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16. Abstract

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An instrumented pavement marker to record the number of tire hits received was also developed during the study. The circuitry is described and hit count data obtained with instrumented lane line markers is reported.

The report concludes with an analysis of data from several long-term (5 year) adhesive test sections on a state highway. Data from another test section show that it is possible to replace a missing marker with a new marker installed directly on the pavement failure spot, instead of along side of it.

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ON THE RETENTION OF REFLECTIVE RAISED PAVEMENT MARKERS

by

John T. Tielking and James S. Noel

Research Report 477-1F
on
Research Study No. 2-10-86-477
Asphalt Concrete - Pavement Marker Compatibility Study

Sponsored by

Texas State Department of Highways and Public Transportation

in cooperation with

The U.S. Department of Transportation
Federal Highway Administration

June 1988

Texas Transportation Institute
Texas A&M University System
College Station, Texas 77843

METRIC CONVERSION FACTORS

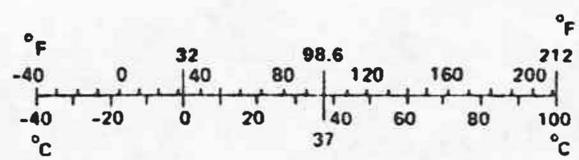
Approximate Conversions to Metric Measures

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

*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



PREFACE

This report describes the work done under Project 477, "Asphalt Concrete-Pavement Marker Compatibility Study." The study was conducted by the Texas Transportation Institute (TTI) of Texas A&M University as part of a cooperative research program sponsored by the Texas State Department of Highways and Public Transportation and the Federal Highway Administration.

The authors wish to acknowledge the assistance of Dr. Roger McNees of TTI during the first year of this project, who provided invaluable background information from his previous research on pavement markers. Mr. Jamie Fernandez, a graduate student from Colombia, was responsible for the construction and operation of the laboratory pavement fatigue test experiment. Portions of his thesis on this endeavor are reproduced herein. Field survey data collected by Mr. Robert K. Price were used in this report. We express our appreciation to Mr. Edward V. Kristaponis of the Federal Highway Administration for his personal interest in this project and helpful suggestions.

John T. Tielking
James S. Noel

November 1987

ABSTRACT

This report contains the results of a study directed toward increasing the retention time of raised pavement markers on asphalt concrete pavement. The kinematics of a tire impacting a pavement marker was studied by high-speed photography, to guide development of a laboratory apparatus that simulates pavement loading by a tire rolling over a marker. A laboratory investigation of the effect of adhesive type on fatigue strength of asphalt pavement was made. It was found that bituminous adhesive is distinctly superior to epoxy adhesive on new asphalt surfaces. The distinction between bituminous and epoxy adhesive is less pronounced on stiffer (seasoned) pavements.

An instrumented pavement marker to record the number of tire hits received was also developed during the study. The circuitry is described and hit count data obtained with instrumented lane line markers is reported.

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KEY WORDS

Raised Pavement Marker, Bituminous Adhesive, Epoxy Adhesive, Pavement Fatigue, Traffic Counting

IMPLEMENTATION STATEMENT

The research conducted under this project has provided new information on the retention of raised pavement markers. Marker retention time is found to be limited by the fatigue strength of the pavement surface. Laboratory study, during the project, found that pavement fatigue strength is influenced by the type of adhesive used to attach a marker. Bituminous adhesive was found to be superior to epoxy adhesive when used on new asphalt pavements. This information is corroborated by recent field surveys conducted by SDHPT and should be implemented by recommending that bituminous adhesive be used instead of epoxy to attach raised markers to new asphalt pavements.

Other findings of this project relate to how a tire impacts a marker, and the frequency of tire hits at a specific highway location. This information will be implemented in further study of the retention problem, which should result in the capability to predict marker retention times from measurements of pavement surface material properties.

DISCLAIMER

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I. INTRODUCTION

The use of reflective raised pavement markers (RRPM) to supplement highway delineations is greatly appreciated by motorists. At night, their high reflectivity enhances lane delineation, giving the driver an additional feeling of security. Day and night, by a series of tire-marker impacts, the RRPM will gently remind the driver to check his or her lane position. Enthusiastic receptance of the RRPM has resulted in their ever-increasing usage on the nation's highways.

BACKGROUND

Raised pavement markers are far more prevalent in southern states than in the north where snow removal equipment precludes their use. Several million raised markers are currently in service on Texas highways. They are attached by adhesive bonding to the pavement surface. The installed cost is approximately $2/marker. Although the RRPM generally perform well, and there are no plans to discontinue their use, two distinct maintenance problems (reflectivity and retention) have arisen. Both of these problems were addressed in earlier research by the Texas Transportation Institute (Study No. 2-18-82-322) completed in August of 1984, with findings reported in References [1-4]. The study reported herein is concerned only with the retention problem.

It has long been recognized that raised pavement markers are generally lost by a failure in the surface of the pavement itself, rather than by failure of the adhesive or break-up of the marker. Missing markers are usually found by the roadside, intact and with a "divot" of pavement attached to the base. Loose markers are another road hazard. The marker retention problem is far more serious on asphalt pavement (ACP) than on portland cement pavement (PCC). Since about 90 percent of Texas highways are asphalt-surfaced, the present study was focused on asphalt concrete-pavement marker compatibility.

A distinct shape effect on retention was found in the earlier research [3]. On all pavements, round ceramic markers (traffic buttons) are retained much better than the square base plastic markers. The present study was thus able to narrow its focus to the square-base markers, which are referred to here as RRPM.

OBJECTIVES

The primary objective of this study is to learn how to lengthen the service life of markers installed on asphalt concrete pavements. The work intends to provide an understanding of the marker-adhesive-pavement system, which will enable the installation technique and adhesive to be selected that will maximize the retention time of a marker on a particular pavement. Specific study objectives were to

1. Evaluate effects of marker dimensions and shape,
2. Determine pavement strength requirements,
3. Develop field tests to evaluate marker-pavement compatibility.

The achievement of objective 2 is central to the entire project. The effects of marker geometry can be meaningfully evaluated when the pavement failure mechanism (for marker impact loads) is understood, and only then can field tests for marker retention properties of a pavement be developed. The project concentrated on gaining basic knowledge, such as how a tire impacts a marker and the failure mechanism (fatigue) in the pavement surface.

For an immediate response to meeting the goal of increased retention time, the project gathered suggestions and ideas for alternative methods of attaching a marker to a pavement.

ALTERNATIVE ATTACHMENT SCHEMES

Formal and informal brainstorming sessions, and discussions with many people resulted in a wide variety of attachment schemes to lengthen the service life of reflective raised pavement markers. The proposed methods, described below, have been grouped into the following categories: other adhesives, surface treatments, and surface changes.

Other Adhesives

Bituminous adhesive is a primary candidate for replacing the various types of epoxy that have been used. A number of districts have laid test sections with bituminous adhesive, some as early as 1983. In March and April of 1986 Mr. Robert Price of Division D-9 inspected test sections in the Abilene, Bryan, Tyler, San Antonio, and Wichita Falls Districts. The series of inspection report memos by Mr. Price indicate generally superior performance of bituminous adhesive. In some cases the retention percentage of markers attached with bitumen was twice as high as that of the markers attached with epoxy. Bituminous adhesive is not without disadvantages, however, there have been reports of marker sliding and submerging (due to apparent reaction of bituminous adhesive with bituminous concrete). We obtained a block of bituminous adhesive to use in our laboratory experiments.

The study supervisor discussed the pavement marker retention problem with research people in several tire and rubber companies. Gencorp (formerly General Tire & Rubber) suggested we look at some of the new unvulcanized rubber compounds that are vulcanized in place with moderate pressure at ambient temperature. This concept is used in the butyl pad that attaches temporary markers to a pavement. Pressure vulcanized adhesives are an attractive alternative to bituminous adhesive which must be applied at high temperature (~200°F). Gencorp recommends a rocket insulation material that is a mixture of polysulfide rubber and epoxy resin [5].

Surface Treatments

These methods propose to alter a small region of the asphalt pavement where a marker will be placed. Ideas for doing this are:

Indentation. A weight is dropped on the surface prior to attaching a marker. This will compact (and strengthen) a small volume of asphalt under the marker and provide a slightly concave surface for adhesive bonding.

Puncturing. An aerator-type tool is used to make several holes in the asphalt that will fill (at least partially) with adhesive when the marker is installed.

Injection. A low viscosity penetrant is injected into the surface to change asphalt properties where a marker will be installed. The altered properties will permit the adhesive to penetrate deeper into the surface.

Microwave A short microwave burst is used to locally loosen the mix and allow deeper penetration of the adhesive.

Surface Changes

These are ideas to significantly change the surface material itself, in the region where a marker will be placed.

Base Pad. A rubber base pad (say 5x5 in) covering an area slightly larger than the marker base (4x4 in) will absorb impact loads and provide a larger pavement adhesive area.

New Material. A rotomill or similiar device would be used to dig a trench that will be filled with a stronger paving material (e.g., sulflex or a rubber extended asphalt) which will retain markers better.

The idea to locally embed a stronger material in the surface where markers are to be placed is attractive. Some laboratory work would be performed to find out if there will be a problem in bonding the stronger material to existing asphalt.

Several of the alternative attachment schemes are worthy of investigation. Before doing so, however, a research methodology must be developed. The methodology is based on an initial hypothesis of the failure mechanisms, and preferably includes a means for accelerated testing.

RESEARCH METHODOLOGY

The problem of pavement marker retention has been approached in this project by studying the fatigue characteristics of asphalt pavements under the repetitive loads imparted by tires striking a pavement marker. The hypothesis is made that pavement failure, when a marker comes loose, is a fatigue failure. Contrary to an abrupt fracture of the pavement, the fatigue failure accumulates during a long sequence of repetitive load cycles. A physical indication of retention failure being a fatigue failure is the absence of ductile deformation at the asphalt failure surfaces where a marker has been lost.

An important feature of the fatigue hypothesis is the possibility of performing accelerated fatigue experiments in the laboratory. Since fatigue is a brittle-type failure, there is very little time-dependence in the mechanism. The failure depends on the number of load cycles (tire hits) and is relatively insensitive to the frequency of the loading. The insensitivity to load frequency makes accelerated testing possible.

This approach requires some basic knowledge about the tire-marker impact event. Specifically, we need to know:

1. Marker impact kinematics - how a tire goes over a marker.

2. Marker impact forces - the force impulse vector transmitted by the marker to the pavement.

Research on the physics of tire-marker impact is described in the next chapter. The findings obtained guided the development of a laboratory apparatus to measure the fatigue endurance of an asphalt surface under the cyclic loads transmitted by a pavement marker.

In order to relate the laboratory fatigue data to marker retention time on a highway, a hit counting pavement marker was developed. This instrumented pavement marker (described in Chapter III) gives a readout of the number of times it has been struck by a tire. This readout is divided by the daily traffic passing the marker to obtain the hit incidence factor. The hit incidence factor allows the laboratory cycles-to-failure to be related to highway retention time.

The fifth chapter of this report gives data from the highway test sections that were put down to field test some different adhesives. Another test section to evaluate a marker replacement technique is also described.

A survey to learn about experiences of other states that make extensive use of RRPM is reported in Chapter VI.

Chapter VII contains conclusions (what has been learned) and recommendations for further study of asphalt concrete-pavement marker compatibility.

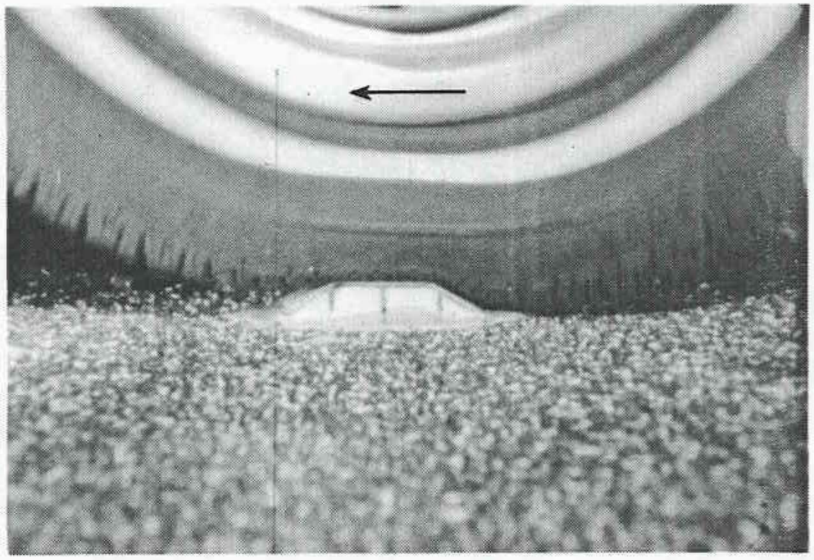
II. THE TIRE-MARKER IMPACT EVENT

A tire traveling at 50 mph (880 ips) will traverse the 4 inch span of a pavement marker in 4.5 milliseconds. This duration of traverse is too short to visually determine the effect of a marker on the path of a tire. In order to perform analysis and experiments on the marker-pavement combination it is necessary to know the kinematics of a tire impacting a marker.

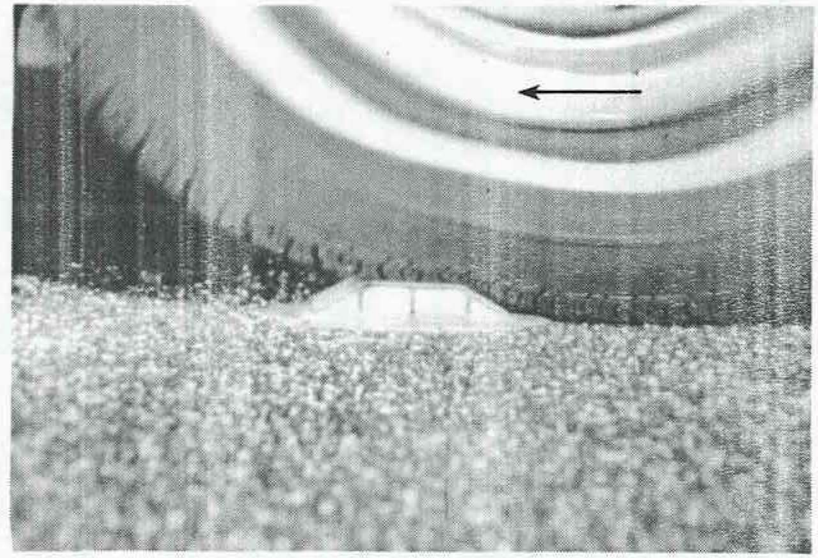
MARKER IMPACT KINEMATICS

A high-speed motion picture camera was focused on a 4x4 inch marker placed on an asphalt test track at the TTI Proving ground. To avoid enveloping the marker, a small car with P165/80R13 size tires was used. After a few practice runs, it was possible to hit the marker at highway speed with some regularity. The camera was operated at a filming rate of 500 frames per second. This rate gave about 4 pictures (frames) of the tire traversing the marker at 60 mph (the highest speed tested). A representative sequence of 4 frames taken at 60 mph is shown in Figure 1 on the next page. This sequence is typical of what was found for this tire. Regardless of speed (up to 60 mph) or inflation pressure (25, 35, 45 psi), the tire is seen to (a) impact the marker on about the upper third of the sloping face, (b) roll over the entire top face, and (c) make contact with the sloping face on the far side of the marker. It had been suggested that, at high tire pressures, the tire might only impact the sloping face and a portion of the top face. This was thought to be more likely to happen with a small tire than a large one. However, the high-speed photographic results we obtained indicate that considerable load is placed on top of the marker by a tire. We are presuming that large tires behave in a manner similar to these findings for a small tire. These observations were used in the design of an experiment to measure the fatigue strength of asphalt experiencing tire-to-marker impact loads.

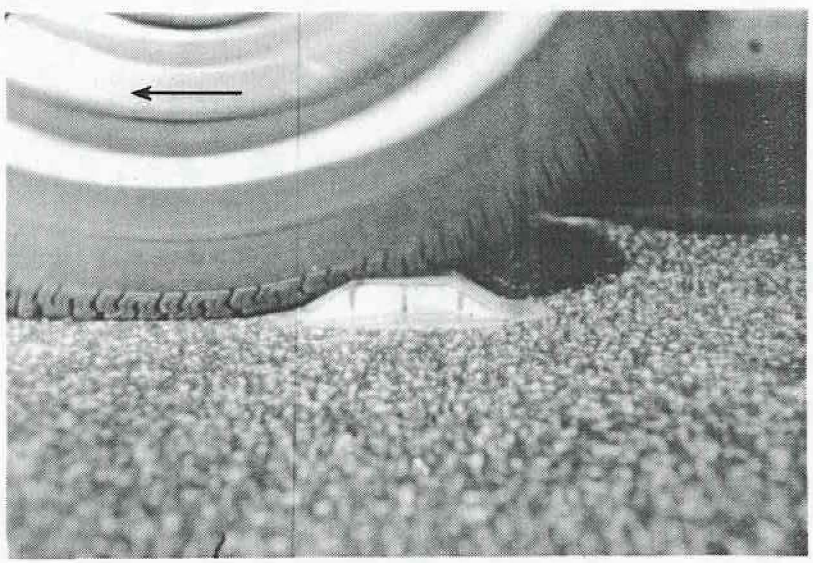
The filming was done with Eastman High Speed Color Negative film. A positive print has been transferred to VHS videotape with the various tire impact sequences identified by subtitles. Please contact the Study Supervisor if you wish to borrow the tape. The photographs shown in this report are from the positive film print.



