```

PLOT D_2

```
MISSING VALUE TREATMENT: LISTWISE

              10.0000                                                  30.0000
                 10             15              20              25          30
                 -+---------------+---------------+---------------+---------------+
O        5.00000  +
3        4.50000  +
         4.00000  +                                            1
M        3.50000  +
I        3.00000  +               1
S        2.50000  +
S        2.00000  +
         1.50000  +
         1.00000  +               1
        0.500000  +       1
         0.00000  +       1
                 -+---------------+---------------+---------------+---------------+
                 10             15              20              25          30
              10.0000                                                  30.0000

TOTAL POINTS PLOTTED:5                    2 TIME
```

PLOT E

```
              10.0000                                                       30.0000
                 10              15              20              25              30
                 -+---------------+---------------+---------------+---------------+
0       50.0000   +                                           1
6       47.5000   +
        45.0000   +
R       42.5000   +
E       40.0000   +
F       37.5000   +               1
L       35.0000   +
O       32.5000   +
S       30.0000   +      1        1
T       27.5000   +
        25.0000   +
        22.5000   +
        20.0000   +      1
                 -+---------------+---------------+---------------+---------------+
                 10              15              20              25              30
              10.0000                                                       30.0000

TOTAL POINTS PLOTTED:5              2 TIME
```

PLOT F

```
               10.0000                                                      60.0000
                 10           20           30          40           50           60
                 -+------------+------------+-----------+------------+------------+
0       40.0000   +
4       36.6667   +                                                               1
        33.3333   +
E       30.0000   +
P       26.6667   +                                                               1
O       23.3333   +
X       20.0000   +
F       16.6667   +
A       13.3333   +
I       10.0000   +
L       6.66667   +                   1
        3.33333   +
        0.00000   +    2
                 -+------------+------------+-----------+------------+------------+
                 10           20           30          40           50           60
               10.0000                                                      60.0000

TOTAL POINTS PLOTTED:5              2 TIME
```

PLOT G

```
              10.0000                                                    50.0000
                  10             20             30             40             50
                  -+--------------+--------------+--------------+--------------+
0       70.0000   +
7       65.0000   +
        60.0000   +                                               2
B       55.0000   +
R       50.0000   +
O       45.0000   +
K       40.0000   +                     1
E       35.0000   +
N       30.0000   +
        25.0000   +
        20.0000   +
        15.0000   +        2
        10.0000   +
                  -+--------------+--------------+--------------+--------------+
                  10             20             30             40             50
              10.0000                                                    50.0000

TOTAL POINTS PLOTTED:5                1 TRAFFIC
```

PLOT H

```
              10.0000                                                    60.0000
                  10          20          30          40          50          60
                  -+-----------+-----------+-----------+-----------+-----------+
0       70.0000   +
7       65.0000   +
        60.0000   +                                                            2
B       55.0000   +
R       50.0000   +
O       45.0000   +
K       40.0000   +                  1
E       35.0000   +
N       30.0000   +
        25.0000   +
        20.0000   +
        15.0000   +     2
        10.0000   +
                  -+-----------+-----------+-----------+-----------+-----------+
                  10          20          30          40          50          60
              10.0000                                                    60.0000

TOTAL POINTS PLOTTED:5                2 TIME
```

PLOT I

```
                 10.0000                                                    60.0000
                  10        20        30        40        50        60
                  -+---------+---------+---------+---------+---------+
 0      40.0000  +
 4      36.6667  +                                                   1
        33.3333  +
 E      30.0000  +
 P      26.6667  +                                                   1
 O      23.3333  +
 X      20.0000  +
 F      16.6667  +
 A      13.3333  +
 I      10.0000  +
 L      6.66667  +              1
        3.33333  +
        0.00000  +   2
                  -+---------+---------+---------+---------+---------+
                  10        20        30        40        50        60
                 10.0000                                                    60.0000

TOTAL POINTS PLOTTED:5                 2 TIME
```

PLOT J

```
                 10.0000                                                    50.0000
                  10           20           30           40           50
                  -+------------+------------+------------+------------+
 0      40.0000  +
 4      36.6667  +                                           1
        33.3333  +
 E      30.0000  +
 P      26.6667  +                                           1
 O      23.3333  +
 X      20.0000  +
 F      16.6667  +
 A      13.3333  +
 I      10.0000  +
 L      6.66667  +                  1
        3.33333  +
        0.00000  +      2
                  -+------------+------------+------------+------------+
                  10           20           30           40           50
                 10.0000                                                    50.0000

TOTAL POINTS PLOTTED:5                 1 TRAFFIC
```

PLOT K

ENTER VERTICAL VARIABLE AND OPTIONAL RANGE OF VALUES:

MISSING VALUE TREATMENT: LISTWISE

```
                     10.0000                                                   60.0000
                       10        20        30        40        50        60
                       -+----------+----------+----------+----------+----------+
                                                                                1
0         70.0000  +                                                            1
6         60.0000  +
          50.0000  +
R         40.0000  +
E         30.0000  +
F         20.0000  +                     11
L         10.0000  +
O         0.00000  +  1 2
S                  -+----------+----------+----------+----------+----------+
T                   10        20        30        40        50        60
                 10.0000                                                 60.0000

TOTAL POINTS PLOTTED:7                   2 TIME
```

PLOT L

```
                     10.0000                                                   60.0000
                       10        20        30        40        50        60
                       -+----------+----------+----------+----------+----------+
0         70.0000  +
7         65.0000  +                                                            2
          60.0000  +
B         55.0000  +
R         50.0000  +
O         45.0000  +
K         40.0000  +                      1
E         35.0000  +
N         30.0000  +
          25.0000  +
          20.0000  +
          15.0000  +    2
          10.0000  +
                   -+----------+----------+----------+----------+----------+
                    10        20        30        40        50        60
                 10.0000                                                 60.0000