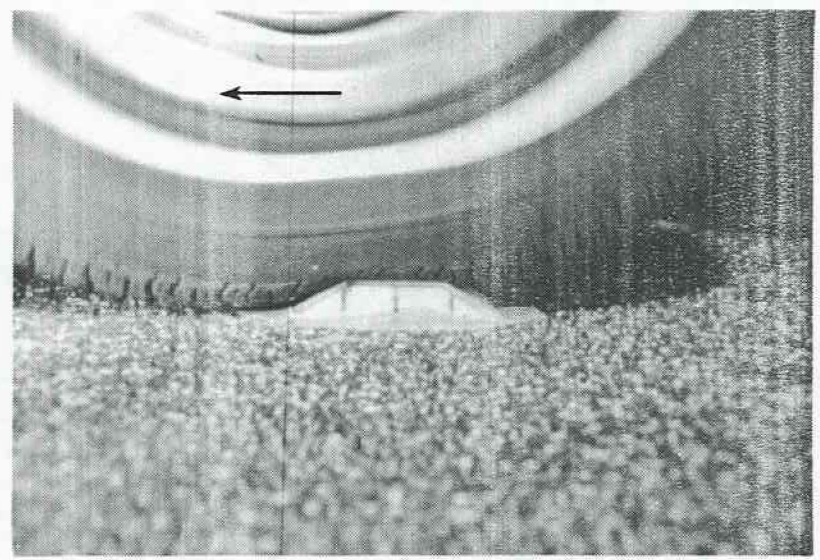
2 35 psi 60 mph On Top



1 35 psi 60 mph Approaching



4 35 psi 60 mph Leaving



3 35 psi 60 mph Descending

Figure 1. Tire-Marker Impact Kinematics

MARKER IMPACT FORCES

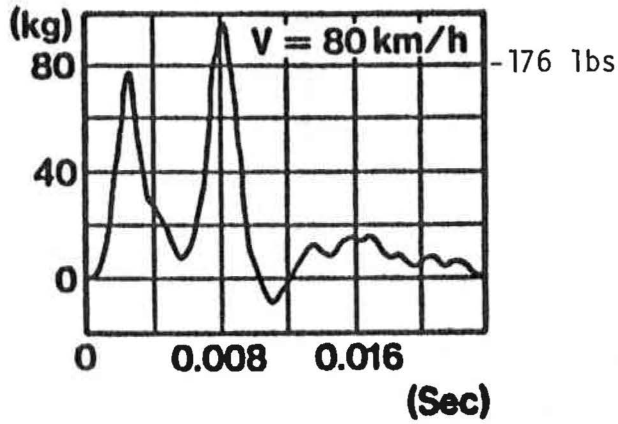
The impact of a tire against a marker is a short duration event with forces that may vary quite rapidly. The magnitude of the force peak is subject to speculation at this time. We were able to get some data on small obstacle impact forces from the tire industry, whose interest in pavement markers is moderate, motivated by interest in understanding the 'ride' quality of a tire. Useful information and some numerical data were obtained from General Tire (Akron) and Bridgestone (Japan).

The information sought from the tire industry is numerical data on forces developed by a tire impacting a pavement obstacle. These data are typically measured, for tire and vehicle research purposes, by transducers and accelerometers on the wheel spindle. No one, to our knowledge, has measured impact forces at the marker-pavement interface. General Tire expressed an interest in doing this, and expected to begin a pilot test program in the near future with an instrumented cleat bonded to a pavement.

Although early attempts to measure tire ride over obstacles used spindle force transducers, current practice is to use accelerometers. Very little force data are available, but enough has been obtained to give a general idea of the contact force levels that could be involved in a tire-marker impact event. Spindle force data mesured by General Tire for a large passenger car tire impacting a rectangular cleat, 2 inches wide by 0.5 inches high and bonded to an asphalt test track, show a maximum force amplitude of 200 pounds at 29 mph.

The data sent by Bridgestone were obtained using a trapezoidal-profile (smiliar to an RRPM) instrumented cleat on a laboratory roadwheel. The profile dimensions are: base 1.6 in, height 0.4 in, top 0.8 in.. A small passenger tire, size 155SR13, tested at 80 km/h (50 mph) impacted the cleat with peak vertical force of 100 kg (220 lb) and peak tangential force of 70 kg (154 lb). These forces were recorded at the cleat and are believed to be representative of the force levels that a tire at highway speeds may impart to a pavement marker. With larger passenger car tires and truck tires, the force levels will be higher but perhaps do not exceed 1000 pounds. It should be noted that the peak force appears for a very short duration of time.

The plot below, from Bridgestone's roadwheel data shows that the vertical force exceeds 80 kg (176 lb) for less than one millisecond.



It would be most desirable to measure impact forces directly at the marker-pavement interface. Such measurements were planned, but development of an instrumented marker to simply record the number of impacts took much longer than anticipated. The hit counting marker is now operational (Chapter III), and some additional circuitry should permit force levels (peak forces) to be stored also. This will be done if the project is continued.

III. HIT COUNTING PAVEMENT MARKER

Utilization of laboratory fatigue data to predict pavement marker retention time requires knowledge of hit rates on markers in various highway applications. Marker hit rates were estimated by previous TTI researchers, by visual counting during daylight hours. As it is often difficult to detect when a tire strikes a marker, and markers may be hit more often at night than during the day, it was felt that a means of automatic hit count data collection was needed.

INSTRUMENTATION

A 4x4 inch reflective raised pavement marker (Stimsonite Model 88), was instrumented to record the number of tire hits received. The hit counting marker (Fig. 2) is completely self-contained and cannot be distinguished from other markers by a vehicle driver. A separate display unit is plugged into the marker to read the number of hits recorded. Reading a hit count takes about 3-4 seconds at the marker location on the highway. The following is a brief description of the circuits used in the marker and in the display unit. Figure 3 shows a block schematic diagram of the circuitry in both units.

Pavement Marker Circuit

The piezoelectric crystal (XTAL in Fig. 3) transducer/pulse shaper develops a pulse or series of pulses each time the marker is struck. The pulse stretcher eliminates any extraneous pulses that may be generated by individual impacts. The tire impact pulse is then fed to the BCD up counters which accumulate and store the number of hits. The current hit count is stored at the output of the counters and the inputs of the buffers as four BCD digits. Power is denied the buffers by a magnetic reed switch, S1. This prevents excess battery drain from adverse weather effects on the output pins in the side surface of the marker. Placement of a small magnet on the top surface of the marker will activate the reed switch, supplying power to the buffers which allow the BCD data to be fed to the display unit. If desired, a reset switch, S2, on the display unit can be used to set all the counters in

Figure 2. Hit Counting Pavement Marker

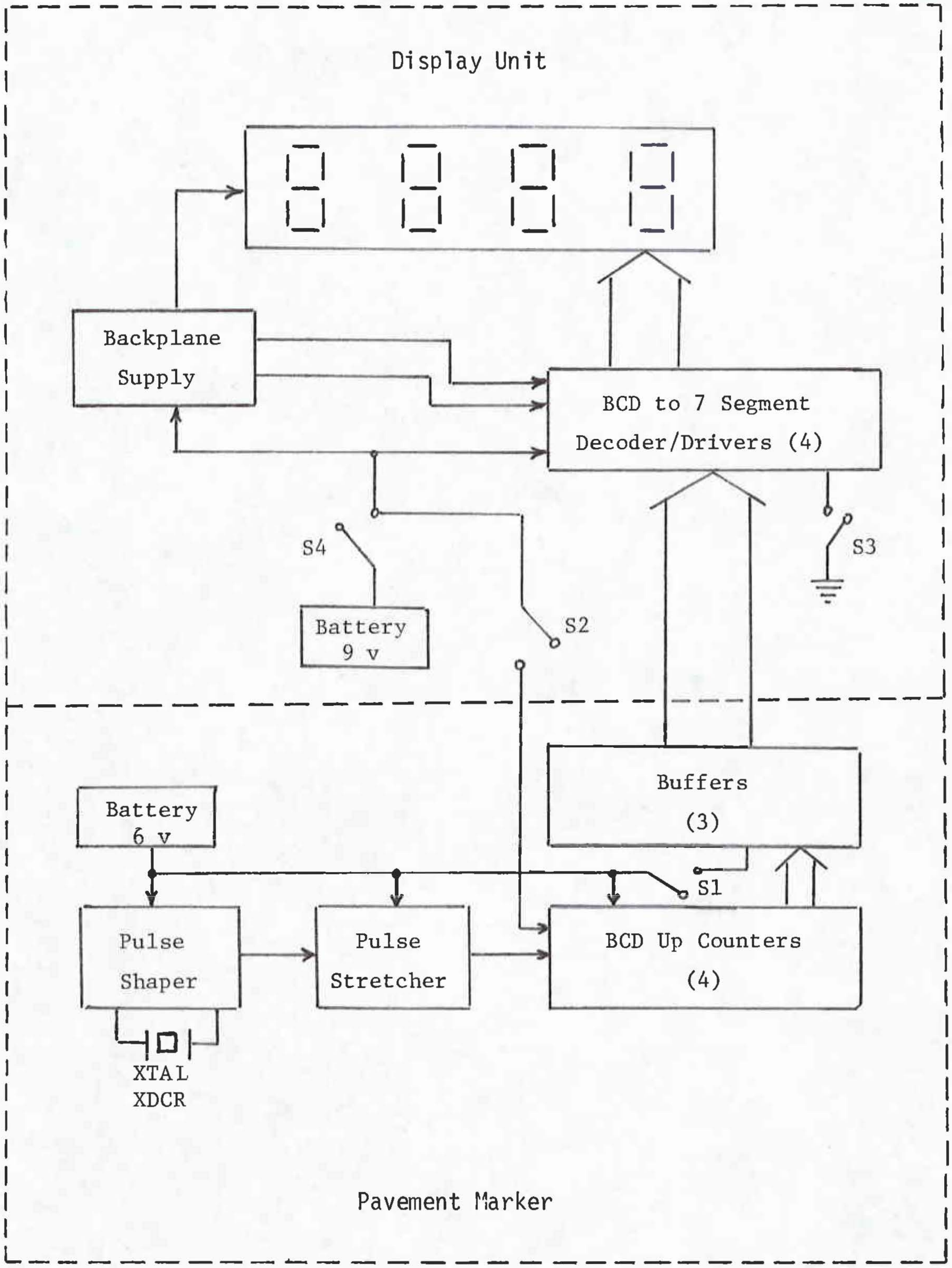


Figure 3. Block Schematic of Pavement Marker and Display Unit Electronics

the marker to zero.

Display Unit Circuit

The display unit is connected by a ribbon cable that is plugged into a flush-mounted connector on the side of the marker. When the magnetic reed switch is activated, output data from the buffers in the marker are fed to the BCD decoder/drivers and then onto the four-digit liquid crystal display. Switch S3 is used to latch the decoder/drivers so that the hit count display is maintained after the display unit is unplugged from the marker. When the display unit is in LATCH mode, switch S2 will reset the counters in the marker to zero. Switch S4 turns off the battery power in the display unit.

The pavement marker is instrumented by milling out a rectangular cavity to hold the electronic components and two small lithium batteries. A rectangular side opening is cut to hold the 20-pin female connector, which is flush-mounted with epoxy. The electronic circuitry is wired separately and tested carefully before embedding in the marker. All of the components are packed in the marker with epoxy adhesive, which has proved to be a good insulating compound. This is the same epoxy that is used to attach the marker to the pavement.

The six volt battery supply inside the marker is activated by soldering together two wires protruding from the epoxy packing underneath the marker. This is done just before installing the marker on the highway. Hit count data can then be taken over about a three month period, determined by circuit life of the lithium batteries. The hit count data reported here were taken on a highway near College Station during the month of May, which had some very hot days and some rain. We could not detect any weather effects on performance of the marker hit counter. The counter was checked by driving a car over it at highway speed.

HIGHWAY HIT COUNT DATA

Two instrumented lane line hit counters were placed on a straight section of FM 60 (eastbound) near College Station. This is a four-lane divided highway with speed limit posted at 50 mph, on which we also were monitoring a test section of markers placed alternately with bituminous and epoxy adhesives. An instrumented marker was installed at location A shown in Figure 4. Another instrumented marker was placed at location B (not shown in Fig. 4), 560 feet east of location A. There were no driveways or other means of access to the highway within the test section.

During the week of May 18, 1987, a traffic counter* tube was installed across the two eastbound lanes of FM 60, about 100 feet east of hit counting marker A (see Fig. 4). The traffic counter gives a count of vehicle axles crossing the tube. This is taken as equal to the number of tires that may hit a pavement marker. Table 1 gives the traffic count data and the display hit counts recorded by the instrumented markers at locations A and B. An indication of the reliability of these data is given in Figure 5 which shows a straight line fit to the cumulative marker hit and axle count data. The slope of this line is the hit incidence factor (hit rate), here found to be 0.0058 hits/axle for the one-week period. Over a three-week period, the hit counters averaged 45 hits/day. Using an average axle count of 7000/day, the incidence factor is slightly higher (0.0064 hits/axle). It should be noted that the estimate of 1.5 percent of traffic striking a lane line marker, made previously by TTI researchers McNees and Noel, predicts an incidence factor of 0.015 x 3500/7000 = 0.0075 hits/axle, assuming two axles for each vehicle. The assumption of two axles per vehicle is realistic for this test section, which has very little truck traffic.

Table 1.

Marker Hit and Traffic Data on FM 60

	Date	Hit Count		Axle Count	
	May	A	B	Daily	Total
(Mon)	18	70	-	-	-
	19	34	84	6791	6791
	20	40	64	6902	13693
	21	44	30	7064	20757
(Fri)	22	26	94	7190	27947

*Streeter-Richardson TrafiCOMP III.