TOTAL POINTS PLOTTED:5                   2 TIME
```

PLOT M

APPENDIX C

DALLAS -- SAN ANTONIO STUDY DATA 274 (1977-1979)

DALLAS -- SAN ANTONIO STUDY DATA 274 (1977 - 1979)

(3-03-76-079)

February 8, 1978

The purpose of this study is to evaluate the field performance of the various reflective markers in use or offered for use by the Department. Locations in San Antonio and Dallas were selected for placement of marker test sections.

Seven different Type II CR markers were selected for evaluation. These were as follows:

1. Stimsonite Marker, manufactured by Amerace-Esna.
2. Stimsonite Marker with pressure sensitive adhesive backing.
3. New type Ray-O-Lite Marker with air-gap reflector, manufactured by Ray-O-Lite Division of ITL. (Withdrawn from market before project complete.
4. Old type Ray-O-Lite Marker with solid reflector.
5. Ray-O-Lite Marker with pressure sensitive adhesive backing. These markers also have air-gap reflectors.
6. Old type Penmark low intensity reflectance ceramic marker, manufactured by Ferro Corporation. (Model P-17).
7. New type Permarkhigh intensity reflectance ceramic marker manufactured by Ferro Corporation. (Model P-175).

Two hundred and seventy-five of each type marker were obtained. Samples were taken at random and tested for compliance with applicable specifications. The specific intensity of the reflectors was determined on forty of each type marker. The Stimsonite markers self-adhering markers complied with applicable requirements of Item 752 with exception of one marker which had a clear lens specific intensity of 2.6. The adhesion value of the pressure sensitive backing was 24 psi. The new type Ray-O-Lite marker with air-gap reflectors fell below the required adhesion test value of 500 psi. This was due primarily to a loosely bonded sand on the bottom of the markers. Six of the 40 Ray-O-Lite air-gap markers tested for reflectance had values below 3.0.

The lowest was 2.4. The Ray-O-Lite self-adhering markers complied with applicable requirements of Item 752 with the exception of one marker which had a clear lens specific intensity of 2.9. The adhesion value of the pressure sensitive backing was 20.4 psi. The old type Ray-O-Lite markers with solid reflectors met the requirements of Item 752 except for reflectance. Most of the markers tested fell below the minimum specific intensity required for the clear lens. The old type Permark low intensity ceramic markers met the requirements of Special Specification Item 7147 except that the specific intensity value for some of the clear lens and most of the red lens were below the specification minimum. The new type Permark high intensity markers met the requirements of Item 7147. The specific intensity of the reflectors also complied with the requirements of Item 752.

Data on Placement

The seven types of markers were placed according to the pattern shown on the following page. Where the markers were placed in pairs, the reflectance had been determined on one of them which would be removed after a period of time, and then the reflectance would be determined again to evaluate the effect of traffic.

The San Antonio test sections were placed on I-10 from Fredericksburg Road Southeast to I-35 and on I-35 from the Stockyards South to I-10.

I-10 is a four lane divided roadway carrying approximately 90,000 vpd. It is an asphalt concrete surface. Markers were placed March 8 and 9, 1977.

Weather: March 8 - Clear, 66 to 85 F pavement temperature.
March9 - Cloudy to partly cloudy 63 to 73 F pavement temperature.

Surface preparation: None other than sweeping or blowing dirt from pavement surface.

Epoxy used: Epostik B-27, manufactured by Industrial Coating Specialties Corporation, December 1976, for Requisition No. 29-7-3140F. Originally tested and approved under

Laboratory No. J76481107 for Type II-M adhesive.

I-35 is a four lane divided asphaltic concrete surfaced roadway carrying approximately 80,000 vpd. Markers were placed March 16, 1977.

Weather: Cloudy to partly cloudy, 72__to 92__pavement temperature.

Surface preparation: Same as I-20 except that spots for self-adhering markers in Series 16 through midway in Series 19 were ground. This was done because pavement was quite rough.

Epoxy used: Same as I-10.

A total of 833 markers were placed on the San Antonio test sections.

Series 1 through second group in Series 7 placed on Eastbound I-10.
Third group in Series 7 through Series 13 placed on Westbound I-10.
Series 14 through Series 16 placed on Southbound I-35.
Series 17 through fourth group in Series 20 placed on Northbound I-35.

The Dallas test sections were placed on SH 183 from Mockingbird Lane to near International Place. This is a six lane divided roadway carrying approximately 70,000 vpd. The roadway surface is portland cement concrete. Both Westbound lane lines and the inside lane line of Eastbound SH 183 were placed on April 13, 1977.

Weather: Clear, 79_F to 91_F pavement temperature.

Surface preparation: None.

Epoxy used: Epostik B-27, manufactured by Industrial Coating Specialties Corporation, December 1976, for Requisition 29-7-3790F. Originally tested and approved under Laboratory No. J7641115 for Type II-M adhesive.

Series 21 through 26 placed on SH 183 Westbound, Inside lane line.
Series 27 through 32 placed on SH 183 Westbound, Outside lane line.
Series 33 through 36 placed on SH 183 Eastbound, Inside lane lines.
Series 37 through 40 placed on SH 183 Eastbound, Outside lane lines.

Evaluation of Marker Performance

Both the San Antonio and Dallas installations were surveyed by D-9 personnel and selected markers removed for reflectance testing at three and six month intervals. These surveys included a slow drive over the installation at night to evaluate reflectivity. The markers selected for reflectivity testing in the laboratory were taken up at this time. A daytime evaluation to ascertain damage to the markers was also performed by walking along the shoulders and median.

	Three Months	Six Months
San Antonio	6-22-77	9-16-77
Dallas	7-20-77	10-25-77

Table 1 presents a summary of the condition of the San Antonio installation by pavement sections. Table 2 shows the same information for Dallas.

As previously indicated, the reflectance of 40 markers of each type selected at random was determined in the laboratory and twenty of each type were placed on the Dallas and San Antonio test section with the intention of removing them at intervals and bringing them into the laboratory for determination of reflectivity after being subjected to traffic. Tables 3 and 4 show the initial reflectance and reflectance after being subjected to traffic for markers taken from the San Antonio and Dallas installations after approximately three months under traffic. Tables 5 and 6 give this information for the installations after six months under traffic. All values shown were determined at a horizontal entrance angle of zero degrees. The reflectance was determined initially on the markers as received. The reflective faces were then scrubbed lightly with a hospital brush and a mild detergent solution. This removed dirt which had collected, in most cases, near the bottom of the reflectors. Asphaltic tracked onto the markers or tire marks was not removed by washing.

Discussion

The primary problem encountered during placement which would affect performance of the installations was improper proportioning of the epoxy resin and hardener components. The ratio of resin and hardener, based on analysis

TABLE 1
SUMMARY ON MARKER INSTALLATION
CONDITION BY PAVEMENT SECTIONS - SAN ANTONIO

I-10 Eastbound - 39 of each Marker Placed

Marker Type	Three Months: Missing	Three Months: Partial or no Reflectivity	Six Months: Missing	Six Months: Partial or no Reflectivity
Stimsonite	1	1	7	9
Ray-O-Lite (Air-Gap Reflector)	0	4	3	17
Ray-O-Lite (Solid Reflector)	0	2	0	14