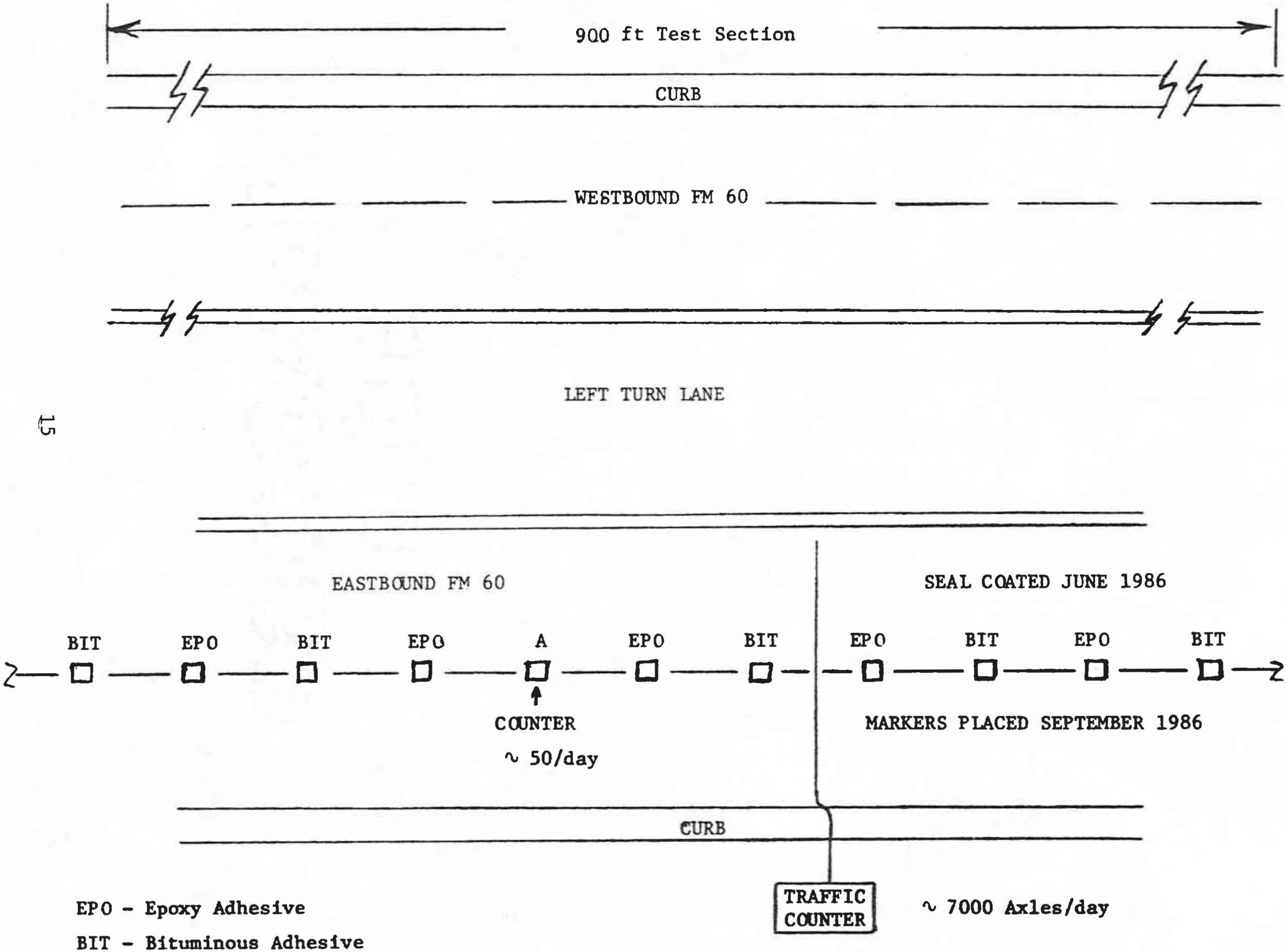


Figure 4. Seal Coat Test Section

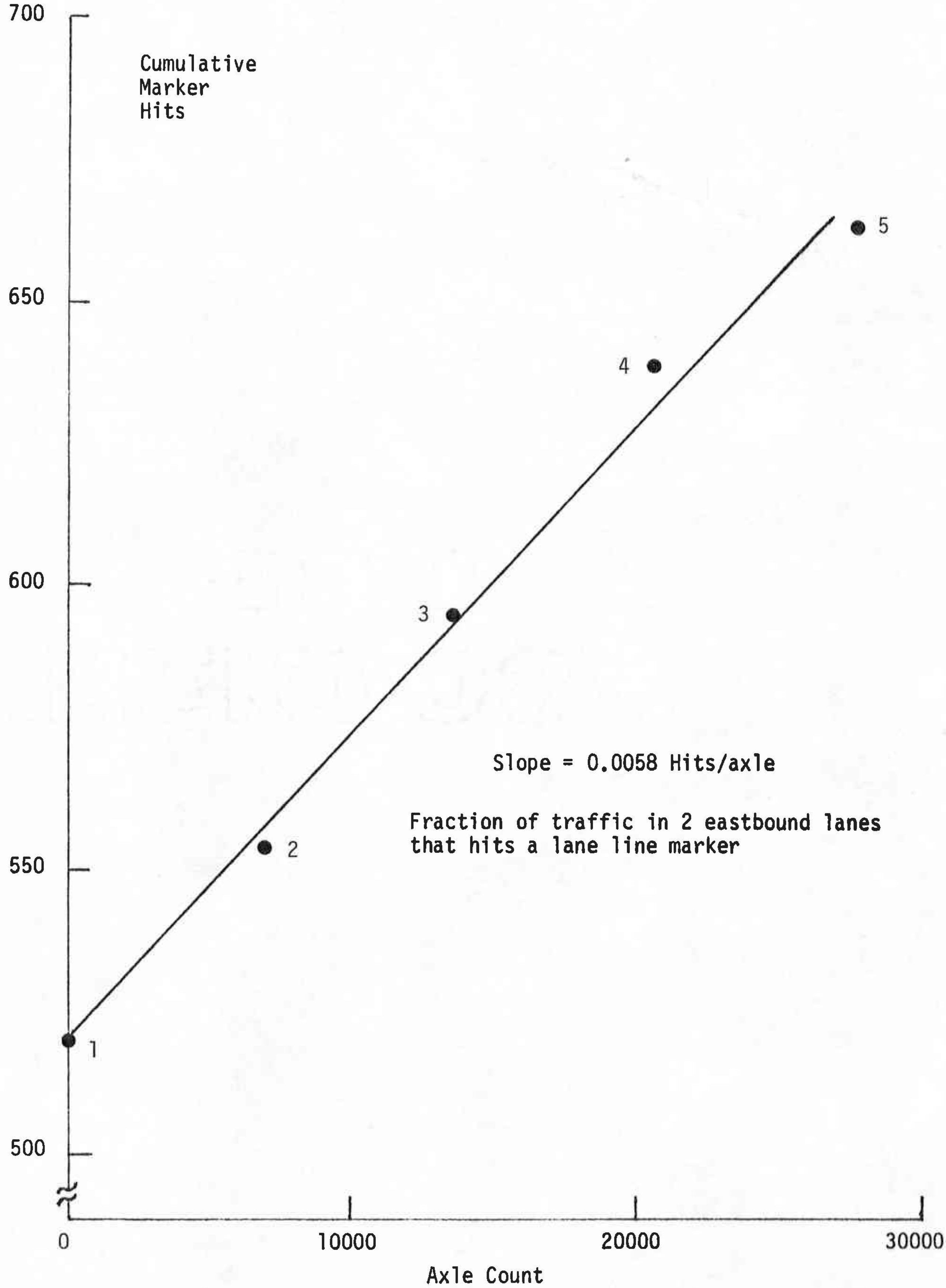


Figure 5. One Week Accumulation of Marker Hit Data

IV. LABORATORY STUDIES

The laboratory studies began with the development of an experiment to measure the shear force required to dislodge a marker from the surface of an asphalt concrete slab. We began by building an apparatus that would slowly push a pneumatic tire against the sloping reflectorized face of the marker. This was thought to be the most realistic method of load application for the purpose of measuring the static strength of adhesion between marker and pavement. It was found, however, that not enough friction could be generated between the tire and the marker to push the marker out of the pavement. A much simpler fixture, using a rigid bar to pull horizontally on a marker, was then constructed to give the capability to dislodge a marker by application of a slowly increasing shear force.

The finding that the friction force between a tire and a marker is insufficient to permit a tire to dislodge the marker by horizontal shear force is an indication that a different failure mechanism is responsible for a marker coming loose from the pavement. It seems quite likely that marker retention time is limited by a fatigue failure in the pavement surface. This hypothesis is made in view of knowledge that fatigue failures occur with cycle load amplitudes that are significantly below the quasistatic strength of the material. Tire-marker friction may be sufficient to contribute to the cyclic load amplitudes that cause fatigue failure.

It was thus concluded that our laboratory studies should address the marker retention problem from a fatigue viewpoint. Accordingly, an apparatus was built in the second year of the project to measure the fatigue endurance of an asphalt pavement under cyclic loads representing tires repeatedly impacting a marker. The pavement fatigue studies are reported later in this chapter.

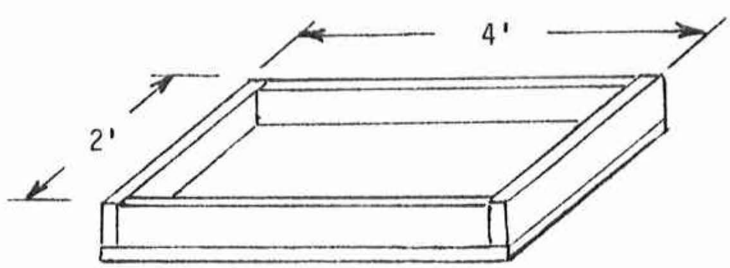
QUASISTATIC SHEAR FORCE EXPERIMENTS

These experiments were performed to measure the shear strength of asphalt concrete supporting a pavement marker. Earlier work [3] on the pavement marker retention problem had obtained data on the pull-up strength of pavement supporting a marker. The pull-up strength and the shear strength are obtained

by application of quasistatic (slowly applied) forces. These are not the same forces that a marker in service imparts to the pavement but they do provide basic property data which, when combined with data from time dependent loads, will lead to an understanding of the service failure of asphalt concrete supporting a pavement marker.

Asphalt Pavement Sample. The work began by building an asphalt concrete slab on which test markers could be placed. To hold the asphalt, a 2x4 foot plywood tray with 2x4 inch lumber edges was made.

Sample Volume $1.88\ ft^3$



Asphalt Sample Tray

The asphalt concrete for the slab was contributed by Young Brothers Contractors, a local asphalt producer. It was a type D concrete with AC-20 cement and crushed limestone.

The sample was left inside the asphalt laboratory at a temperature of 75°F for 24 hours, after which it was reheated up to 290°F and placed in the plywood tray in two layers, each approximately two inches thick. The layers were immediately compacted with a steel roller weighing 500 pounds. Each layer was given 20 passes of the steel roller. The final compaction was done using a pneumatic tire compactor weighing approximately 500 pounds, passing over the sample 150 times. The compactor tire pressure was 40 psi. The approximate contact area was 42 in^2, so that the pressure transmitted to the asphalt by the compactor was approximately 11.9 lbs/in^2.

The following property tests were performed on the slab material.

1. Bulk specific gravity of the compacted paving mixture (ASTM D1188 or ASTM D2726).
2. Maximum specific gravity of the loose paving mixture (ASTM D2041).

These tests showed

Bulk Specific Gravity = 2.212

Maximum Specific Gravity = 2.436

Percent Air Voids in Compacted Mixture = 10.13%

For comparison, the typical air voids content (AV) of a field mix is

AV (immediately after construction) = 8%

AV (after second summer) = 3-4%

The effect of air voids was not studied in this project. We are unaware of any previous investigation of the effect of air voids on pavement marker retention.

The resulting asphalt concrete slab appeared to be suitable for marker adhesion tests. The top surface, however, was not as smooth as field type D asphalt pavements but good enough so as to not adversely influence the test results. The failures obtained by dislodging markers were very similar to those found in highway pavements.

On the top of the asphalt concrete surface test markers and metal plates were placed either with epoxy marker adhesive (Type II-M) or bituminous adhesive, following all the recommended practices for those materials.

Pneumatic Tire Shear Test. A pneumatic tire was used in the initial attempt to dislodge a marker by a quasistatic shear force. A test fixture, described here, was designed to push a tire against the sloping reflectorized face of a marker. The tire was mounted on a locked wheel and pushed by a hydraulic actuator. The test fixture could carry weights providing vertical load to increase the friction force between the tire and the marker. Front and side views of the tire fixture are shown in Figures 7 and 8 on the next two pages.

After considering various types and sizes of tires, a 4.5/10.0-5 go-cart tire was selected. Basically, this is a 10 inch diameter tire with a 5 inch tread width. The tire was inflated to the maximum allowable pressure of 4 kg/cm^2 (56.8 psi). A dead weight of 605 lbs was applied to the tire.

When the test was performed, it was found that even at the high load the fixture was carrying, and the low speed of horizontal force application, the tire slid over the marker producing no failure of the asphalt supporting the marker. The maximum horizontal force that could be applied to the tire was approximately 600 lbs, independent of vertical load.

We concluded that it would not be possible to dislodge a marker with a quasistatic shear force applied by a pneumatic tire. A much simpler, positive contact, loading fixture was made and the desired shear force failure data obtained.

Marker Plate Pulling Fixture. The second attempt to measure the shear force needed to dislodge a pavement marker used the pulling fixture shown in Figure 6. This consists of a pulling arm connected to a rigid edge that will apply shear force to marker size metal plates attached to the asphalt slab. The pull force was applied by a hydraulic actuator.

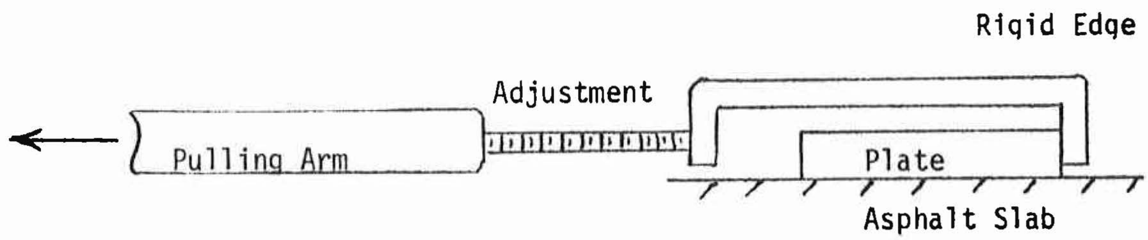


Figure 6. Plate Pulling Fixture

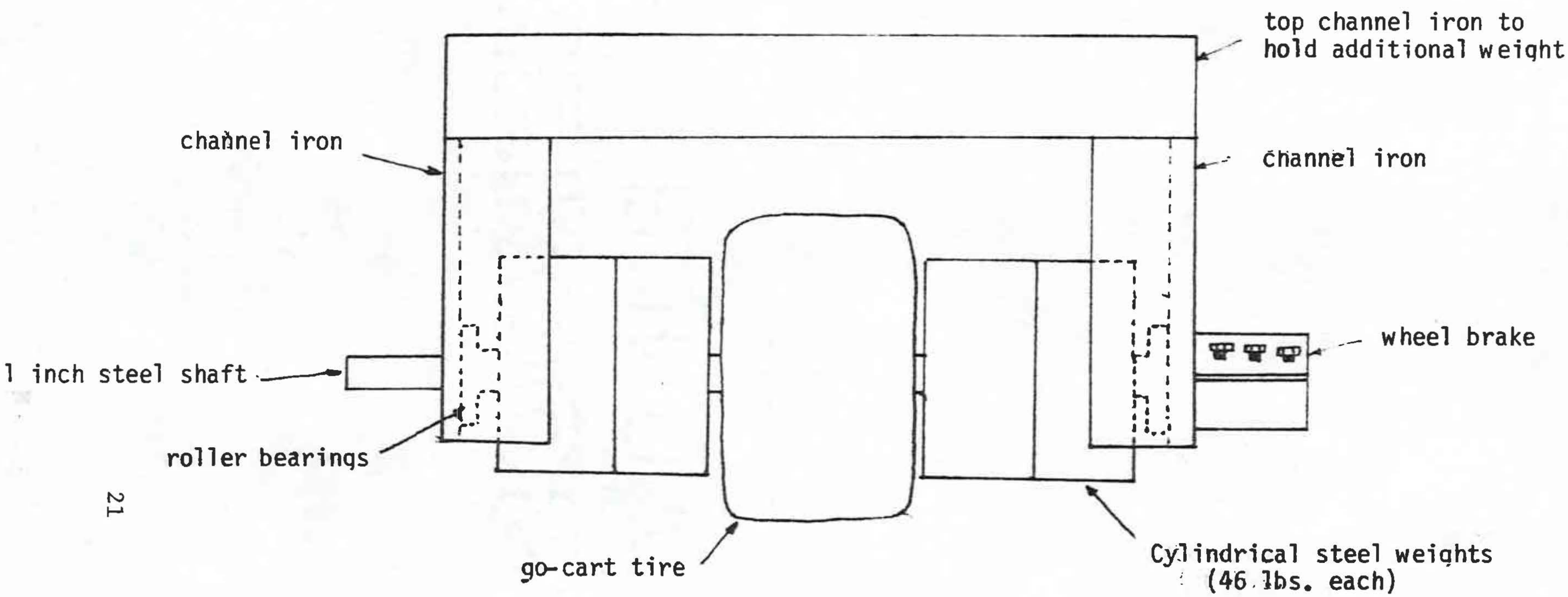


Figure 7. Pneumatic Tire Test Fixture (Front View)

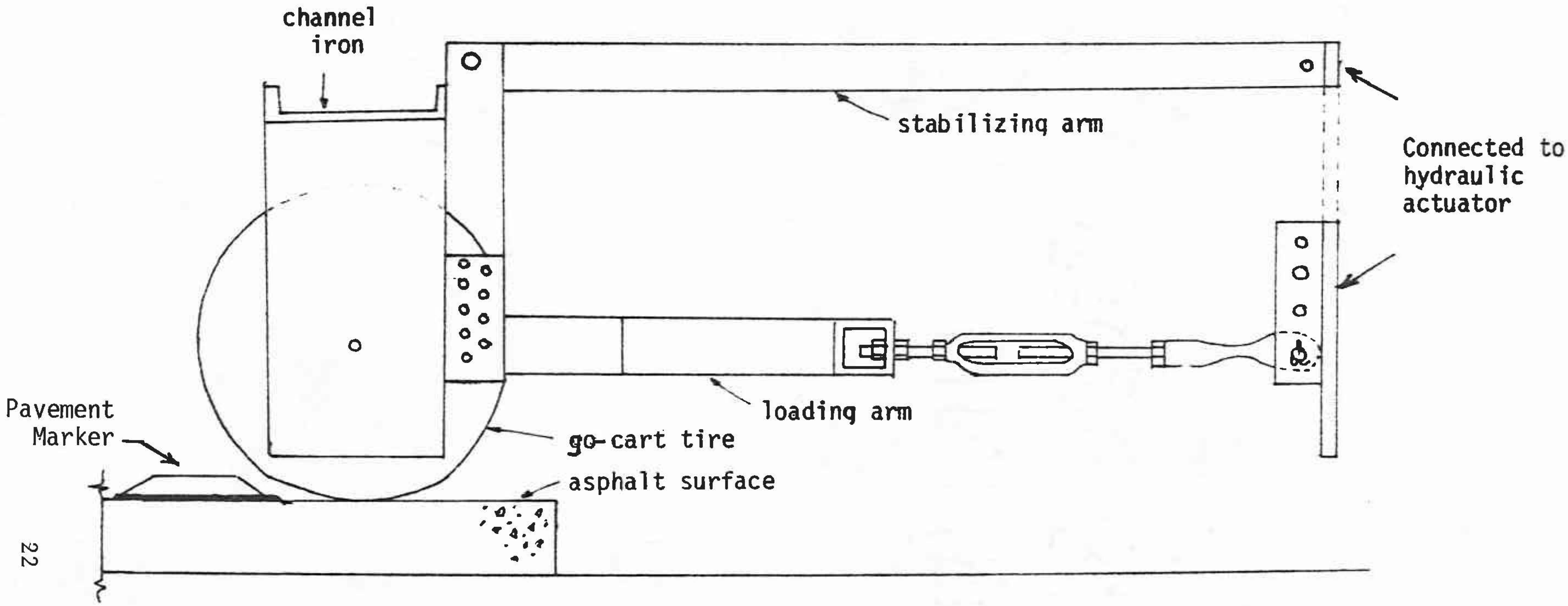


Figure 8. Pneumatic Tire Test Fixture (side view)

The metal plates were 4x4 inch, cut from 3/4 inch bar stock, so that the adhesion area was the same as the marker's adhesion area. These plates were attached to the asphalt slab using the same adhesives and procedures as used to attach markers.

In additional experiments, markers and metal plates were adhesively attached on places where markers had been dislodged. These were tested in order to see if there was any advantage in placing a marker on the failure spot left by a dislodged marker.

The types of adhesives used were Type II-M epoxy and bituminous adhesive, obtained from the warehouse of District 17 (Bryan).

The actual testing procedure begins by placing the pulling fixture on top of the marker. Using the adjustable mechanism of the arm, the fixture is positioned in such a way that the pulling edge is barely touching the marker. The zero displacement is recorded from the actuator output. The force is applied slowly and the force and displacement to failure are recorded. It was possible to obtain asphalt failure loads using actual markers as well as the 4x4 inch metal plates.

The results of the quasistatic shear force experiments using epoxy adhesive are given in Table 2. The results of experiments using bituminous adhesive are given in Table 3. All failures are in the asphalt concrete surface; the markers and adhesive always remained intact. Failure data obtained with actual markers (M) and the metal marker plates (MP) are given in the tables. All tests were performed at room temperature, approximately 23°C. The asphalt slab curing time when a test was performed is given in the tables also.

It is observed, in Table 2, that the failure stress is highest for the marker plate attached with epoxy to the place where a marker had earlier been disloged (failure spot). With bituminous adhesive, the failure load was lowest when the marker was placed on a failure spot.

The quasistatic failure loads tabulated here are approximately the same as the failure loads found by the pull-up tests conducted earlier on a variety of highway pavements by Project 322. These tests are described on pages 66-71 of Reference [3].

Table 2. Failure Load and Displacement of Markers (M) and Marker Plates (MP) Attached with Epoxy Adhesive

Test Type	Slab Curing	Displacement (in)	Load (lbs)	Adhesive Area*	Stress (psi)
MP	24 hrs	0.81	2517	27.0	93.2
MP	68 hrs	0.39	1866	23.0	81.1
MP	68 hrs	0.38	2546	27.0	94.3
† M	4 days	0.48	2831	24.0	118.0
† MP	4 days	0.55	3369	29.1	115.8
M	5 days	0.37	2015	19.4	103.8
M	5 days	0.25	1705	17.6	96.9
M	85 days	Tray Moved	2092	19.4	107.8

*Area of adhesive (in^2) found attached to dislodged marker. The adhesive area is generally larger than the marker base area (16 in^2). Stress is calculated by dividing failure load by adhesive area.

†Marker was placed on top of a failure spot.

Table 3. Failure Load and Displacement of Markers (M) and Marker Plates (MP) Attached with Bituminous Adhesive

Test Type	Slab Curing	Displacement (in)	Load (lbs)	Adhesive Area*	Stress (psi)
M	30 hrs	-	988	11.5	85.9
M	30 hrs	0.58	1420	16.0	88.8
M	3 days	0.51	1180	19.0	62.1
MP	4 days	2.88	845	Extreme Sliding	
MP	4 days	0.57	810	"	"
†MP	4 days	1.29	571	"	"

*, †same as for Table 2

PAVEMENT FATIGUE TESTING

With the likelihood that marker retention will be improved when the fatigue life of the asphalt concrete supporting the marker is increased, a fatigue test was designed to simulate the repetitive loads that a marker imparts to the pavement when hit by a car or truck tire.

It was shown in the high-speed photography study reported in Chapter II that tires, regardless of speed (up to 60 mph) or inflation pressure (25, 35, 45 psi), impact the marker on about the upper third of the sloping face, roll over the entire top face and make contact with the sloping face on the far side of the marker.

Based on what was established in the aforementioned study and in order to perform the fatigue testing, a pneumatic driven and controlled system consisting of three rams was assembled. One 5 inch diameter ram is used to apply a pulsating downward load to a 4x4 inch steel plate, simulating a marker, while two 2.5 inch diameter rams apply an alternating moment. The steel plate is adhesively attached to the slab of asphalt concrete pavement to be tested.

The alternating loads impart a rocking motion to the surface of the asphalt in addition to the downward pulsation. The resultant load generates both compressive and tensile stresses in the asphalt under the plate. The tensile stresses are responsible for the fatigue failure of the asphalt concrete.

Description of the Fatigue Tester

The fatigue tester has three component parts. They are:

(1) Specimen tray and base
(2) Actuators and reaction beam
(3) Cycler circuit

In order to explain how the whole set-up was conceived to work, a detailed description of each of the components is given below.

Specimen Tray and Base. The specimen tray and base (Figure 9) consists of a 2x4 foot half inch steel base plate bolted to the laboratory floor with the same bolts that support the reaction beam (described below). A steel frame to hold the ACP samples is attached to the base plate. This frame holds

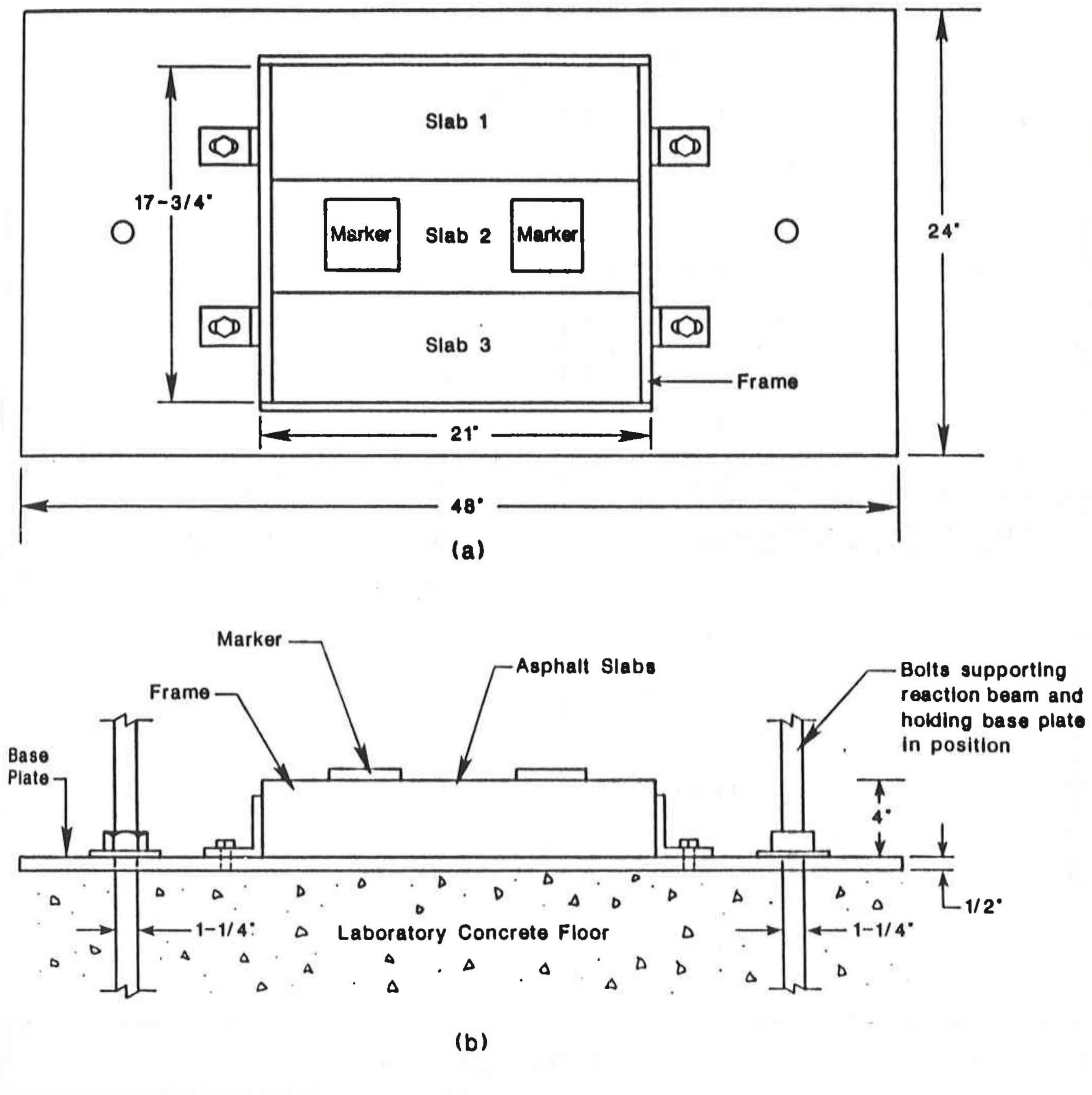


Figure 9. Specimen Tray and Base

three asphalt slabs, each 6 inch wide by 20 inches long by 3 inches thick. The test is performed upon the center slab while the two side slabs provide a confining pressure to the one being tested. This pressure is applied by tightening the bolts that connect the frame.

Two tests can be performed on each of the slabs because the rams are not located at the center of the reaction beam span, being slightly offset to one side. After a test has been performed on a slab, another test can be performed on the same slab by rotating it 180 degrees. However, this should only be done after the slabs have gone through an unstressed period for at least two days.

Actuators and Reaction Beam. As was mentioned before, the actuators of the system are three pneumatic rams (cylinders), one 5 inch diameter and two 2.5 inch diameter, which react against a 4 inch wide flange steel beam (reaction beam) supported by two all-threaded 1.25 inch rods. The threaded rods permit the distance above the asphalt slab to be adjusted by turning the fastening nuts. At the same time, the rods hold the base plate in position as they extend downward through holes in the structural slab that forms the floor of the laboratory. Additionally, the reaction beam and the rods are used to lift the rams, small beam, and "marker" plate when a sample has been fatigue failed. This facilitates the change of sample and the adhesive attachment of a new marker plate.

The force applied by the marker plate on the pavement specimen depends on the cross-sectional area of the cylinders and on the air pressure in the lines feeding the cylinders. The cylinder force as a function of the air pressure (P psi) is given as:

$$F = \frac{\pi\ (2.5)^2}{4}\ P = 4.909\ P \qquad \text{(small cylinders)}$$

$$F = \frac{\pi\ (5)^2}{4}\ P = 19.635\ P \qquad \text{(large cylinder)}$$

At P = 100 psi the force delivered by the small and large cylinders is 409.9 lbs. and 1963.5 lbs., respectively.

The forces applied by the rams are transmitted to the marker by means of a small steel beam bolted to the marker with four 0.25 inch bolts. The small steel beam is pinned to clevises, on the movable end of each of the rams.

Additionally, a pair of steel tubes was designed to work as constraints against the vertical displacement of the asphalt slabs with respect to the frame. These elements or "beam stabilizers" consist of two columns of adjustable length, one of which rests on the asphalt slab being tested and a second which rests on a spacer on top of the base plate. Both of the beam stabilizers react against the reaction beam (see Figure 11 on the next page).

Cycler Circuit. The cycler circuit controls (a) the order in which the rams actuate in the fatigue loading of the pavement specimen, (b) the magnitude of the forces being applied by the rams, and (c) the speed at which these fatigue loads are applied.

The cycler circuit was designed by Southwestern Controls of San Antonio, Texas, the firm which furnished the equipment as well. It was required that the system provide the sequence of force applications shown below (Figure 10):

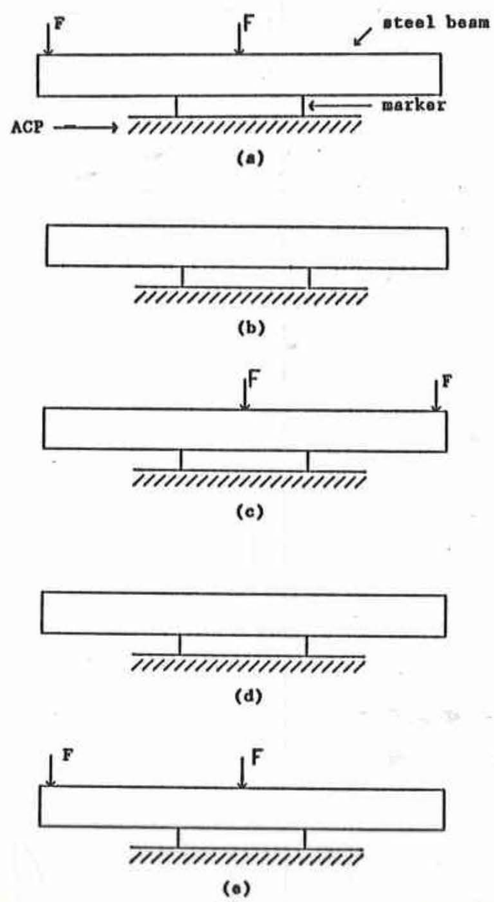


Figure 10. Fatigue Loading Cycle

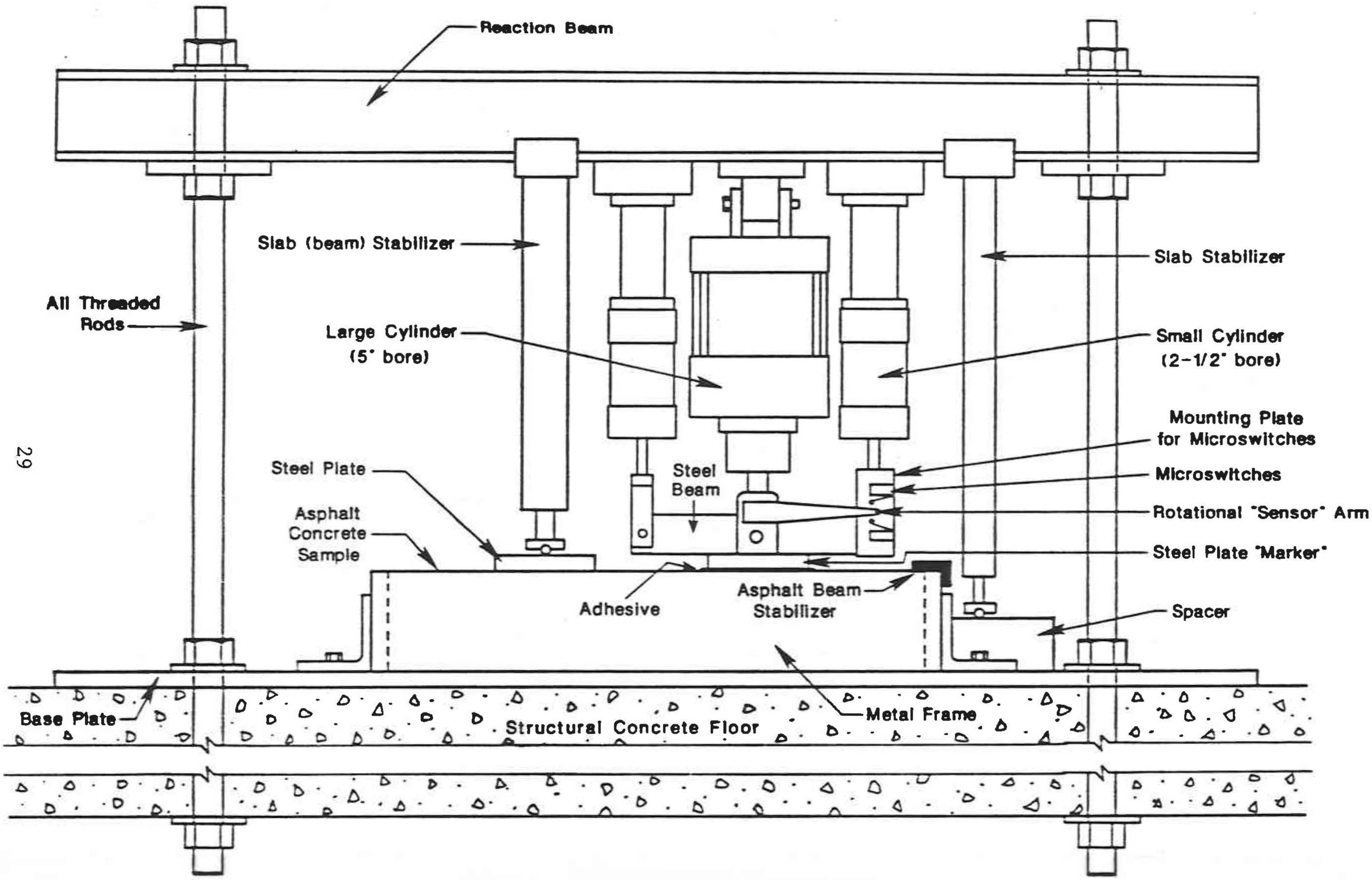


Figure 11. Experimental Set-Up

Fatigue Loadings

Initially, an attempt was made to program the fatigue tester to apply a step imposition and removal of the test load. However, due to the characteristics of pneumatic equipment, the stepped force pattern was not achieved. Instead, a sinusoidal-type cycle was obtained. Loads actually build up over a small period of time until a pre-set pressure is reached and then they gradually decrease down to zero. The pressure build-up rate is faster for the large cylinder than for the small cylinders. The forces applied by the rams are directly proportional to the ram diameter and the air pressure. Figure 12 shows the pattern of the fatigue loads in each cycle.

It can be seen that during what has been defined as one cycle in this test, the center cylinder load applications are twice as frequent as that of the side cylinders.