Ferro (Low Intensity Reflector)	9*	19	18*	36
Ferro (High Intensity Reflector)	1*	9	3*	21
Stimsonite (Self Adhering)	18	1	21	1
Ray-O-Lite (Self Adhering)	30	0	34	3

I-10 Westbound - 39 of each Marker Placed

Marker Type	Three Months: Missing	Three Months: Partial or no Reflectivity	Six Months: Missing	Six Months: Partial or no Reflectivity
Stimsonite	0	0	0	2
Ray-O-Lite (Air-Gap Reflector)	0	0	1	14
Ray-O-Lite (Solid Reflector)	0	5	0	22
Ferro (Low Intensity Reflector)	2*	12	2*	23
Ferro (High Intensity Reflector)	3*	6	3*	22
Stimsonite (Self Adhering)	25	0	25	3
Ray-O-Lite (Self Adhering)	34	0	36	0

*Marker in place, but clear lens missing.

TABLE 1 (continued)

I-35 Southbound - 18 of each Marker Placed

Marker Type	Three Months		Six Months	
	Missing	Partial or no Reflectivity	Missing	Partial or no Reflectivity
Stimsonite	0	4	0	7
Ray-O-Lite (Air-Gap Reflector)	0	1	0	5
Ray-O-Lite (Solid Reflector)	0	1	0	4
Ferro (Low Intensity Reflector)	0*	6	0	2
Ferro (High Intensity Reflector)	2*	6	0	9
Stimsonite (Self Adhering)	13	0	14	2
Ray-O-lite (Self Adhering)	11	1	12	3

I-35 Northbound - 23 of each Marker Placed

Marker Type	Three Months		Six Months	
	Missing	Partial or no Reflectivity	Missing	Partial or no Reflectivity
Stimsonite	0	1	0	5
Ray-O-Lite (Air-Gap Reflector)	0	1	0	10
Ray-O-Lite (Solid Reflector)	0	4	0	11
Ferro (Low Intensity Reflector)	0	7	1*	15
Ferro (High Intensity Reflector)	1*	6	4*	15
Stimsonite (Self Adhering)	18	0	18	0
Ray-O-Lite (Self Adhering)	21	0	21	0

*Marker in place, but clear lens missing

TABLE 2
SUMMARY OF MARKER INSTALLATION
CONDITION BY PAVEMENT SECTIONS - DALLAS

	SH 183 Westbound (Inside Lane) - 36 of each Marker Placed			
	Initial Inspection		Second Inspection	
Marker Type	Missing	Partial or no Reflectivity	Missing	Partial or no Reflectivity
Stimsonite	0	2	0	12
Ray-O-Lite (Air-Gap Reflector)	0	7	0	20
Ray-O-Lite (Solid Reflector)	0	5	0	19
Ferro (Low Intensity Reflector)	0	10	2*	18
Ferro (High Intensity Reflector)	0	5	1*	12
Stimsonite (Self Adhering)	15	1	25	2
Ray-O-Lite (Self Adhering)	4	4	19	8
	SH 183 Westbound (Outside Lane) - 36 of each Marker Placed			
Stimsonite	1	2	2	18
Ray-O-Lite (Air-Gap Reflector)	0	3	1	18
Ray-O-Lite (Solid Reflector)	0	7	1	27
Ferro (Low Intensity Reflector)	2*	17	11*	27
Ferro (High Intensity Reflector)	3*	6	3*	20
Stimsonite (Self Adhering)	20	0	25	6
Ray-O-Lite (Self Adhering)	15	2	31	3

*Marker in place, but clear lens missing.

TABLE 2 (Continued)

SH 183 Eastbound (Inside Lane) - 24 of each Marker Placed

Marker Type	Initial Inspection		Second Inspection	
	Missing	Partial or no Reflectivity	Missing	Partial or no Reflectivity
Stimsonite	0	1	0	3
Ray-O-Lite (Air-Gap Reflector)	0	5	0	7
Ray-O-Lite (Solid Reflector)	0	1	0	10
Ferro (Low Intensity Reflector)	0	7	1*	9
Ferro (High Intensity Reflector)	2*	2	2*	9
Stimsonite (Self Adhering)	7	3	14	4
Ray-O-Lite (Self Adhering)	2	2	14	2

SH 183 Eastbound (Outside Lane) - 24 of each Marker Placed

Marker Type	Initial Missing	Initial Partial or no Reflectivity	Second Missing	Second Partial or no Reflectivity
Stimsonite	0	1	0	11
Ray-O-Lite (Air-Gap Reflector)	0	1	0	17
Ray-O-Lite (Solid Reflector)	0	8	0	21
Ferro (Low Intensity Reflector)	0	5	1*	21
Ferro (High Intensity Reflector)	1*	3	2*	18
Stimsonite (Self Adhering)	12	1	18	2
Ray-O-Lite (Self Adhering)	2	1	21	4

*Marker in place, but clear lens missing.

TABLE 3
REFLECTANCE DATA, SAN ANTONIO
INITIAL VS. THREE MONTHS UNDER TRAFFIC

Marker I.D.	Location	Original Reflectance Crystal	Original Reflectance Red	Reflectance After Subjecting to Traffic: As Received Crystal	As Received Red	Washed Crystal	Washed Red
Series 1 Stimsonite		6.7	1.7	0.43	0.09	1.00	0.16
Series 5 Stimsonite		7.2	1.1	0.43	0.14	1.20	0.32
Series 10 Stimsonite		7.2	2.0	0.33	0.24	0.64	0.44
Series 15 Stimsonite		7.7	2.3	0.19	0.09	0.16	0.08
Series 20 Stimsonite		8.2	1.4	0.28	0.14	0.32	0.16
Series 5 Stimsonite (Self Adhering)		2.6	1.4	0.33	0.19	0.36	0.20
Series 15 Stimsonite (Self Adhering)		7.9	0.51	0.19	0.05	0.32	0.08
Series 1 Ray-O-Lite (Air-Gap)		3.9	0.84	0.33	0.14	0.32	0.08
Series 5 Ray-O-Lite (Air-Gap)		5.7	1.5	0.47	0.19	0.48	0.32
Series 10 Ray-O-Lite (Air Gap)		6.6	1.4	0.52	0.28	0.60	0.32
Series 15 Ray-O-Lite (Air-Gap)		6.4	1.4	0.24	0.09	0.52	0.12
Series 20 Ray-O-Lite (Air-Gap)		3.9	1.2	0.24	0.09	0.24	0.12
Series 15 Ray-O-Lite (Air-Gap Self Adhering)		4.7	0.93	0.19	0.09	0.16	0.12
Series 1 Ray-O-Lite (Solid Reflector)		1.8	0.57	0.14	0.10	0.24	0.16
Series 5 Ray-O-Lite (Solid Reflector)		2.7	0.69	0.28	0.09	0.44	0.20
Series 10 Ray-O-Lite (Solid Reflector)		2.0	0.49	0.19	0.09	0.36	0.08
Series 15 Ray-O-Lite (Solid Reflector)		2.5	0.73	0.14	0.05	0.16	0.16
Series 20 Ray-O-Lite (Solid Reflector)		2.3	0.45	0.24	0.09	0.24	0.12

TABLE 3 (Continued)

San Antonio, Three Months Under Traffic

Marker I.D.	Location	Original Reflectance Crystal	Original Reflectance Red	Reflectance After Subjecting to Traffic: As Received Crystal	As Received Red	Washed Crystal	Washed Red
Series 1 Ferro (Low Intensity)		1.6	0.21	0.09	0.05	0.63	0.36
Series 5 Ferro (Low Intensity)		1.3	0.16	0.09	0.05	0.20	0.08
Series 10 Ferro (Low Intensity)		1.8	0.12	0.14	0.05	0.32	0.08
Series 15 Ferro (Low Intensity)		1.8	0.12	0.09	0.05	0.20	0.08
Series 20 Ferro (Low Intensity)		0.95	0.04	0.09	0.09	0.04	0.04
Series 1 Ferro (High Intensity)		4.3	0.88	0.14	0.19	0.28	0.08
Series 5 Ferro (High Intensity)		4.6	0.84	0.05	0.19	0.08	0.36
Series 10 Ferro (High Intensity)		5.4	1.0	0.14	0.09	0.51	0.36
Series 15 Ferro (High Intensity)		5.0	0.58	0.09	-	0.32	-

Locations: Series 1 - I 10 Eastbound

Series 5 - I 10 Eastbound

Series 10 - I 10 Westbound

Series 15 - I 35 Southbound

Series 20 - I 35 Northbound

TABLE 4
REFLECTANCE DATA, DALLAS
INITIAL VS. THREE MONTHS UNDER TRAFFIC

Marker I.D. Location	Original Reflectance Crystal	Original Reflectance Red	Reflectance After Subjecting to Traffic: As Received Crystal	As Received Red	Washed Crystal	Washed Red
Series 21 Stimsonite	4.6	1.4	0.12	0.08	0.48	0.32
Series 25 Stimsonite	7.8	1.8	0.52	0.40	0.87	0.40
Series 30 Stimsonite	6.6	1.4	0.36	0.16	0.87	0.24
Series 35 Stimsonite	7.0	1.5	0.24	0.32	1.30	0.28
Series 40 Stimsonite	6.3	1.6	0.59	0.32	2.00	0.32
Series 21 Stimsonite (Self-Adhering)	4.5	0.94	0.08	0.12	0.20	0.20
Series 30 Stimsonite (Self-Adhering)	6.9	1.4	0.32	0.36	0.87	0.59
Series 21 Ray-O-Lite (Air-Gap)	4.8	0.76	0.12	0.12	0.20	0.20
Series 25 Ray-O-Lite (Air-Gap)	6.7	1.7	0.16	0.08	0.24	0.08
Series 30 Ray-O-Lite (Air-Gap)	4.5	1.5	0.16	0.20	0.24	0.16
Series 35 Ray-O-Lite (Air-Gap)	4.3	1.6	0.24	0.08	0.44	0.12
Series 40 Ray-O-Lite (Air-Gap)	2.4	0.34	0.63	0.08	1.30	0.04
Series 21 Ray-O-Lite (Air-Gap Self-Adhering)	4.1	1.7	0.08	0.24	0.16	0.20
Series 35 Ray-O-Lite (Air-Gap Self-Adhering)	2.9	1.3	0.32	0.36	0.44	0.36
Series 21 Ray-O-Lite (Solid)	3.0	0.77	0.20	0.08	0.32	0.16
Series 25 Ray-O-Lite (Solid)	3.0	0.57	0.75	0.56	0.75	0.44
Series 30 Ray-O-Lite (Solid)	2.1	0.69	0.36	0.32	0.55	0.24
Series 35 Ray-O-Lite (Solid)	2.6	0.37	0.48	0.36	0.71	0.28
Series 40 Ray-O-Lite (Solid)	2.8	0.53	0.59	0.63	0.87	0.08

TABLE 4 (Continued)

Dallas - Three Months Under Traffic

Marker I.D.	Location	Original Reflectance		Reflectance After Subjecting to Traffic			
				As Received		Washed	
		Crystal	Red	Crystal	Red	Crystal	Red
Series 21 Ferro	(Low Intensity)	1.1	0.16	0.16	0.04	0.16	0.04
Series 25 Ferro	(Low Intensity)	2.1	0.21	0.16	0.08	0.12	0.04
Series 30 Ferro	(Low Intensity)	2.1	0.25	0.12	0.08	0.40	0.12
Series 35 Ferro	(Low Intensity)	2.0	0.16	0.20	0.08	0.40	0.08
Series 40 Ferro	(Low Intensity)	2.1	0.25	0.36	0.12	0.48	0.16
Series 21 Ferro	(High Intensity)	5.2	0.88	0.12	0.16	0.20	0.44
Series 25 Ferro	(High Intensity)	5.0	0.88	0.28	0.20	0.51	0.36
Series 30 Ferro	(High Intensity)	5.0	0.79	0.08	0.12	0.40	0.12
Series 35 Ferro	(High Intensity)	4.2	0.67	0.12	-	0.51	-
Series 40 Ferro	(High Intensity)	5.0	0.75	0.52	0.28	1.30	0.44

Locations: Series 21 - SH 183 Westbound, Inside Lane

Series 25 - SH 183 Westbound, Inside Lane