The duration of the cycle is not fixed but can be changed by means of a flow control valve. The cycle duration goes from 0.8 seconds on the low side to 5 seconds on the high side. During the actual testing, the cycle time was kept constant and equal to 1 second. The loading time of one of the side cylinders can be considered to be near 0.5 second, while the loading time for the center cylinder is near 0.25 second; in comparison, the time it takes for a car travelling at a speed of 55 mph to roll over a marker is 4.5 milliseconds. So the time scales are comparable.

Although no data have been obtained by the tire industry specifically concerning forces on pavement markers, studies by General Tire and Bridgestone on ride quality of tires, performed on tires impacting pavement obstacles, provided valuable information. The forces measured are described in Chapter II of this report. They are assumed to be very similar to the force levels that an average tire at highway speeds may impart to a pavement marker. Larger passenger cars and trucks will impart higher forces but peak forces will probably stay below 1000 pounds.

Force and Stress Distribution. In order to develop the fatigue experiment to simulate pavements being subjected to the application of fatigue loads by markers that are repeatedly hit by car and truck tires, it was necessary to establish, as a basis for the study, a specific condition which was to be represented by the test.

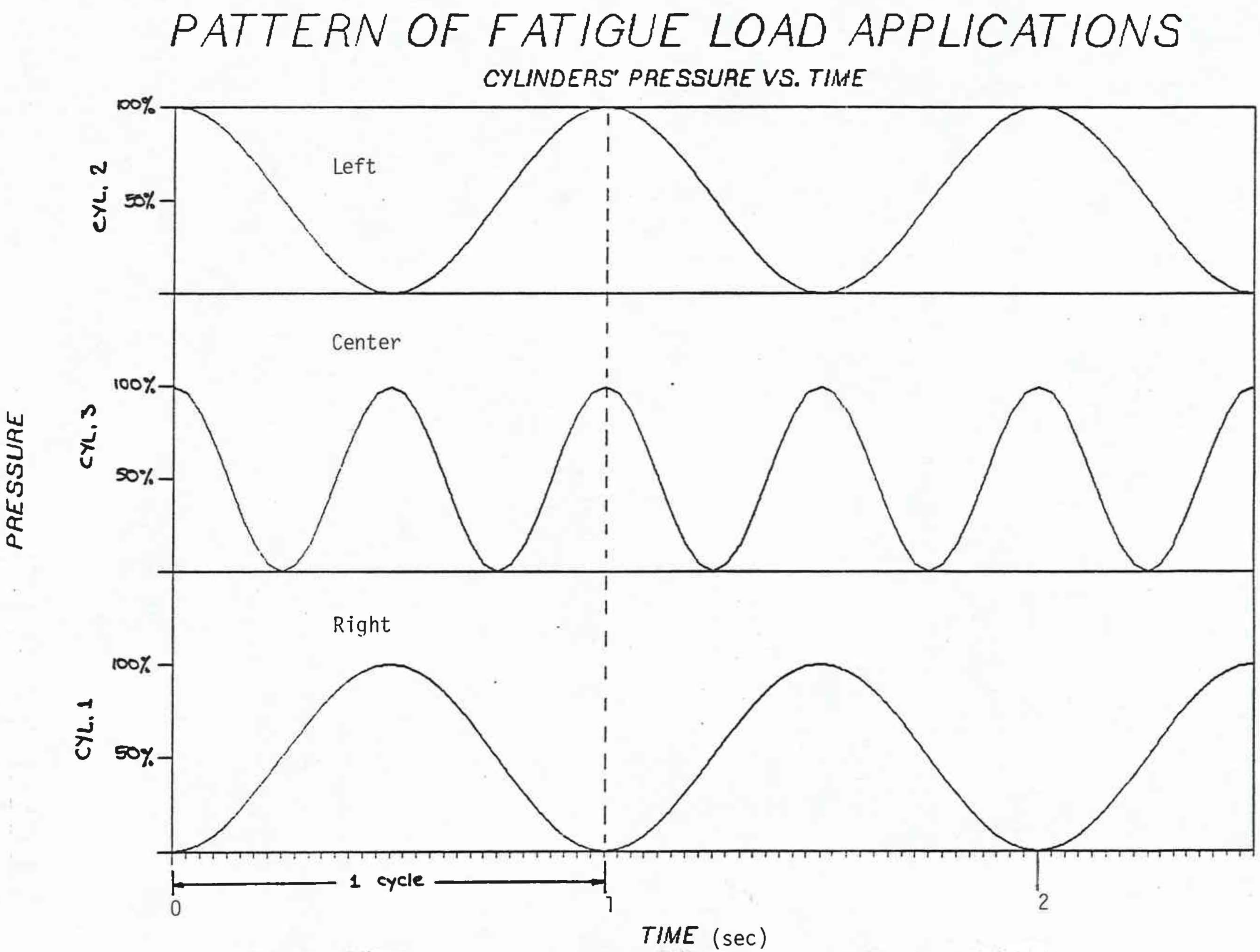


Figure 12. Cylinder Pressure Cycle Timing

After considering the various possible conditions of the marker, including the location, direction and magnitude of the forces to be applied, it was established that the condition to be represented corresponded to a vertical force application on the edge of the non-reflectorized sloping side of the RRPM as shown in Figure 13. This condition does not represent the most common occurrence (that is, a vertical force application on the edge of the reflectorized sloping face) but is the most critical for the pavement in terms of the negative moment produced. The stresses produced by that moment on the opposite side of the marker are supposedly responsible for the failure of the pavement.

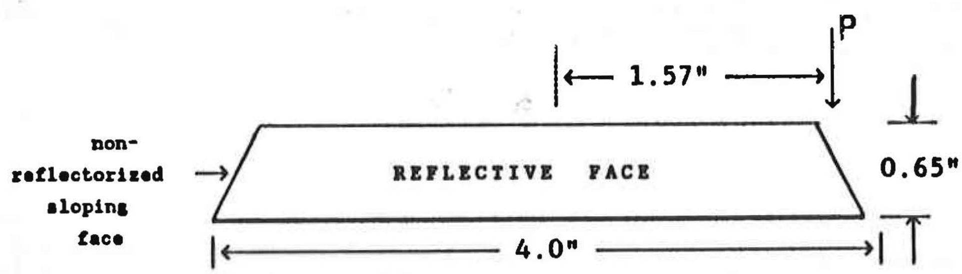


Figure 13. Critical Force Condition

Once this decision was reached, the next step was to do a force analysis on that system to establish the value of the forces that the rams in the fatigue tester had to apply.

Consider the RRPM shown in Figure 13, where the force (P) is applied at the edge of the non-reflectorized sloping face of the marker. The force P can be translated to the center of gravity of the marker adding a moment equal to P times the distance to the original force (1.57") at that point (Figure 14).

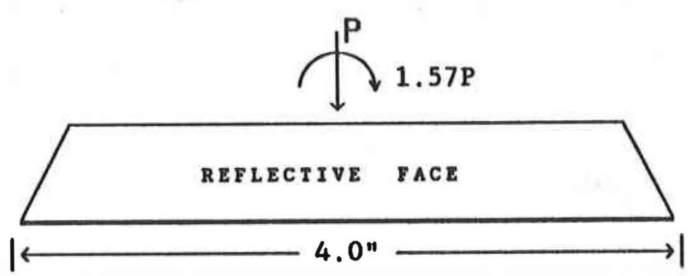


Figure 14. Force Translation

Assuming that the marker is completely rigid and perfectly attached to the surface of the pavement, and applying the superposition principle, the pavement force patterns shown in Figure 15 are obtained.

The uniform force is produced by the force P divided by 4, the length of the marker (considering force per linear inch), and the triangular forces are produced by the moment at the center of the marker. The stresses between the marker and the pavement can thus be conveniently calculated.

Table 4 presents the pressures at which the tests were performed together with the forces associated with these pressures, and the stresses generated at the edges of the marker on the pavement. It should be noted, though, that there are limitations on the ranges of pressures to be used, due to manufacturer's specifications on the valves and cylinders. The maximum and minimum allowable pressures are 120 and 25 psi respectively.

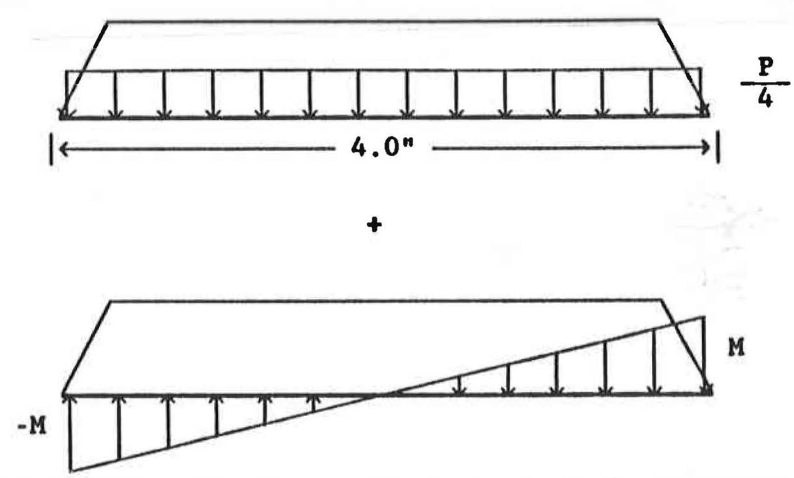


Figure 15. Resulting Forces on the ACP

Instrumentation

Because of the difficulty of establishing with precision the number of repetitions to failure for asphalt fatigue tests, an arbitrary rotation of the

Table 4. Air Line Pressures, Cylinder Forces, and Resulting Pavement Surface Stresses

P_{R1} (psi)	P_{R2} (psi)	Small Cylinder Force (lbs)	Large Cylinder Force (lbs)	Maximum Tensile Stress (psi)	Maximum Compressive Stress (psi)
55	25	271	491	-259	641
66	30	325	589	-311	769
77	35	379	687	-363	898
88	40	433	785	-414	1026
99	45	487	884	-466	1154
110	50	542	982	-518	1282
121	55	596	1080	-570	1410

P_{R1} - Pressure on the lines feeding the small cylinders

P_{R2} - Pressure on the lines feeding the large cylinder marker with respect to a horizontal line was adopted as a definition of the failure condition.

The rotation considered in this case is a rocking motion that occurs when there is a difference between the displacements produced by one of the small cylinders and the displacement produced by the center cylinder. At the beginning of each test, both displacements are similar, but as the test progresses the higher tensile stresses on the edges of the marker will cause a progressive damage which will be responsible for an increasing rotation amplitude. The value of the rotation amplitude chosen to define pavement failure is large enough to assure failure under the edges of the marker, but small enough so that the test is stopped before total failure occurs. This is convenient because, at the time of failure, the material under the edges of the marker, which is what is really being tested, is the material for which the number of cycles has been obtained.

The rotation amplitude selected as the failure criterion was chosen after several trial runs. Those runs allowed the visualization of an approximate vertical displacement of either of the smaller cylinders which would produce a rotation for which there was a guaranteed failure of the material under the edges of the marker. The next step was to build a sensing device which would stop the system when the pre-established rotation was reached.

Figure 16 shows a schematic of how the failure condition is reached.

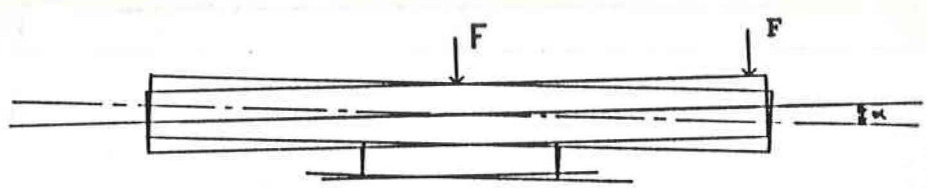


Figure 16. Schematic of the Failure Condition

It was found that a differential vertical displacement equal to 0.12 inches was a value that produced an acceptable rotation to define as the failure condition. Knowing that the distance from the center of the beam to the point where the small cylinder's force is considered to be applied is equal to 4.438 inches, the rotation failure angle is obtained. However, the assumption that the arc followed by the small cylinder rod is the secant of the angle has to be made (Figure 17). If α is the critical angle of rotation for which the deflection is 0.12 inches, then

$$\sin \alpha = \frac{0.12}{4.44} = 0.027$$

$$\alpha = \arcsin (0.027) = 1.55 \text{ deg}$$

<u>Cut-off circuit</u>. The failure sensing mechanism built for the system consists basically of a metal arm positioned to activate a pair of microswitches which close a circuit when the failure amplitude is reached, thus stopping the test (Figure 17 and Figure 11). The arm is connected to the clevis of the center cylinder where it does not rotate, but displaces vertically. The microswitches are mounted on a small aluminum plate bolted to the clevis of one of the small cylinders. Because the metal plate is free to rotate around the pin of the center cylinder, the microswitches undergo both a vertical displacement and a rotation. At the point when this rotation goes beyond the pre-established rotation for which failure was defined, the system is stopped. The two microswitches are connected in series. This configuration guarantees that a microswitch will be actuated when the material at either edge of the marker fails.

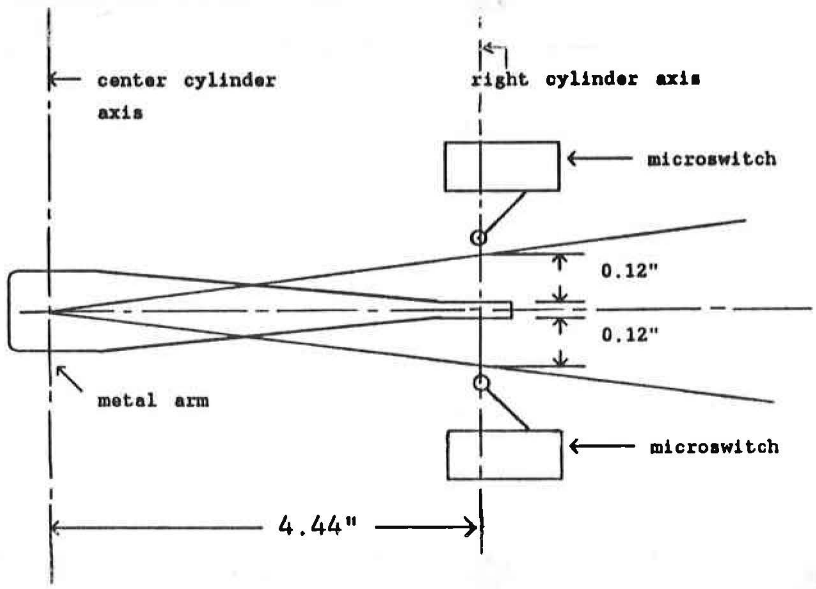


Figure 17. Angle of Rotation at which Failure Occurs

The other parts of the cut-off circuit are a relay switch, a reset button, a 115 VAC power supply, and a solenoid valve, which shifts to a position where the air supply of the system is cut when any of the microswitches is actuated, thus stopping the test.

Cycle Counter. This component of the system is a small pneumatic counter which is connected to the line feeding one of the small cylinders (refer to Figure 11). It registers each force application by means of a diaphragm which in turn moves a numeric dial. The counter has the capability of being reset which made it more functional because of the repetitiveness of the test. During the first trial runs of the experiment some problems were experienced with the counter due to its high pressure sensitivity. However, this inconvenience was solved by installing a flow control valve in the line to the counter and restricting the air flow to the counter.

Materials

Aggregate. A mixture of crushed limestone and field sand was chosen for the aggregate, as these materials generally produce a high quality mix which performs well in both test and field conditions. A maximum particle size of 1/2 (100 percent passing the 1/2 in. sieve; some retained on the 3/8 in. sieve) was chosen. The aggregates were blended to meet the 1983 TSDHPT aggregate grading specification band for type D mixes fine graded surface courses (3), in accordance with Test Method Tex-200-F.

Asphalt Concrete Mix. The bituminous materials chosen for the fabrication of the pavement specimens were Texaco AC-5 and Texaco AC-20. The Test Method Tex-204-F, Design of Bituminous Mixtures, was performed using the chosen aggregate and the AC-20; the optimum binder content was found to be 5.25%. However, that asphalt content proved to be high for the molding of the samples. Therefore, after a trial and error process, the binder content was lowered to 4.5% for the AC-20 and 4.25% for the AC-5.

Resilient Modulus (MR).. In this study, the Resilient Modulus Test was used to characterize the stiffnesses of the mixes with which the fatigue tests were run. The following results were obtained.

Asphalt Cement Grade	%AV	$M_R(10^6$ psi)
AC-5	3.9	0.166
AC-20	2.7	0.335

As was expected, the value of the resilient modulus for the mix prepared with asphalt cement AC-20 was higher. This was exactly what was expected to be accomplished by varying the AC grade; in this way the retention results for the different AC grades could be related to the stiffnesses of the mix.

Pavement Specimens. The asphalt concrete slabs used to perform the fatigue tests were fabricated in the McNew Asphalt Laboratory using the Cox Compacting Machine together with a special mold. The dimensions of the specimens were 6 inch wide by 20 inch long by 3 inch deep.

The specimens were molded by layers, each layer being one inch thick and fabricated with a 4600 gm. mix batch. The material was mixed at 300°F and molded at 275°F. Each of the batches was placed, spread and leveled inside the hot mold. Eighty 500-psi load applications distributed along the sample length were applied to each layer. An additional 100 force applications were applied to the last layer before the specimen was taken to a Universal Compacting Machine. A final static load application of 15,000 lbs. for 1.5 minutes was applied to the slab for leveling. Next, the slab was taken out of the mold, labeled and allowed to cool to room temperature.