Series 30 - SH 183 Westbound, Outside Lane

Series 40 - SH 183 Eastbound, Outside Lane

TABLE 5
REFLECTANCE DATA, SAN ANTONIO
INITIAL VS. SIX MONTHS UNDER TRAFFIC

Marker I.D. Location	Original Reflectance		Reflectance After Subjecting to Traffic			
			As Received		Washed	
	Crystal	Red	Crystal	Red	Crystal	Red
Series 4 Stimsonite	9.3	1.2	0.37	0.09	0.47	0.13
Series 8 Stimsonite	7.4	1.9	0.51	0.28	0.90	0.37
Series 14 Stimsonite	4.8	1.6	0.14	0.14	0.13	0.17
Series 18 Stimsonite	4.5	1.7	0.19	0.14	0.43	0.56
Series 3 Ray-O-Lite (Air-Gap)	3.9	0.92	0.42	0.23	0.39	0.21
Series 8 Ray-O-Lite (Air-Gap)	5.7	1.4	0.28	0.23	0.39	0.30
Series 14 Ray-O-Lite (Air-Gap)	6.3	0.88	0.37	0.14	0.26	0.09
Series 18 Ray-O-Lite (Air-Gap)	2.9	0.96	0.23	0.14	0.21	0.17
Series 8 Ray-O-lite (Air-Gap Self Adhering)	3.7	1.6	0.37	0.19	0.39	0.34
Series 3 Ray-O-Lite (Solid)	2.9	0.77	0.28	0.05	0.21	0.04
Series 8 Ray-O-Lite (Solid)	1.5	0.69	0.23	0.09	0.21	0.13
Series 14 Ray-O-Lite (Solid)	2.7	0.77	0.19	0.05	0.13	0.09
Series 18 Ray-O-Lite (Solid)	2.6	0.73	0.19	0.09	0.13	0.09
Series 3 Ferro (Low Intensity)	1.6	0.16	0.19	0.05	0.17	0.04
Series 8 Ferro (Low Intensity)	1.6	0.21	0.19	0.05	0.17	0.09
Series 14 Ferro (Low Intensity)	1.7	0.16	0.05	0.05	0.09	0.04
Series 3 Ferro (High Intensity)	5.6	0.88	0.37	0.19	0.52	0.39
Series 8 Ferro (High Intensity)	5.4	0.92	0.09	0.14	0.05	0.05
Series 14 Ferro (High Intensity)	4.3	0.88	0.09	-	0.05	-
Series 18 Ferro (High Intensity)	5.8	0.79	0.09	0.09	0.05	0.05

Locations:
Series 3 - I-10 Eastbound
Series 4 - I-10 Eastbound
Series 8 - I-10 Westbound
Series 14 - I-35 Southbound
Series 18 - I-35 Northbound

TABLE 6
REFLECTANCE DATA, DALLAS
INITIAL VS. SIX MONTHS UNDER TRAFFIC

Marker I.D. Location	Original Reflectance Crystal	Original Reflectance Red	Reflectance After Subjecting to Traffic: As Received Crystal	As Received Red	Washed Crystal	Washed Red
Series 23 Stimsonite	5.0	1.3	0.20	0.24	0.24	0.24
Series 28 Stimsonite	5.0	1.4	0.12	0.20	0.28	0.36
Series 32 Stimsonite	8.8	1.5	0.60	0.16	0.65	0.16
Series 38 Stimsonite	6.5	1.9	0.12	0.20	0.12	0.12
Series 23 Stimsonite (Self Adhering)	3.4	0.76	0.16	0.12	0.24	0.08
Series 23 Ray-O-Lite (Air-Gap)	3.8	1.5	0.40	0.20	0.32	0.16
Series 28 Ray-O-Lite (Air-Gap)	2.9	1.8	0.20	0.16	0.24	0.20
Series 32 Ray-O-Lite (Air-Gap)	5.5	1.0	0.16	0.12	0.20	0.16
Series 38 Ray-O-Lite (Air-Gap)	4.0	1.1	0.20	0.20	0.28	0.20
Series 33 Ray-O-Lite (Air-Gap Self Adhering)	4.2	1.1	0.24	0.24	0.20	0.20
Series 23 Ray-O-Lite (Solid)	2.0	0.69	0.24	0.12	0.20	0.16
Series 28 Ray-O-Lite (Solid)	2.0	0.57	0.12	0.08	0.12	0.08
Series 32 Ray-O-Lite (Solid)	1.3	0.49	0.12	0.04	0.12	0.04
Series 33 Ray-O-Lite (Solid)	1.6	0.49	0.16	0.12	0.24	0.12
Series 38 Ray-O-Lite (Solid)	1.5	0.65	0.12	0.12	0.12	0.12
Series 23 Ferro (Low Intensity)	1.9	0.25	0.12	0.04	0.16	0.08
Series 28 Ferro (Low Intensity)	2.1	0.25	0.08	0.08	0.08	0.08
Series 32 Ferro (Low Intensity)	1.4	0.16	0.08	-	0.16	-
Series 33 Ferro (Low Intensity)	1.8	0.25	0.08	0.04	0.08	0.08
Series 38 Ferro (Low Intensity)	1.6	0.21	0.08	0.04	0.12	0.08
Series 23 Ferro (High Intensity)	4.7	0.84	0.12	-	0.16	-
Series 28 Ferro (High Intensity)	4.0	0.92	0.04	-	0.08	-
Series 33 Ferro (High Intensity)	4.8	0.79	0.08	-	0.12	-
Series 38 Ferro (High Intensity)	5.0	0.71	0.04	0.08	0.04	0.16

Locations: Series 23 - SH 183 Westbound, Inside Lane
Series 28 - SH 183 Westbound, Outside Lane
Series 32 - SH 183 Westbound, Outside Lane
Series 33 - SH 183 Eastbound, Inside Lane
Series 38 - SH 183 Eastbound, Outside Lane

of mixed epoxy taken from the markers is shown in Table 7. A large amount of excess hardener was present in the mixed material taken at the beginning of Series 1 and 2. Examination of the epoxy placed on the roadway indicated that the epoxy used in placing most of Series 2 and the first half of Series 3 did not set properly, but remained gummy. Because of this, several of the markers in these series were moved by the traffic impact.

All ten of the Stimsonite and Ray-O-Lite markers were missing when the six month inspection came from this portion of the installation.

On the Dallas installation, the proportioning was more consistent, but the adhesive was a little high on hardened content. The material was not as well mixed as desired displayed by evidence of black and white streaks in the epoxy.

The proportioning problems were due in part to the fact that the hardener component of the adhesive had thickened on storage. The viscosity at the time of use was above the specification maximum, which made it more difficult for the machine to handle.

The loss of epoxy bonded markers after six months under traffic was negligible except for the San Antonio section on which the epoxy was badly off ratio. The asphaltic concrete surface was extremely high on both installations. The asphaltic concrete surface on I-35 was quite rough, so the surface on Series 16 through midway in Series 19 where the self-adhering markers were placed was ground to see if this would give a better surface. One marker which was improperly placed had to be removed, and it came up quite easily. The grinding produced a weak layer of material on the surface. The loss of markers on this section of roadway was essentially the same as that on the other sections of I-10 and 35.

The Ray-O-Lite self-adhering marker from Series 40 scheduled for reflectance test and the Ferro high intensity reflective button from Group 2,

TABLE 7
VARIATION OF MARKER ADHESIVE
FROM CORRECT MIXING RATIO

	Time Sample Taken	Composition
San Antonio	Start of Series 1	47% Excess Hardener
	Start of Series 2	71% Excess Hardener
	Start of Series 4	29% Excess Hardener
	Start of Series 6	9% Excess Hardener
	Start of Series 8	19% Excess Hardener
	Start of Series 10	30% Excess Hardener
	Start of Series 12	23% Excess Hardener
	End of Series 13	24% Excess Hardener
	Start of Series 14	6% Excess Resin
	Start of Series 15	3% Excess Resin
	Middle of Series 16	15% Excess Hardener
	Start of Series 17	5% Excess Hardener
	Start of Series 18	9% Excess Hardener
	End of Series 20	*90% Excess Resin
Dallas	Start of Series 21	4% Excess Hardener
	Start of Series 24	12% Excess Hardener
	Start of Series 25	12% Excess Hardener
	Start of Series 27	10% Excess Hardener
	End of Series 36	11% Excess Hardener

*This condition occurred only with last five markers placed. Machine ran out of hardener.

Series 31, were inadvertently coated with traffic paint during striping operation by a maintenance crew sometime prior to three month inspection. The Ray-O-Lite self-adhering marker, Group 3, Series 14, and the Ray-O-Lite air-gap reflective marker, Group 4, Series 14 were burned prior to the the three month inspection. It was found that a collision had occurred near this spot and the Police Department propped warning flares against the markers and the heat melted the plastic.

With regard to durability, all the various types of markers show some damage after six months. Only one of the Stimsonite epoxy bonded markers had been damaged sufficiently that it had lost all reflectivity, but a number of them had cracks or were chiped in the face so that they exhibited only partial reflectivity. In the case of the Ray-O-Lite with air-gap reflectors, four of the markers had loast all reflectivity. One of the old type Ray-O-Lites had lost all reflectivity. For those markers listed as exhibiting partial reflectivity, this is normally loss of reflectivity in one of the two lens. Some of the Ray-O-Lite air-gap reflectors that are damaged evidence cracking of the lens in a pattern similar to that obtained when a rock strikes a piece of glass, i.e., cracks radiating out from a central point. Both types of Ray-O-Lite markers show some separation of one of the lens from the shell or body of the marker. The fact that the lens are not molded as an integral part of the shell makes them more susceptible to this type of damage.

Both types of ceramic markers show a fairly high loss of lens from the markers. In the case of the old type markers, this is contrary to previous experience. Loss of lens has not ceased manufacture of the old type marker, which has an epoxy bonded lens, and which was manufacturing only the new high intensity marker at the time these markers were obtained. The markers placed were made especially for the test installations, and apparently a goodbond between the lens and the ceramic body was not obtained. A number of each type also are cracked, shipped or separating from the reflective backing. Over half of the ceramic markers are recorded as having only partial reflectivity. Much of the loss of reflectivity is due to accumulation of dirt and debris in front of the lens rather that to damage.

Several of the ceramic markers placed in Dallas had one of the flanges adjacent to the clear reflector broken off.

The reflectivity of all the various type of markers showed a large drop after three months under traffic. There was a small additional drop at six months. There was a wide variation in reflectivity for the individual markers of any one type. The average specific reflectance values are tabualted in Table 8.

Summary

Based on the observations at three and six months, it appears that the Stimsonite markers are the most durable and also have slightly better retention of reflectivity. The Ray-O-Lite air-gap and solid reflector markers both evidence more damage than the Stimsonite markers. The Ferro high intensity markers initially comply with the specific intensity requirements of Item 752, but their reflectance drops to a very low level after exposure to traffic. Loss of and damage to lens is a problem with both types of Ferro markers. The extremely high loss rate of the self adhering markers indicate that they are not suitable for use on high traffic roadway.

All of the markers evidence more rapid deterioration that anticipated, indicating that a better marker than is presently available is need for high traffic areas.

TABLE 8

AVERAGE REFLECTANCE OF MARKERS REMOVED FROM ROADWAY

	3 Months				6 Months			
	San A. As Received	San A. After Washing	Dallas As Received	Dallas After Washing	San A. As Received	San A. After Washing	Dallas As Received	Dallas After Washing
*Stimsonite	0.31	0.57	0.32	0.94	0.30	0.48	0.24	0.31
*Ray-O-Lite (Air-Gap)	0.33	0.39	0.24	0.43	0.33	0.33	0.24	0.25
Ray-O-Lite (Solid)	0.20	0.29	0.52	0.64	0.22	0.17	0.15	0.16
Ferro (Old)	0.10	0.28	0.20	0.31	0.14	0.14	0.09	0.12
Ferro (New)	0.10	0.30	0.22	0.58	0.16	0.17	0.07	0.10

*These figures include both epoxy bonded and self-adhering markers.

APPENDIX D

TEXAS LOCATIONS AND CORE SAMPLE DATA

TEST LOCATIONS AND CORE SAMPLE DATA

Location	Core #	Lift Heights (g)	Top Lift Heights (g)	Compo- sition	Weight Air	Weight Water	Density	Tensile Strength @ Failure psi	Traffic $\times 10^6$	Time	% Losses	Maximum Strength psi	Corr. Strain in/in	Tough- ness		
Huntsville	1	4.6	1.37	340 TOD	628.9	361.5	0.0849									
US 190	2	2.6	1.25	292 MID	570.5	329.1	0.0853	186.91	9.86	—	6.76	183.7	.0062	20.6		-1
	3	5.3	1.10	292 Iron	510.5	294.4	0.0853	179.41								
	4	2.8	1.175		542.5	314.25	0.0858	184.76								
Huntsville	1	5.0	1.375	340 IO TOD	637.25	365.0	0.0845									
US 75	2	2.2	1.24	292 MID	560.0	315.8	0.0828	164.55	3.64	—	7.69	183.7	.0039	48.2	2x4	-1
	3	2.2	1.40	10 Base	662.9	376.2	0.0835	187.67								
	4	4.9	1.335		634.75	364.7	0.0849	199.81								
Nacodoches	1	2.4	1.4	Sealcoat	614.0	336.5	0.0799									
TX 21	2	2.5	1.145	292 Base	624.25	342.5	0.0800	179.51	1.28	—	9.40	162.1	.005	16.5	4x4	0
	3	2.6	1.4		612.9	335.0	0.0796	170.30								
	4	1.35	1.30		552.0	301.8	0.0797	136.63								
San Antonio	1	4.0	1.1	340	459.2	247.25	0.0782									
I 35	2	3.6	1.5	292	452.0	245.1	0.0789	13.45	5.11	2.0	9.00	91.7	.0100	16.8	4x4	0
SW of town	3	3.3	1.18		500.75	268.3	0.0777	97.11								
30 miles	4	6.7	1.27		556.8	302.9	0.0792	114.54								
Nacogdoches	1	6.0	1.51	340	692.9	387.25	0.0819									
224	2	3.6	1.64	292	753.0	420.0	0.0817	200.88	3.72	—	0.00	195.0	.0080	17.7	4x4	0
	3	1.6	1.6		753.75	418.25	0.0811	189.09								
	4	6.8	1.8		849.25	474.15	0.0818									
Lufkin	1	1.1	1.45	Seal	609.5	344.3	0.0830									
TX 7E	2	1.6	1.2	292	525.25	296.5	0.0829	49.07	.41	—	2.43	52.0	.0081	8.0	4x4	0
	3	1.0	1.025		426.80	244.3	0.0844	54.35								
	4	1.0	1.015		404.1	228.1	0.0829	52.69								
College	1	2.8	.91	340	388.3	214.2	0.0805									
Station	2	2.7	.92	292	392.6	216.5	0.0805	211.27	1.86	1.0	25.00	214.6	.0024	10.5	4x4	0
TX 6	3	2.5	.825		365.0	205.0	0.0824	153.97								
	4	2.4	.835		374.7	212.0	0.0832	248.66								

Location	Core #	Lift Heights (g)	Top Lift Heights (g)	Compo-sition	Weight Air	Weight Water	Density	Tensile Strength @ Failure psi	Traffic x106	Time	% Losses	Maximum Strength psi	Corr. Strain In/In	Tough-ness		
San Antonio	1	3.2	0.820	340	306.7	146.7	0.0692									
IH 10E	2	3.5	0.800	292	297.3	142.2	0.0692	132.5	8.03	2.0	1.58	.0037	8.7			
	3	3.3	0.715		267.0	130.3	0.0705	101.5							4x4	0
	4	3.2	0.686		275.7	*34.8	0.0707	141.52								
San Antonio	1	3.2	1.55	340	658.1	362.5	0.0804									
IH 10 NW	2	4.3	1.60	292	679.8	376.7	0.0809	119.11	3.07	1.4	0.0	125.0	.0053	16.0	Ceramics	
	3	3.0	1.51		667.3	368.0	0.0805	122.26							& 4x4	0
	4	4.3	1.062		472.3	258.1	0.0796	133.68								
Lufkin	1	7.0	1.54	340	789.8	480.0	0.0921									
TX 7	2	7.4	1.465	292	748.5	452.5	0.0913	141.23	.68	.9	26.09	137.8	.0038	30.0		
	3	7.5	1.705		861.3	518.8	0.0908	144.31							2x4	-1
	4	9.2	1.40		715.5	434.1	0.0918	127.78								
Brownfield	1	5.5	1.03	340	457.2	24.5	0.0762									
US 82	2	5.2	1.27	292	540.3	284.3	0.0762	218.05	4.76	2.5	3.78	217.8	.0066	28.3		
	3	4.6	1.4		607.2	325.0	0.0777								4x4	0
	4	5.5	1.46		627.5	333.2	0.0770	217.48								
Lubbock	1	3.7	1.125	340	479.2	251.4	0.0760									
IH 27	2	3.6	0.930	292	397.0	207.8	0.0758		.14	2.0	58.82	158.1	.0055	17.8		
	3	3.8	0.925		404.8	217.7	0.0781								4x4	0
	4	4.2	1.170		447.8	236.8	0.0766									
Corrigan	1	4.0	1.15	340	541.75	300.6	0.0811									
US 287	2	9.0	1.435		644.3	361.4	0.0822	144.85	.66	.9	1.12	147.7	.0061	18.2		
	3	9.0	1.5		680.0	380.9	0.0821	141.33							4x4	0
	4	8.8	1.375		606.8	335.8	0.0808	156.96								
Lufkin	1	3.1	1.515	340	673.3	369.1	0.0799									
US 287	2	2.5	1.4	292	627.1	345.0	0.0803	134.14	1.74	.9	.38	123.8	.0129	27.4		
	3	4.2	1.465		661.8	364.6	0.0804	120.15							2x4	-1
	4	3.0	1.55		671.5	372.6	0.0811	117.06								

Location	Core #	Lift Heights (g)	Top Lift Heights (g)	Composition	Weight Air	Weight Water	Density	Tensile Strength @ Failure psi	Traffic x106	Time	% Losses	Maximum Strength psi	Corr. Strain in/in	Toughness		
Austin IH 35	1		1.83	340	411.6	173.2	.0623									
	2		.783		276.7	119.7	.0636		56.67	6.9	.31	147.5	.0034	11.3	Ceramics	0
	3		1.106		404.1	180.7	.0653									
	4		.826		281.8	119.3	.0626									
Austin US 290 Eastbound	1		1.315	340	562.2	301.1	.0778									
	2		1.212		508.0	272.0	.0727		5.48	3.0	1.83	152.9	.0021	7.1		
	3		1.155		479.2	256.7	.0777								4x4 (88)	0
	4		1.081		473.5	258.5	.0795									
Austin US 290 Westbound	1		3.349	340	570.8	305.8	.0777									
	2		1.403		599.2	325.8	.0791		5.48	3.0	0.61	130.7	.0018	4.9		
	3		1.345		575.0	311.7	.0788								4x4 (88)	0
	4		1.351		591.5	324.2	.0799									
Diboll US 59	1															
	2		1.606	340	571.4	245.5	.0633		2.05	.9	0.0	166.8	.0040	11.1	2x4 (947)	-1
	3		1.681		600.8	261.2	.0639									
	4		1.694		583.0	255.2	.0642									
Port Lavaca Spur 346	1		1.408	340	661.9	377.3	.0839									
	2		1.598		753.3	430.5	.0843		4.50	2.18	7.11	174.2	.0034	13.1		
	3		1.375		649.4	370.7	.0841								2x4 (947)	-1
	4		1.771		848.4	487.1	.0848									
Victoria Loop 175	1		1.518		612.9	311.8	.0735									
	2		1.083		451.0	234.6	.0753		7.41	3.0	9.58	79.7	.0024	3.5		
	3		1.640		676.1	343.2	.0733								4x4 (88)	0
	4		1.489		625.2	318.3	.0736									

APPENDIX E

PLOTS OF MARKER LOSS BY DIFFERENT VARIABLES