The slabs were tested after curing at room temperature for at least one week but less than a month. Additionally, due to the fact that two tests were performed on each asphalt slab, it was established that after a slab had been tested, the next test on that same slab had to be performed after that slab had rested for at least two days.

Adhesives. The next step in readying for the fatigue test was to adhere the marker to the ACP sample. This procedure varied slightly depending on the type of adhesive used.

For epoxy adhesive, the procedure was to mix the resin and the hardener in a 1:1 ratio until a uniform grey color without streaks was obtained. Then, with the help of a wooden stick, the epoxy was spread evenly on the surface of the ACP, under the metal plate, so that it was 0.125 to 0.250 inches thick after the placement. Following this, the whole unit of reaction beam, rams, force transmitting beam, and metal plate was lowered until the metal plate came into contact with the epoxy and a small bead of it was forced around the edges of the plate. Excessive force could not be applied because a marker/pavement contact was to be avoided. Additionally, not too much epoxy could be applied or the size of the bead would be too large and some error would be introduced because the epoxy would distribute the fatigue loads over a large area of the ACP specimen. On the other hand, if not enough epoxy was applied, a complete coverage of the bottom of the plate would not be obtained.

After adhering the marker the bolts on the reaction beam were adjusted, and the epoxy was allowed to cure for at least four hours.

The bituminous adhesive was initially placed in a 300°F oven, and then its temperature increased to 400°F by heating it with a burner. When the required temperature was reached, the liquid adhesive was poured on top of the surface of the ACP specimen. The set-up was lowered with the crane until the metal plate came in contact with the bitumen and a small bead of it was forced around the edges of the plate, following the same precautions listed above for the epoxy adhesive. The bitumen was the allowed to cure for at least two hours.

Test Results

Temperature (which affects binder stiffness) and stress levels both have a pronounced effect upon fatigue life. Therefore, the temperature was always recorded at the site of the fatigue tester. The fatigue tests were performed at around 68°F, the normal temperature of the structures laboratory (fluctuation above or below 68°F smaller than 5°F were acceptable), and at different stress levels. Applied loads were chosen to be proportionally spaced among the load ranges determined by the equipment specifications. The loads were also chosen so as to have some specimens fail at cycle numbers in the thousands, some at cycle numbers in the tens of thousands, and some at cycle numbers in the hundreds of thousands.

The data recorded from each test were (1) the pressure in the cylinders, from which the loads and the corresponding tensile stresses under the edge of the marker were obtained, and (2) the number of cycles of failure. This number was read directly from the pneumatic counter.

The tensile stresses, σ_t, from each similar test condition (same asphalt cement grade and same marker adhesive) were plotted against the number of cycles to failure, n_f. On these plots, there is one data point for each attachment tested. However, in this research as in all other published fatigue test results, there is quite a bit of scatter in the data points. Attempts were made to fit logarithmic curves of the form $\sigma = A + B \ln (n_f)$, exponential curves of the form $\sigma = A e^{Bn_f}$, and power curves of the form $\sigma = A(n_f)^B$ to the observed fatigue data. The arbitrary constants, A and B, were selected to minimize the sum of the squares of the differences between the curves and the observed data. The method used to quantitatively evaluate the goodness of fit is to calculate the coefficient of correlation, R^2. If the value of R^2 is near unity the fit is good; if it is near zero the fit is poor.

The results of these calculations are summarized in Table 5. The best fit of all data was obtained using a power curve. The plots obtained appear as straight lines when graphed on log-log axes. This was done for Figures 18-21, on the next two pages.

Figure 18. FATIGUE FAILURE OF ACP BY PAVEMENT MARKER LOAD CYCLES
Asphalt Concretes Manufactured with Crushed Limestone, and Tex. AC-5 (+) and Tex. AC-20 (*) Asphalt Cements
Tests Performed Using Epoxy Adhesives

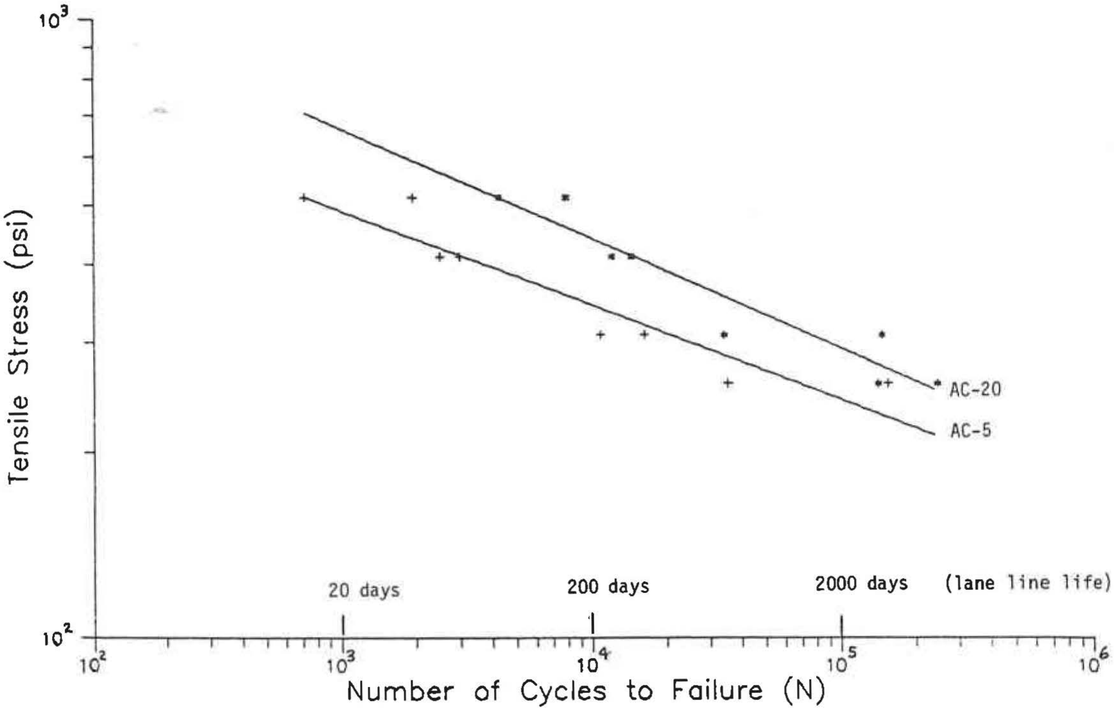


Figure 19. FATIGUE FAILURE OF ACP BY PAVEMENT MARKER LOAD CYCLES
Asphalt Concretes Manufactured with Crushed Limestone, and Tex. AC-5 (*) and Tex. AC-20 (+) Asphalt Cements
Tests Performed Using Bituminous Adhesive

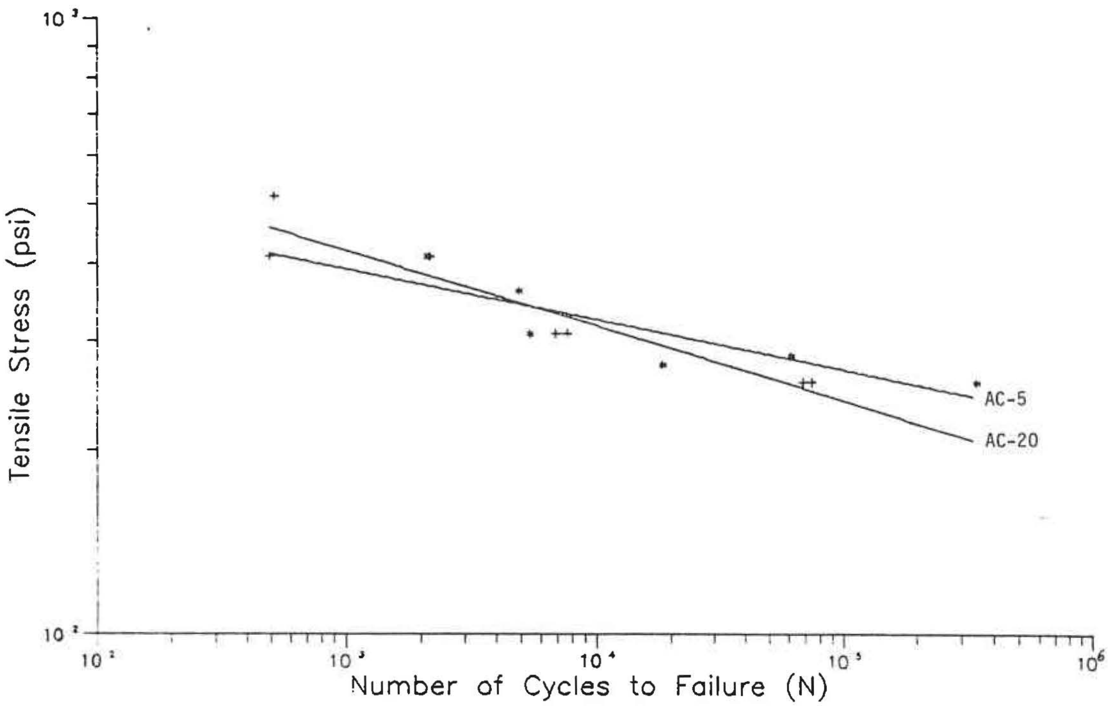


Figure 20. FATIGUE FAILURE OF ACP BY PAVEMENT MARKER LOAD CYCLES
Asphalt Concrete Manufactured with Texaco AC-5
Asphalt Cement and Crushed Limestone
Effect of Bituminous (*) and Epoxy (+) Adhesive

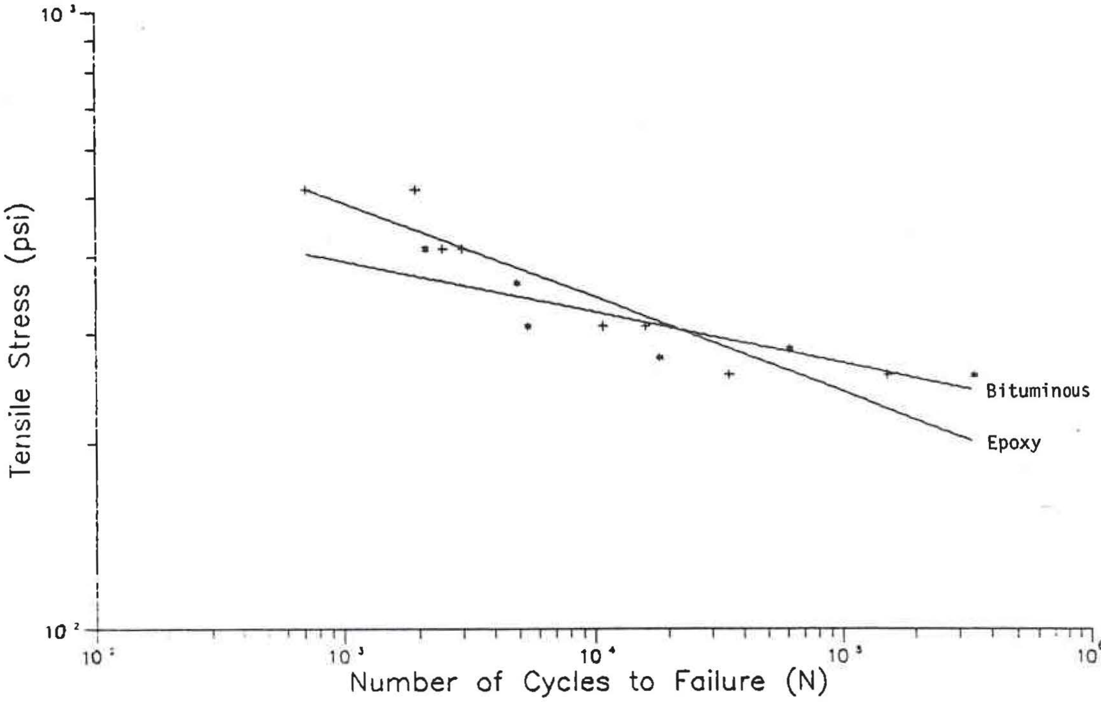
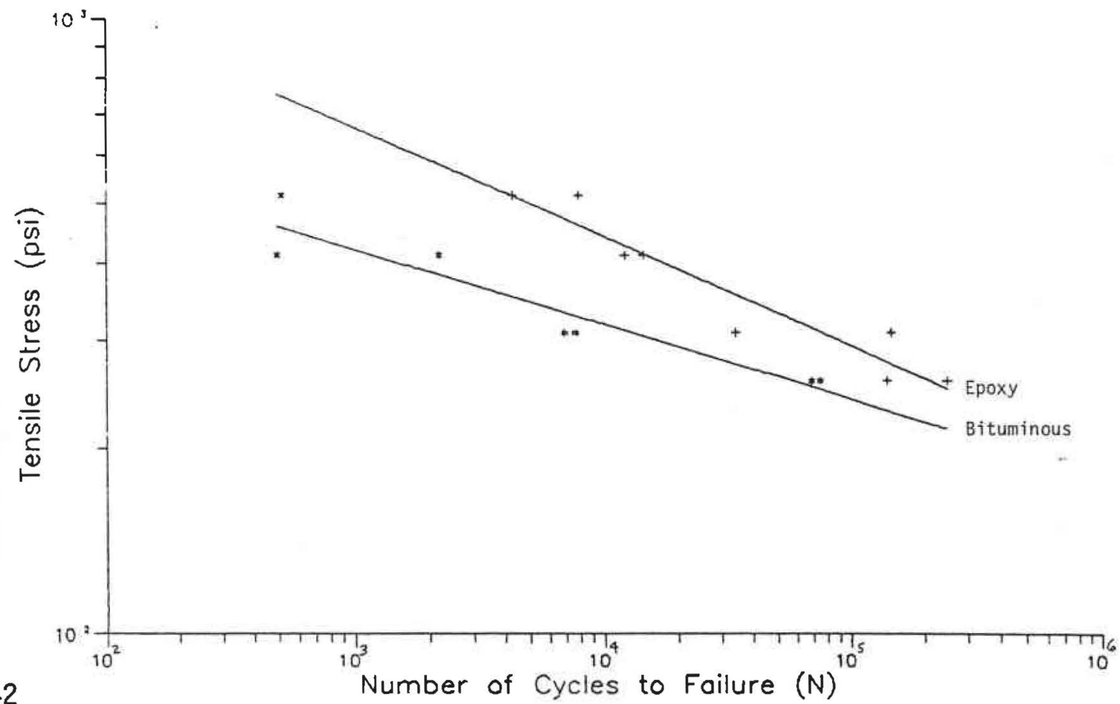


Figure 21. FATIGUE FAILURE OF ACP BY PAVEMENT MARKER LOAD CYCLES
Asphalt Concrete Manufactured with Texaco AC-20
Asphalt Cement and Crushed Limestone
Effect of Bituminous (*) and Epoxy (+) Adhesive



From the plots shown in Figure 18, it can be seen that failure of the asphalt concrete due to the fatigue loads imparted by the marker is reached at a lower number of cycles for lower grade binder asphalt concretes (lower stiffness) using epoxy adhesive. For markers attached with bituminous adhesive (Figure 19) the behavior is not so clear, but it appears that the retention is higher with lower binder grades at lower tensile stresses; at higher tensile stresses, it appears that the retention is lower with lower grade binder asphalt concretes. In order to use the laboratory results in a comparative analysis involving the adhesives, a plot was made for each asphalt cement grade showing the effect of the different adhesives. These results are shown on Figures 20 and 21. The plots show that the retention of markers is clearly affected by the type of adhesive used. For lower grade binder pavements (AC-5) the retention appears to be lower, at higher stress levels, when bituminous adhesive is used. However, at lower stress levels the retention is higher when bituminous adhesive is used. When a higher grade binder is involved (AC-20), there is a marked difference between the retentions obtained with the different adhesives. The retention is seen to be higher when epoxy adhesive is used.

The samples tested in this study were samples for which traffic compaction (in type D mixes, traffic causes the percent air void to reduce from 7-8% to 3-5% after the 3rd summer) was accounted for because compactions of laboratory specimens predict the densities (percent air voids) in the pavement after the 3rd summer. Additionally, the aging potential of the samples was small due to the small percent air voids.

The above results and observations may explain the fact that, in the field, higher retentions have been obtained using bituminous adhesives [4]. During the service life of asphalt concrete pavements, the average stiffness increases due to aging and traffic. So, it is possible that at the early ages of the ACP, when the stiffness is lower, the retention of markers with bituminous adhesive is better than the retention of markers with epoxy adhesive. This can be attributed to a greater compatibility between the pavement material and the bitumen.

With time, the advantage of the bitumen over the epoxy adhesive will decrease until, on an aged pavement, retention of markers attached with epoxy adhesive may become comparable to the retention of markers attached with bituminous adhesive.

V. HIGHWAY TEST SECTIONS

The observation of the durability of test markers placed so as to measure the influence of various parameters has continued throughout the duration of this study. The question of how to quantitatively compare marker retention and then present the results to the user has been solved by using a well known probability density function, the Weibull distribution, to model the rates at which markers are lost.

WEIBULL DISTRIBUTION

In circa 1950 a statistical distribution function with two (sometimes three) arbitrary parameters to tailor the distribution so as to describe a real world phenomenon was proposed by Weibull [6]. It has been used, for example, to characterize the distributions of people's heights, the strengths of glass, and the sizes of tiny particles. But one of its most important applications has been in characterizing the service lives of parts of machines or structures that fail due to fatigue loads.