```
ABSTAT 3.00
FILE: B:MARKERS   REV#16

COMMAND: PLOT

MISSING VALUE TREATMENT: LISTWISE

              0.00000     2.30000     4.60000     6.90000     9.20000
                    1.15000     3.45000     5.75000     8.05000
                 -+------+-----+------+-----+------+-----+------+------+
       66.7000   +              11            1
       64.3179   +
       61.9357   +
       59.5536   +
       57.1714   +
       54.7893   +
       52.4071   +
1      50.0250   +
2      47.6429   +
       45.2607   +            21   11                 1
       42.8786   +
L      40.4964   +
O      38.1143   +
S      35.7321   +
S      33.3500   +
       30.9679   +
       28.5857   +
       26.2036   +          2               1
       23.8214   +
       21.4393   +
       19.0571   +                                       1
       16.6750   +                        1  1 1         1         1
       14.2929   +
       11.9107   +      1     11  111
       9.52857   +
       7.14643   +                  11  1
       4.76429   +
       2.38214   +
       0.00000   +    2  2    1  2  1   3             1          12
                -+------+-----+------+-----+------+-----+------+------+
             0.00000     2.30000     4.60000     6.90000     9.20000
                   1.15000     3.45000     5.75000     8.05000

                                     3 LIFT HT
```

ABSTAT 3.00
FILE: B:MARKERS   REV#16

COMMAND: PLOT

MISSING VALUE TREATMENT: LISTWISE

```
                  .686000      .973250      1.26050      1.54775      1.83500
                         .829625      1.11688      1.40413      1.69138
                  -+------+-----+------+-----+------+-----+------+-----+
          66.7000 +                   1  1   1
          64.3179 +
          61.9357 +
          59.5536 +
          57.1714 +
          54.7893 +
          52.4071 +
1         50.0250 +
2         47.6429 +
          45.2607 +     11    1          1   1          1
          42.8786 +
L         40.4964 +
O         38.1143 +
S         35.7321 +
S         33.3500 +
          30.9679 +
          28.5857 +
          26.2036 +                        1   1  1
          23.8214 +
          21.4393 +
          19.0571 +                                              1
          16.6750 +   1 1            1      1     2  2
          14.2929 +
          11.9107 +11  1                      1    11
          9.52857 +                 1                  1      1
          7.14643 +          2          1
          4.76429 +                              1          1       1
          2.38214 +                 1  1  1     2 1
          0.00000 +              2 1     1        11 11 2 1 212 1      1
                  -+------+-----+------+-----+------+-----+------+-----+
                  .686000      .973250      1.26050      1.54775      1.83500
                         .829625      1.11688      1.40413      1.69138

                                      4 TOP LIFT
```

ABSTAT 3.00
FILE: B:MARKERS   REV#16

COMMAND: PLOT

MISSING VALUE TREATMENT: LISTWISE

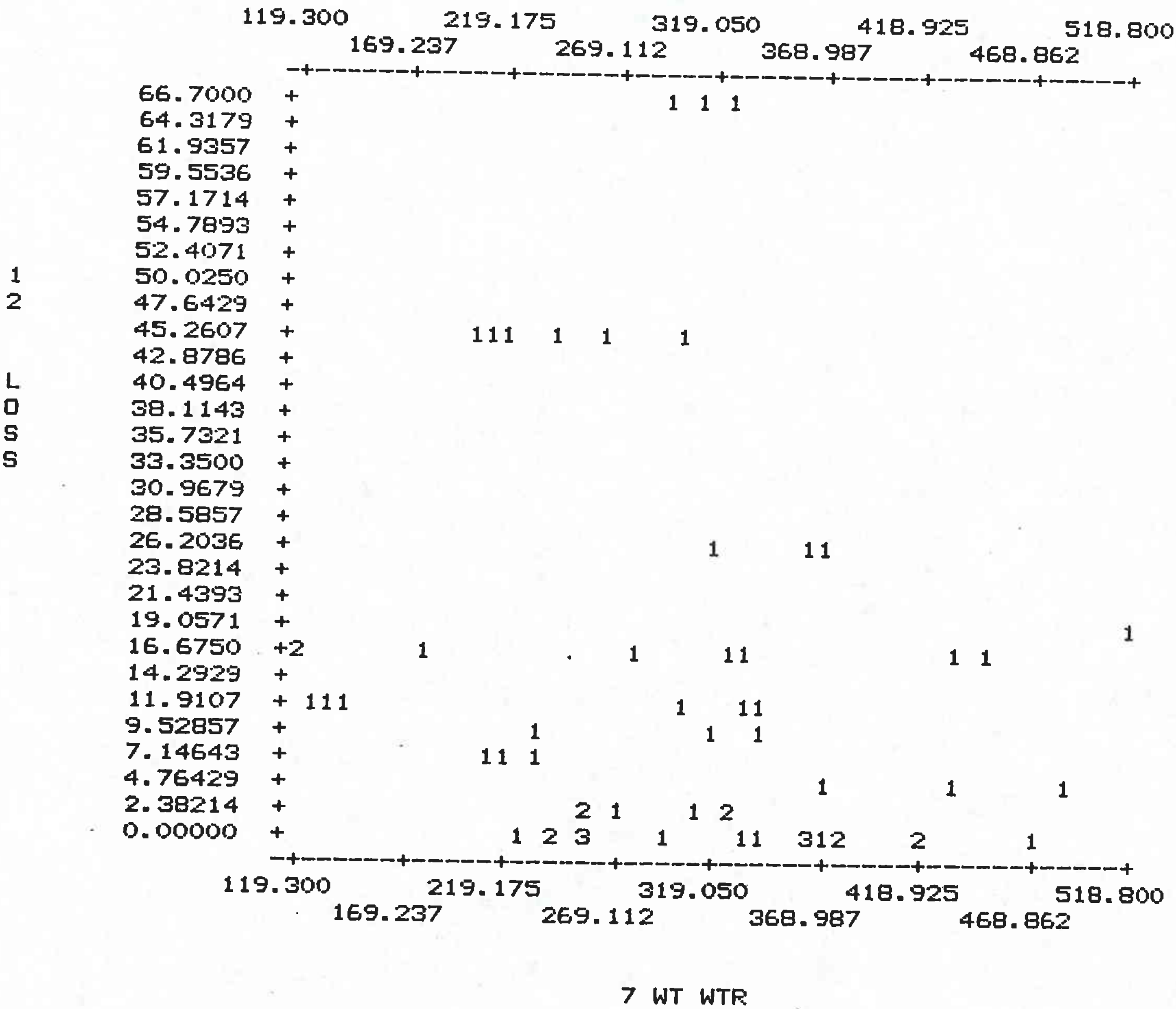
```
                -1.00000      -.500000       0.00000       .500000       1.00000
                      -.750000      -.250000       .250000       .750000
                    -+-------+------+-------+------+-------+------+-------+------+
            66.7000 +                                                            3
            64.3179 +
            61.9357 +
            59.5536 +
            57.1714 +
            54.7893 +
            52.4071 +
1           50.0250 +
2           47.6429 +
            45.2607 +                                                            6
            42.8786 +
L           40.4964 +
O           38.1143 +
S           35.7321 +
S           33.3500 +
            30.9679 +
            28.5857 +
            26.2036 +                                                            3
            23.8214 +
            21.4393 +
            19.0571 +                                                            1
            16.6750 +                                                            8
            14.2929 +
            11.9107 +3                                                           3
            9.52857 +3
            7.14643 +                                                            3
            4.76429 +                                                            3
            2.38214 +                                                            6
            0.00000 +3                                                           F
                    -+-------+------+-------+------+-------+------+-------+------+
                -1.00000      -.500000       0.00000       .500000       1.00000
                      -.750000      -.250000       .250000       .750000

                                         5 MAT TYP
```

```
ABSTAT 3.00
FILE: B:MARKERS    REV#16

COMMAND: PLOT

MISSING VALUE TREATMENT: LISTWISE

              267.000      415.575      564.150       712.725      861.300
                     341.288      489.862      638.437       787.013
                 -+-------+-----+-------+-----+-------+-----+-------+-----+
          66.7000 +                     1  1  1
          64.3179 +
          61.9357 +
          59.5536 +
          57.1714 +
          54.7893 +
          52.4071 +
1         50.0250 +
2         47.6429 +
          45.2607 +         2 1    1   1    1
          42.8786 +
L         40.4964 +
O         38.1143 +
S         35.7321 +
S         33.3500 +
          30.9679 +
          28.5857 +
          26.2036 +                          1     1  1
          23.8214 +
          21.4393 +
          19.0571 +                                                    1
          16.6750 + 2         1            1     1 1      1  1
          11.9107 +11  1                    1    11
          9.52857 +               1               1    1
          7.14643 +           11  1
          4.76429 +                                 1         1       1
          2.38214 +                  11 1      111
          0.00000 +           1 1   1   1     1111 11 32     2       1
                 -+-------+-----+-------+-----+-------+-----+-------+-----+
              267.000      415.575      564.150       712.725      861.300
                     341.288      489.862      638.437       787.013

                                        6 WT AIR
```

ABSTAT 3.00
FILE: B:MARKERS   REV#16

COMMAND: PLOT

MISSING VALUE TREATMENT: LISTWISE



```
ABSTAT 3.00
FILE: B:MARKERS    REV#16

COMMAND: PLOT

MISSING VALUE TREATMENT: LISTWISE

          6.26000E-002 6.99000E-002 7.72000E-002 8.45000E-002 9.18000E-002
                 6.62500E-002 7.35500E-002 8.08500E-002 8.81500E-002
                  -+-------+------+-------+------+-------+------+-------+------+
         66.7000  +                                           21
         64.3179  +
         61.9357  +
         59.5536  +
         57.1714  +
         54.7893  +
         52.4071  +
1        50.0250  +
2        47.6429  +
         45.2607  +                1            1  1 1  1 1
         42.8786  +
L        40.4964  +
O        38.1143  +
S        35.7321  +
S        33.3500  +
         30.9679  +
         28.5857  +
         26.2036  +
         23.8214  +                                      11   1
         21.4393  +
         19.0571  +                                                      1
         16.6750  +1 1  1                    1 11                        11
         14.2929  +
         11.9107  +            1 2                21
         9.52857  +                   11   1
         7.14643  +                         11   1
         4.76429  +                                        111
         2.38214  +                  1         1 211
         0.00000  + 111                           1 43222   1
                  -+-------+------+-------+------+-------+------+-------+------+
          6.26000E-002 6.99000E-002 7.72000E-002 8.45000E-002 9.18000E-002
                 6.62500E-002 7.35500E-002 8.08500E-002 8.81500E-002


                                             8 DENSITY
```

```
ABSTAT 3.00
FILE:  B:MARKERS    REV#16

COMMAND:  PLOT

MISSING VALUE TREATMENT:  LISTWISE

                    0.00000       69.6500       139.300       208.950       278.600
                           34.8250       104.475       174.125       243.775
                     -+------+-----+------+-----+------+-----+------+-----+
           66.7000  +                                   111
           64.3179  +
           61.9357  +
           59.5536  +
           57.1714  +
           54.7893  +
           52.4071  +
1          50.0250  +
2          47.6429  +
           45.2607  +            1     1  1       1         1            1
           42.8786  +
L          40.4964  +
O          38.1143  +
S          35.7321  +
S          33.3500  +
           30.9679  +
           28.5857  +
           26.2036  +                              1   1 1
           23.8214  +
           21.4393  +
           19.0571  +                          1
           16.6750  +                       1  1              3
           14.2929  +
           11.9107  +                  1     12     1  1
           9.52857  +
           7.14643  +
           4.76429  +
           2.38214  +
           0.00000  +        12          31 211 1     111
                     -+------+-----+------+-----+------+-----+------+-----+
                    0.00000       69.6500       139.300       208.950       278.600
                           34.8250       104.475       174.125       243.775