The Weibull distribution was applied to observed marker loss rates, assumed to be a fatigue phenomenon. The algebraic definition of the distribution is written as

$$P_s(n) = \exp\,[-(n/b)^c]$$

where $P_s(n)$ is the so-called survival function, the fraction of the original population that survives after n loadings. For raised pavement markers, $P_s(n)$ represents the fraction of the markers remaining after they have each been subjected to n wheel strikes. The constants, b and c, are parameters selected to best fit the observed data. Sometimes c is referred to as the shape parameter and b as the characteristic life. Just why b is called the characteristic life becomes clear when one realizes that, irrespective of the value of the constant c, P_s is 0.368 when the variable n is equal to b.

So, the resulting curves represent the fraction of markers remaining after any number of tire hits, and different marker systems can then be compared.

DALLAS - SAN ANTONIO STUDY

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

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).
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 Permark low intensity reflectance ceramic marker (Model P-17, manufactured by Ferro Corp.).
7. New type Permark high intensity reflectance ceramic marker (Model P-117).

At four time intervals, three, six, twelve, and 24 months after the test RRPMs were installed, counts of the markers remaining in place were made by SDHPT personnel. The markers numbered 2, 3, and 5 (above) 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; the collective performance of these is shown in the counts tabulated in Table 6.

The documents and data of this study, originally published by the Department, are included as Appendix C of [3].

To get a broad overview of the test results, the retained fraction of the pavement markers (both the Stimsonite and Ray-O-Lite) and of the traffic buttons (Permark P-117), from Table 6, was plotted as a function of the number of tires estimated to have hit each marker. This estimate was made using the

Table 5. Listing of the Fraction of Markers Remaining in Dallas-San Antonio Retention Study

	Markers Installed (Total)	Three Months (Est. Hits)	Six Months (Est. Hits)	Twelve Months (Est. Hits)	Twenty-four Months (Est. Hits)
San Antonio					
IH 10 (Asphalt Pavement)	234	0.996 (24,300)	0.953 (48,600)	0.877 (97,200)	0.826 (194,400)
IH 35 (Asphalt Pavement)	123	1.00 (21,600)	1.00 (43,200)	0.992 (86,400)	0.871 (172,800)
Dallas					
SH 183 (Portland Cement)	360	0.997 (12,600)	0.989 (25,200)	0.931 (50,400)	0.737 (100,800)

daily traffic reported in the two adjacent lanes (to the markers) and the hit rate for lane line markers determined by the instrumented marker described in Chapter III of this report.

The Weibull distributions were then fit to the observations with the results shown in Figure 22a-c, where the solid curve is the prediction given by $P_s(n)$. In this particular study, the asphalt concrete pavement retained the markers better than the Portland cement concrete pavement, a conclusion contrary to many other observations.

LONG-TERM ADHESIVE TEST SECTIONS

Several field studies were initiated on earlier projects with the goal of comparing the performance of several adhesives for bonding the raised reflective pavement markers to the pavement. Asphalt pavement was of the most interest, primarily because the analyses of the observed failures indicated that the retention of the RRPM on asphalt pavement was a big problem, if not the biggest problem. Even though the failure surfaces invariably lay below the marker and its adhesive, there was convincing evidence that the type of adhesive had an influence on the retention of the marker. Several test sections were installed to compare, side by side, the performance of different adhesives.

The tests were designed to characterize the performance of several adhesives, with several types of markers, under several highway conditions. The materials and the details of the test matrix were described in an earlier report [3]. Five types of adhesives were used with six types of markers on five separate test sites. The test sites each had variation in the average daily traffic, the percent trucks, and the age and origin of the asphalt.

Test Materials

The test consisted of using four different manufacturer's 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

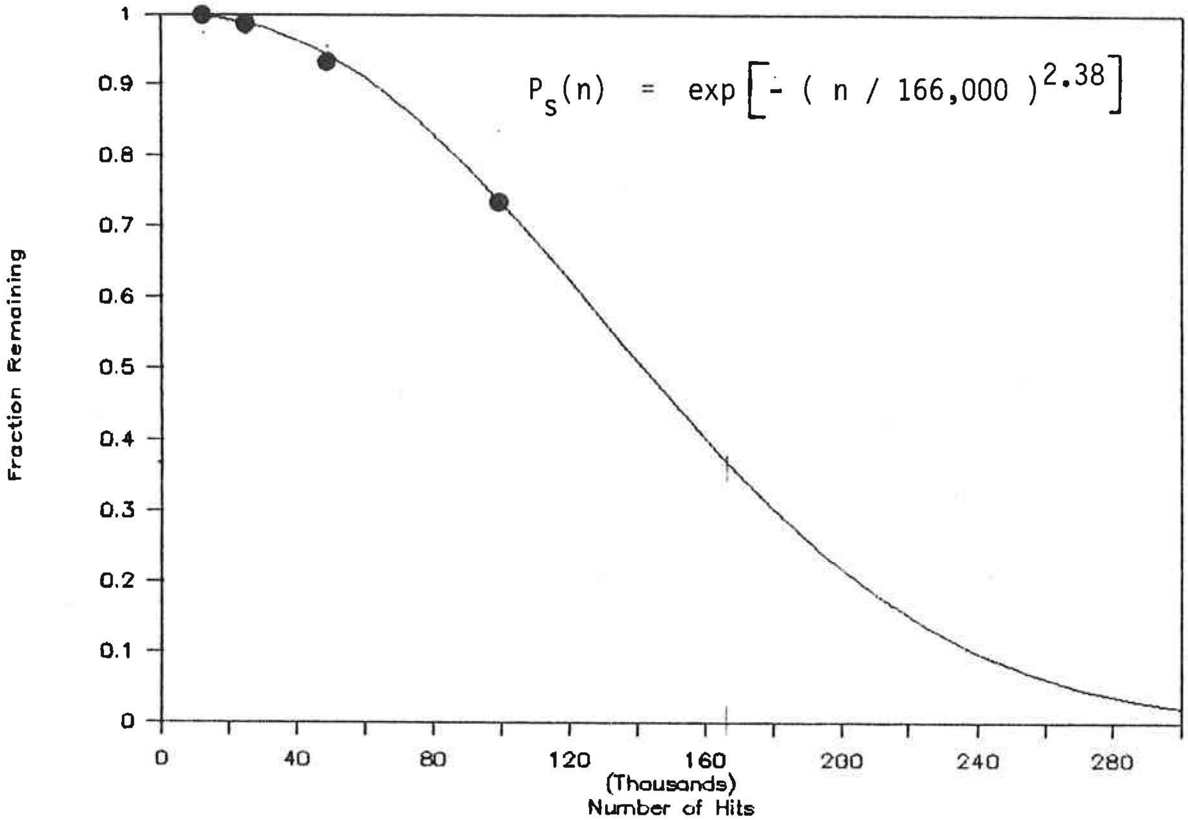


Figure 22 a. The Weibull Distribution Fit to the Marker Losses Observed on IH10 in San Antonio. Asphalt Concrete Pavement.

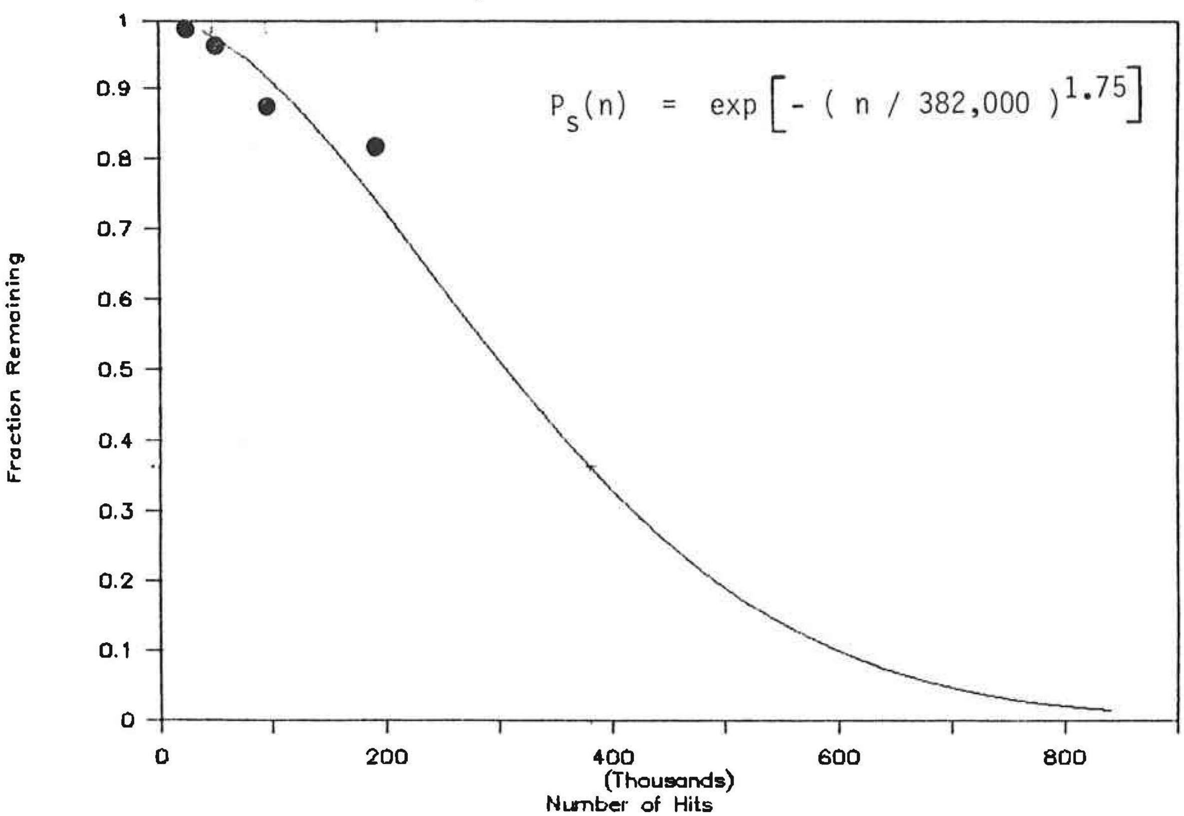


Figure 22 b. The Weibull Distribution Fit to the Marker Losses Observed on IH35 in San Antonio. Asphalt Concrete Pavement.

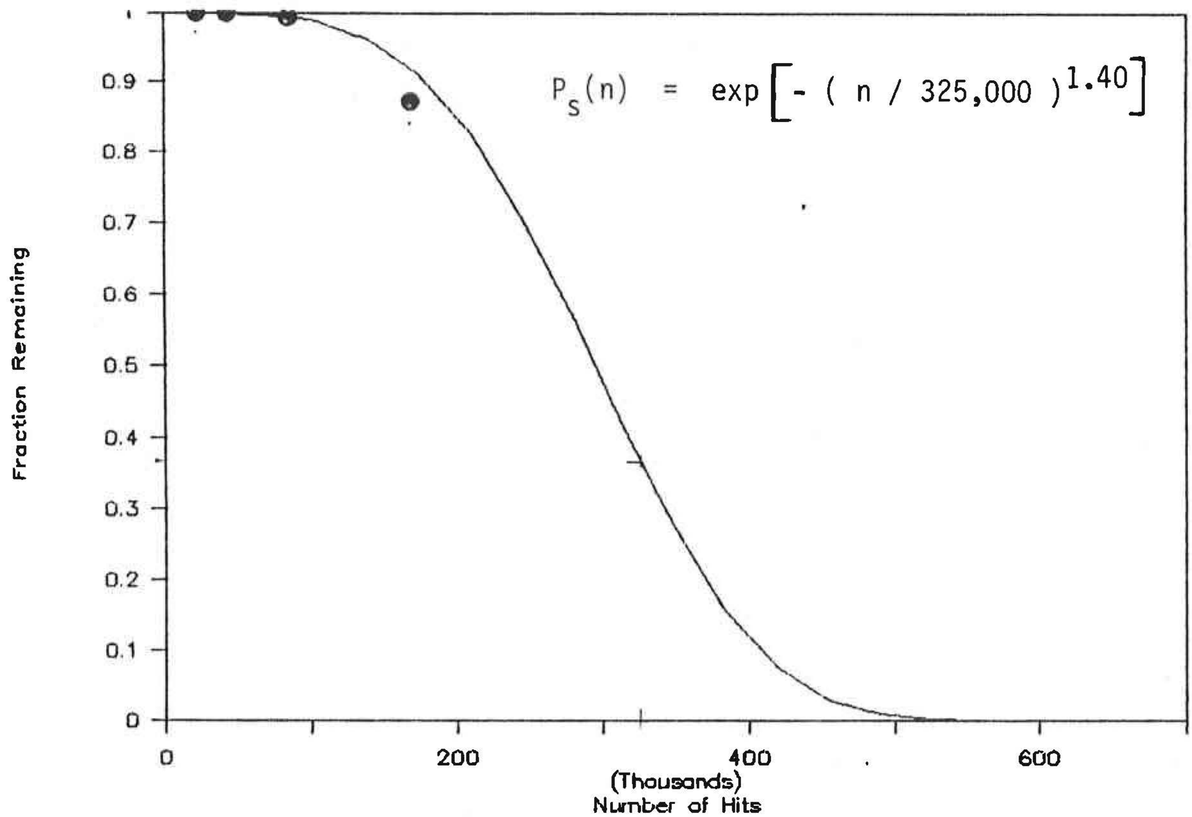


Figure 22 c. **The Weibull Distribution Fit to the Marker Losses Observed on SH183 in Dallas. Portland Cement Concrete Pavement.**

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 Tye I Epoxy, and
5. Twice the circumference of the normal application with the Type I Epoxy from Epoxy Industries.

Various types of reflective markers and traffic buttons (RTB) 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 RRPMs were placed first at one test site and the RTBs were placed first at the second site. The randomized order will be discussed in the description of each test site.

Test Sites

Two test sites consisting of 4,000 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 RRPMs. The American Clay P15 markers with studs were used, however, one P117 with studs and five P7As were used for comparison. Approximately 2,000 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 (RRPM) were placed immediately preceding five American Clay P15A (RTB). The last three RTBs were P7As. Approximately 2,000 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) - Miracles
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.

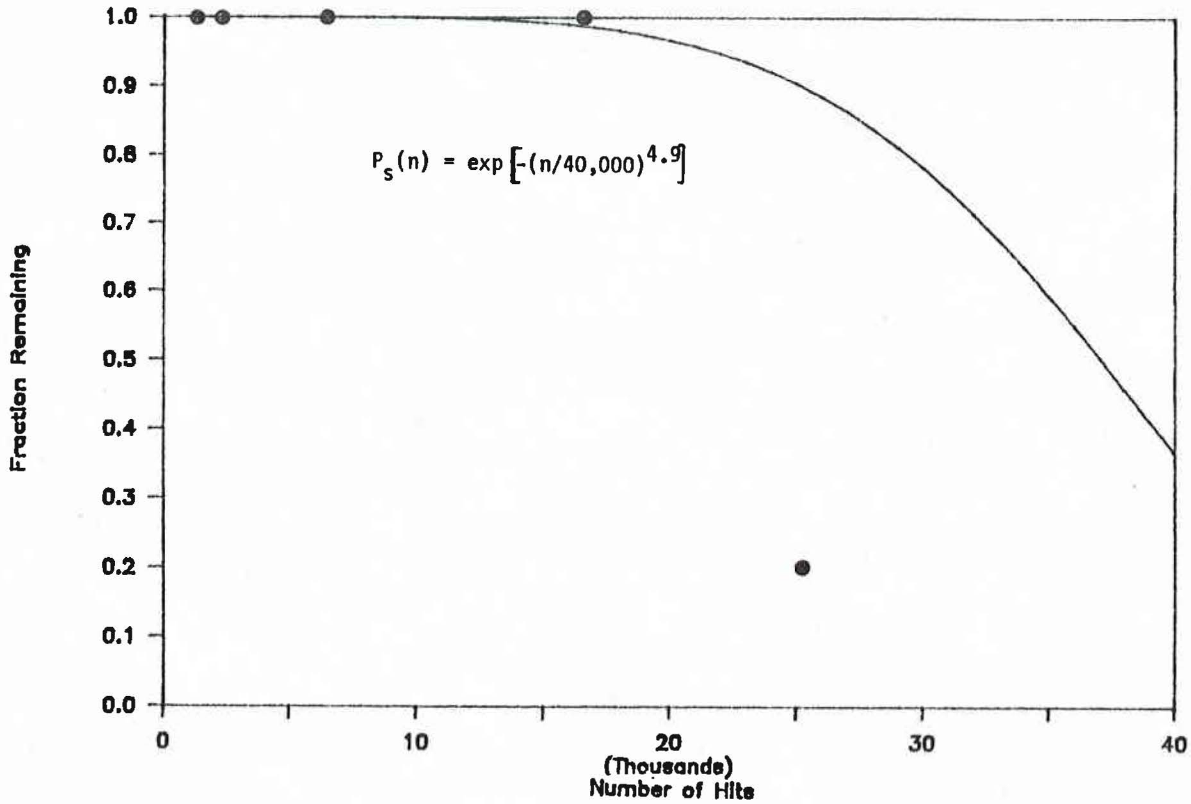
Test Results

When the earlier reports were written, the tests had not been underway long enough to draw meaningful conclusions. Now, however, two years have passed and the observed test results are more significant.