                                          9 TENSILE
```

```
ABSTAT 3.00
FILE: B:MARKERS    REV#16

COMMAND: PLOT

MISSING VALUE TREATMENT: LISTWISE

                  .140000      14.2725      28.4050      42.5375      56.6700
                        7.20625      21.3388      35.4713      49.6038
                     -+------+-----+------+-----+------+-----+------+-----+
             66.7000  +       3
             64.3179  +
             61.9357  +
             59.5536  +
             57.1714  +
             54.7893  +
             52.4071  +
 1           50.0250  +
 2           47.6429  +
             45.2607  +  3  3
             42.8786  +
 L           40.4964  +
 O           38.1143  +
 S           35.7321  +
 S           33.3500  +
             30.9679  +
             28.5857  +
             26.2036  +   3
             23.8214  +
             21.4393  +
             19.0571  +1
             16.6750  +2   3
             14.2929  +                                                     3
             11.9107  + 3     3
             9.52857  +       3
             7.14643  +3
             4.76429  +   3
             2.38214  +    6
             0.00000  +6336
                     -+------+-----+------+-----+------+-----+------+-----+
                  .140000      14.2725      28.4050      42.5375      56.6700
                        7.20625      21.3388      35.4713      49.6038

                                    10 TRAFFIC
```

```
ABSTAT 3.00
FILE: B:MARKERS   REV#16

COMMAND: PLOT

MISSING VALUE TREATMENT: LISTWISE

              0.00000      1.72500      3.45000      5.17500      6.90000
                     .862500      2.58750      4.31250      6.03750
                 -+------+-----+------+-----+------+-----+------+-----+
        46.5000  +        3
        44.8393  +               3
        43.1786  +
        41.5179  +
        39.8571  +
        38.1964  +
        36.5357  +
1       34.8750  +
2       33.2143  +
        31.5536  +
        29.8929  +
L       28.2321  +
O       26.5714  +
S       24.9107  +
S       23.2500  +
        21.5893  +
        19.9286  +
        18.2679  +       1
        16.6071  +       2           3                                3
        14.9464  +
        13.2857  +
        11.6250  +1              3
        9.96429  +
        8.30357  +                       3
        6.64286  +               33
        4.98214  +
        3.32143  +                       6
        1.66071  +
        0.00000  +1      9   3
                 -+------+-----+------+-----+------+-----+------+-----+
              0.00000      1.72500      3.45000      5.17500      6.90000
                     .862500      2.58750      4.31250      6.03750

                                      11 TIME
```

ABSTAT 3.00
FILE: B:MARKERS   REV#16

COMMAND: PLOT

MISSING VALUE TREATMENT: LISTWISE

```
                   52.0000      93.4500      134.900      176.350      217.800
                          72.7250      114.175      155.625      197.075
                      -+-------+-----+------+-----+------+-----+------+-----+
          66.7000  +                                          3
          64.3179  +
          61.9357  +
          59.5536  +
          57.1714  +
          54.7893  +
          52.4071  +
1         50.0250  +
2         47.6429  +
          45.2607  +            3                                       3
          42.8786  +
L         40.4964  +
O         38.1143  +
S         35.7321  +
S         33.3500  +
          30.9679  +
          28.5857  +
          26.2036  +                                         3
          23.8214  +
          21.4393  +
          19.0571  +                           1
          16.6750  +                           2  3                      3
          14.2929  +
          11.9107  +                       3            3
          9.52857  +         3
          7.14643  +                                  3
          4.76429  +                           1           2
          2.38214  +                         3      3
          0.00000  +3                      6       3     3        3
                      -+-------+-----+------+-----+------+-----+------+-----+
                   52.0000      93.4500      134.900      176.350      217.800
                          72.7250      114.175      155.625      197.075

                                        13 STRESS
```

ABSTAT 3.00
FILE: B:MARKERS   REV#16

COMMAND: PLOT

MISSING VALUE TREATMENT: LISTWISE

```
                  1.80000E-003 1.78500E-002 3.39000E-002 4.99500E-002 6.60000E-002
                         9.82500E-003 2.58750E-002 4.19250E-002 5.79750E-002
                          -+------+-----+------+-----+------+-----+------+-----+
             66.7000   +    3
             64.3179   +
             61.9357   +
             59.5536   +
             57.1714   +
             54.7893   +
             52.4071   +
1            50.0250   +
2            47.6429   +
             45.2607   +3       3
             42.8786   +
L            40.4964   +
O            38.1143   +
S            35.7321   +
S            33.3500   +
             30.9679   +
             28.5857   +
             26.2036   +  3
             23.8214   +
             21.4393   +
             19.0571   +  1
             16.6750   + 32 2                                                  1
             14.2929   +
             11.9107   +  33
             9.52857   +3
             7.14643   +   3
             4.76429   + 3
             2.38214   +6
             0.00000   +  36 6   3
                       -+------+-----+------+-----+------+-----+------+-----+
             1.80000E-003 1.78500E-002 3.39000E-002 4.99500E-002 6.60000E-002
                    9.82500E-003 2.58750E-002 4.19250E-002 5.79750E-002

                                       14 STRAIN
```

ABSTAT 3.00
FILE: B:MARKERS   REV#16

COMMAND: PLOT

MISSING VALUE TREATMENT: LISTWISE

```
               3.50000      14.6750      25.8500      37.0250      48.2000
                      9.08750      20.2625      31.4375      42.6125
                  -+------+-----+------+-----+------+-----+------+-----+
         66.7000  +                    3
         64.3179  +
         61.9357  +
         59.5536  +
         57.1714  +
         54.7893  +
         52.4071  +
 1       50.0250  +
 2       47.6429  +
         45.2607  +        3      3
         42.8786  +
 L       40.4964  +
 O       38.1143  +
 S       35.7321  +
 S       33.3500  +
         30.9679  +
         28.5857  +
         26.2036  +
         23.8214  +                                                    3
         21.4393  +
         19.0571  +                               1
         16.6750  +         3
         14.2929  +                             3 2
         11.9107  +      3        3
         9.52857  +3
         7.14643  +                 3
         4.76429  +           3
         2.38214  +  3 3
         0.00000  +     3   3     3 6          3
                  -+------+-----+------+-----+------+-----+------+-----+
               3.50000      14.6750      25.8500      37.0250      48.2000
                      9.08750      20.2625      31.4375      42.6125
```

15 TOUGH

```
ABSTAT 3.00
FILE: B:MARKERS   REV#16

COMMAND: PLOT

MISSING VALUE TREATMENT: LISTWISE

              -1.00000     -.500000      0.00000      .500000      1.00000
                     -.750000     -.250000      .250000      .750000
                  -+-------+-----+------+-----+------+-----+------+-----+
        66.7000  +3
        64.3179  +
        61.9357  +
        59.5536  +
        57.1714  +
        54.7893  +
        52.4071  +
1       50.0250  +
2       47.6429  +
        45.2607  +                          6
        42.8786  +
L       40.4964  +
O       38.1143  +
S       35.7321  +
S       33.3500  +
        30.9679  +
        28.5857  +
        26.2036  +3
        23.8214  +
        21.4393  +
        19.0571  +1
        16.6750  +                          5                         3
        14.2929  +
        11.9107  +
        9.52857  +                          6
        7.14643  +                          3
        4.76429  +3                         3
        2.38214  +
        0.00000  +6                         6
                                            C
                 -+-------+-----+------+-----+------+-----+------+-----+
             -1.00000     -.500000      0.00000      .500000      1.00000
                    -.750000     -.250000      .250000      .750000
```

APPENDIX F

PHYSICAL CHARACTERISTICS OF BITUMINOUS ADHESIVE

PHYSICAL CHARACTERISTICS OF BITUMINOUS ADHESIVE

Specific Gravity	1.80
Weight Per Cubic Foot	50 kg
Softening Point	106°C $\pm$ 5°C
Recommended Pouring Temperature	200° to 220°C
Bitumen Content	25/30%
Filler Minimum 80% Passing 200 Mesh	70/75%
Packing	Silicone lined cardboard tubs with metal bottoms containing approximat 90 kg each.
Softening Point (R&B) of Asphaltic Concrete	80°C $\pm$ 5°C
Penetration at 25°C	22 $\pm$ 5
Shelf Life	Unlimited