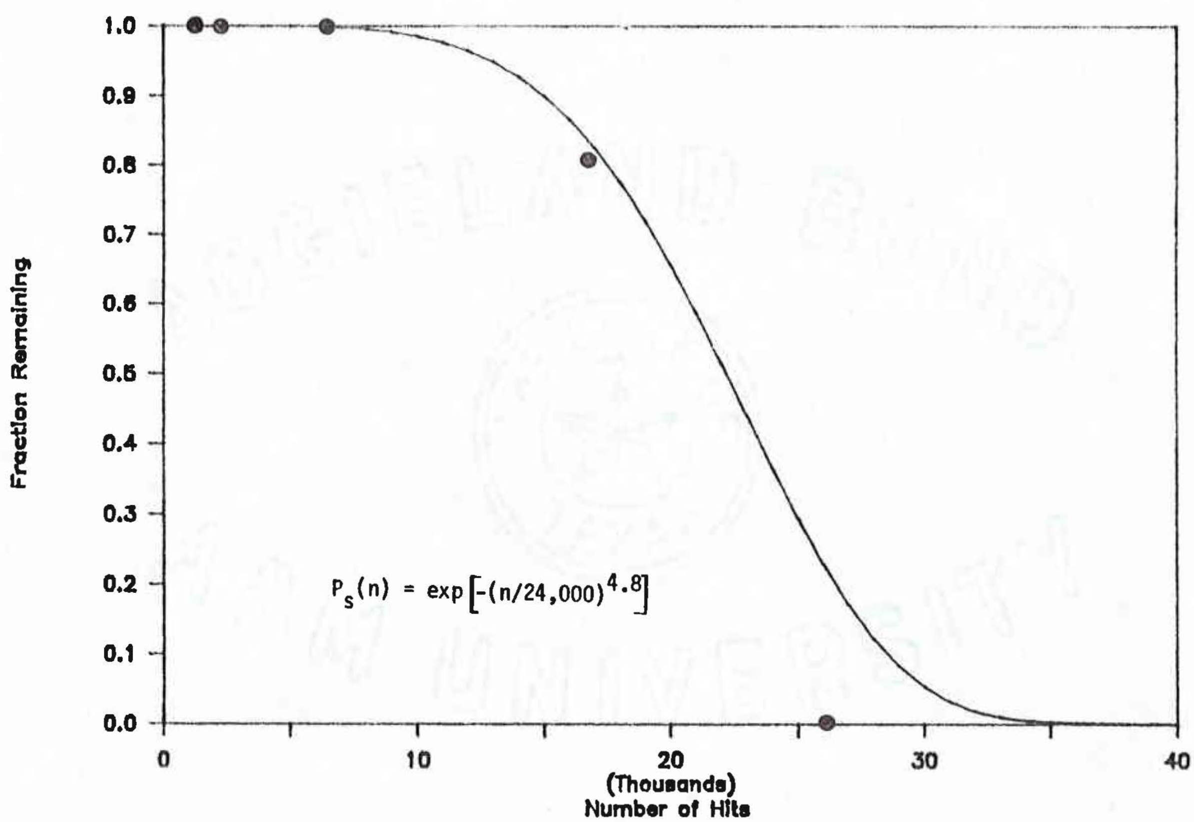
Figures 23(a-e) show the retention rates observed at the two test sites in the Bryan-College Station area. The figures are numbered from best to poorest, with the epoxy by Ring Industries being by far the best.

SEAL COAT TEST SECTION

A pavement test section to compare bituminous and epoxy adhesives on seal coat was put down on a high speed (50 mph) straight section of FM 60 in College Station. This is a four-lane divided highway that had been seal coated about three months before the markers were installed. District 17 (Bryan) installed raised reflective pavement markers, using bituminous adhesive, on September 19, 1986. The lane line markers were placed in

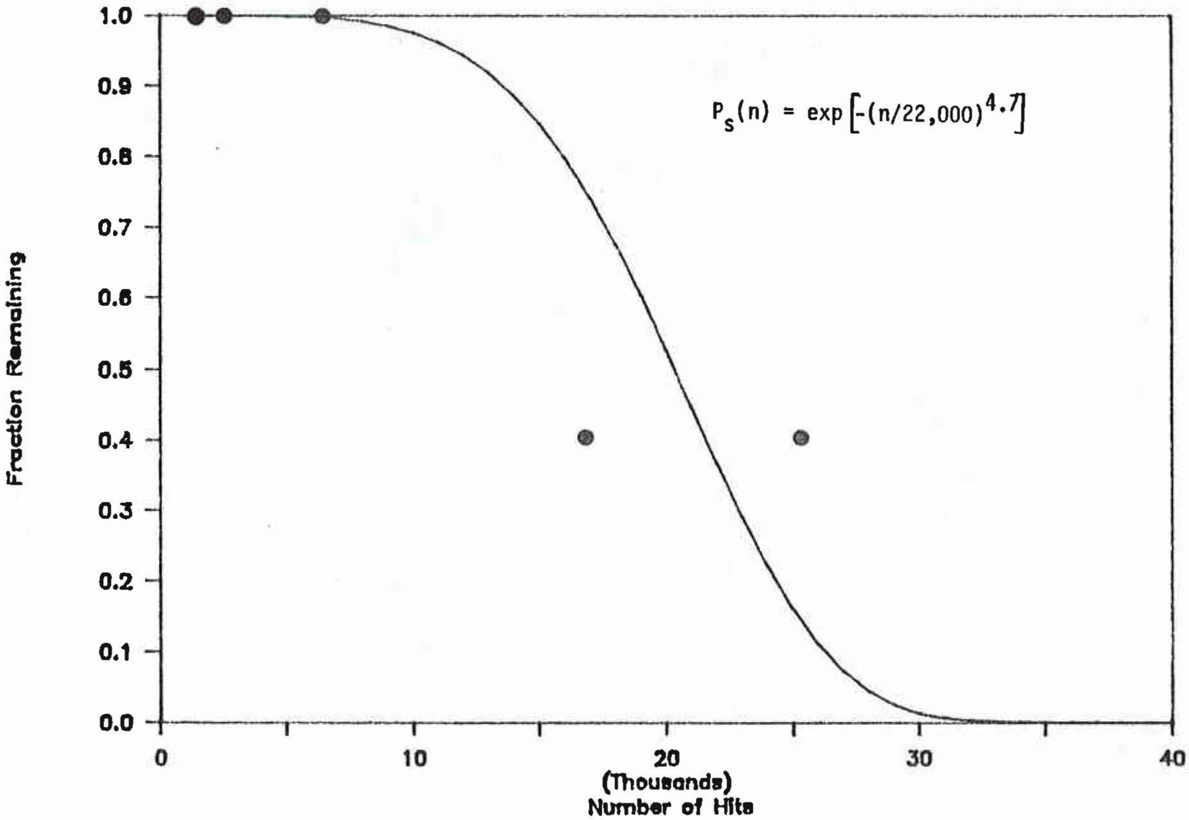


(a) Ring Epoxy

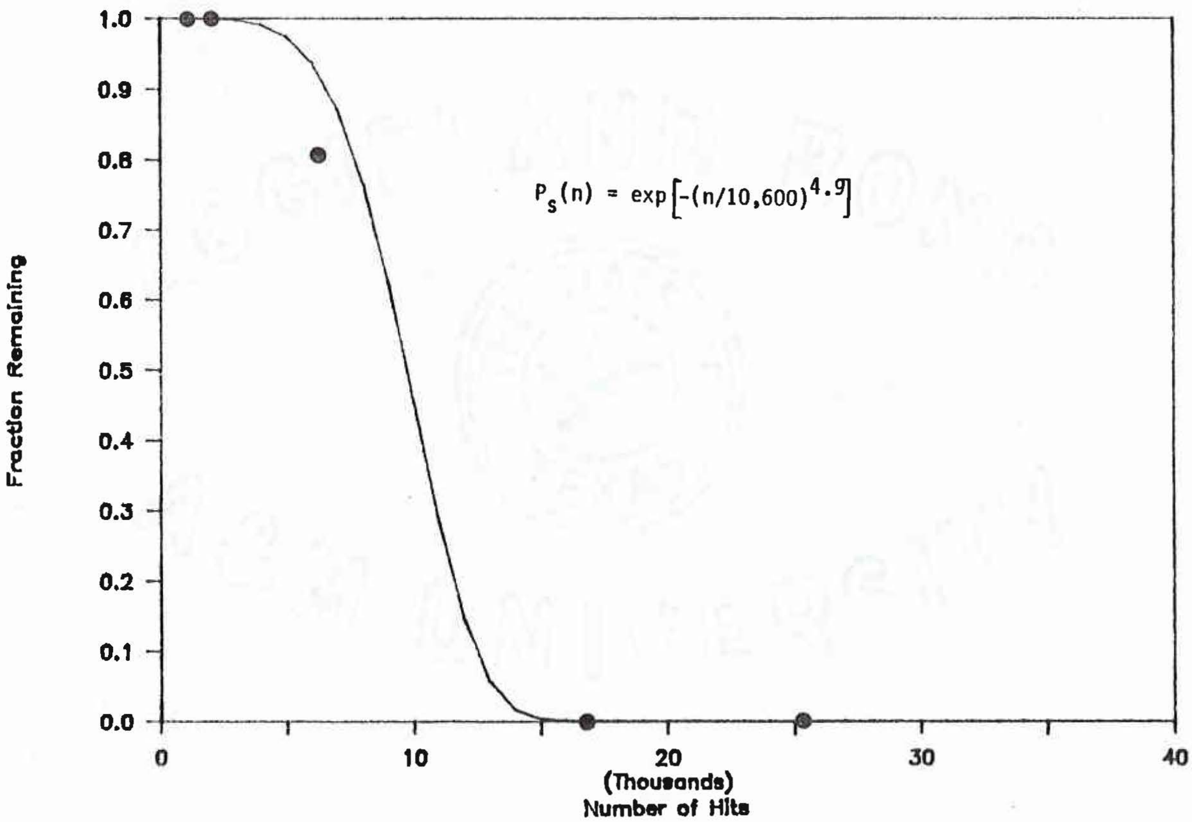


(b) Double-Sized Epoxy Pad

Figure 23. Loss Rates Observed for Five Types of Adhesives on Asphalt Pavements District 17.

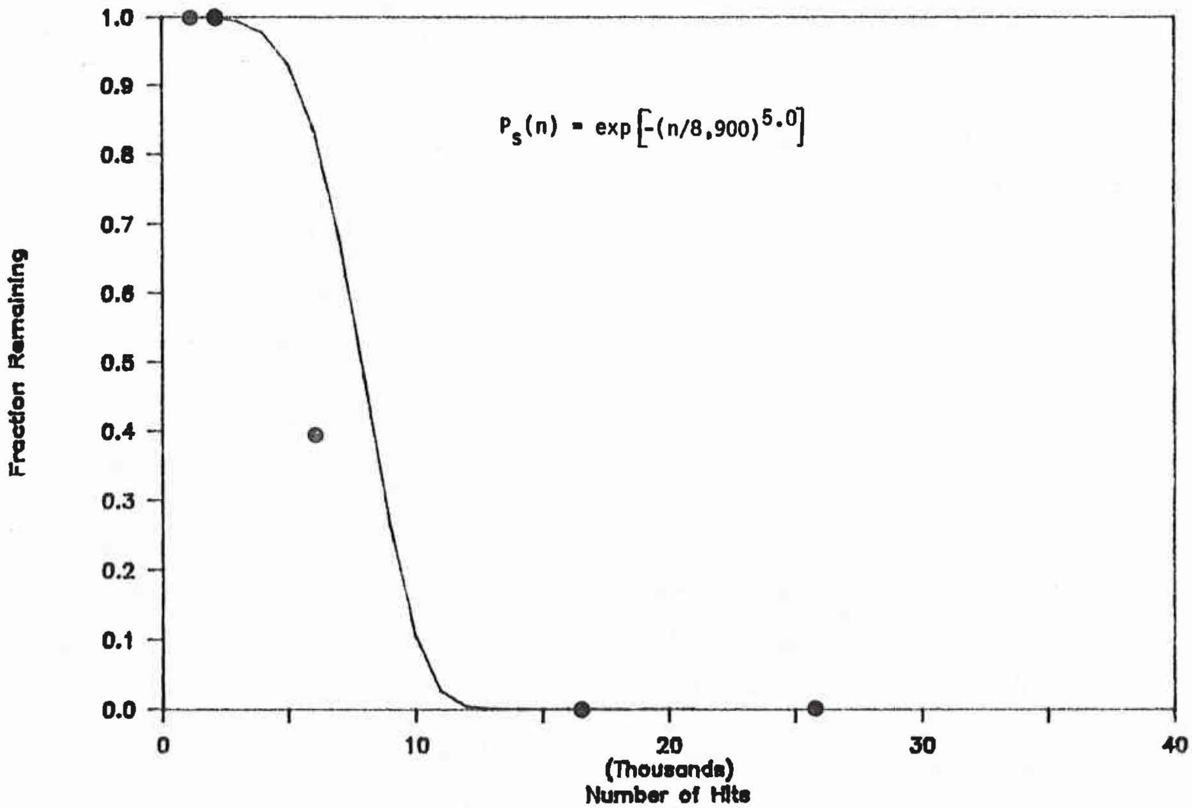


(c) Ferro Epoxy



(d) Conventional Epoxy

Figure 23. Loss Rates Observed for Five Types of Adhesives on Asphalt Pavements District 17. (Continued)



(e) Black Magic

Figure 23. Loss Rates Observed for Five Types of Adhesives on Asphalt Pavements District 17. (Concluded)

alternate skip stripe gaps. On September 26, with permission of District 17, we installed additional lane line markers using epoxy adhesive in the empty skip stripe gaps on each side of the highway. Twelve markers were placed with epoxy on the eastbound side and twelve on the westbound side. The result is a 900 ft two-way test section having lane line markers put down with bituminous adhesive alternating with lane line markers put down with adhesive. A diagram of the layout is shown in Figure 4.

This test section is on FM 60, beginning at the east boundary of the new Texas A&M Research Park (Discovery Road) and continuing east to the driveway of the TAES Onion Breeding and Evaluation Center. It is convenient to the Texas A&M campus so we are able to closely monitor loss rates of markers places with these two very different kinds of adhesive. At the end of this project, 14 months after installation, no markers had been lost.*

The 1984 traffic count near this section was 8164 vehicles in 24 hours (going both directions). Using the 1.5% hit factor estimated for lane line markers, we expected each marker in the test section to be hit about 30 times in a 24 hour period (0.015 x 4082 / 2). Two instrumented markers (described in Chapter III) were also placed in this section. Their data showed a 3-week average of 45 hits per 24 hour period.

REPLACEMENT MARKER TEST SECTION

It was observed that a replacement marker is generally placed adjacent to the surface failure left by the missing marker. The exposed failure spot is then subject to further deterioration by traffic and weather. Since the failure is initially a slight indentation in the pavement, it appears that there may be some advantage gained in locating the replacement marker on top of the failure spot. This procedure would (a) use the slightly larger surface depression area for adhesive bonding, and (b) seal the surface failure left by the missing marker. A test section was placed in a high traffic area to try out this procedure, since the perceived advantages may be outweighed by other effects such as the surface failure region being susceptible to additional failure.

*A subsequent survey made December 7, 1987, found 3 markers missing. Another survey made May 1, 1988 found 1 more marker missing. The 4 missing markers had all been installed with bituminous adhesive.

After obtaining the approval of District 17 (Bryan), a replacement marker test section of 16 lane line markers (Stimsonite 88 Type 1-C) was placed on FM 60 (University Drive) eastbound on a section that had lost all of its lane line markers. The test section begins at the driveway of 524 University Drive East. Marker 1 is in front of the pavement failure spot. The next failure spot is filled with epoxy and marker 2 is placed at surface level over the failure. The remaining markers are alternately placed in front of and over the failure spots. The work was done at dawn on a dry day. Traffic cones were placed in front of each marker to prevent lane changing while the epoxy hardened. The cones were removed after two hours. The 16 markers are at 40 foot intervals, between the skip strips of the lane line, giving the test section a length of 640 feet.

A shot of compressed air was used to blow debris out of a failure spot before filling it with epoxy. A marker failure spot has a small volume so there was no difficulty filling it with epoxy to surface level and placing a marker on top. When driving the test section at night, the illuminated marker string gives no indication of any difference in marker placement.

This test section was installed on July 17, 1986. To date (22 months later) all 16 markers are still in place.

"BITUMEN" vs EPOXY

Another adhesive first suggested by Jack Shockey of Stimsonite and recommended by Roger McNees of the Texas Transportation Institute was a bituminous adhesive sold under the trade name "Bitumen." The single component material is heated to near 400 degrees F (200 degrees C) for placing. This temperature is slightly above the softening point of asphalt, which may account for its success.

Several hundred of the low-profile (2 in x 4 in) reflective markers were installed using the Bitumen adhesive and a like number using the conventional epoxy. These tests were all in District 16 near Corpus Christi.

As shown in Figure 24, the superiority of the bituminous adhesive over epoxy is pronounced. Several engineers, with experience using the bituminous adhesive on Texas roads, report excellent results, suggesting that the service life of markers bonded to asphalt with this adhesive is significantly increased. Further, they confirm that the dramatic cost savings, as calculated by McNees, are actually being realized.

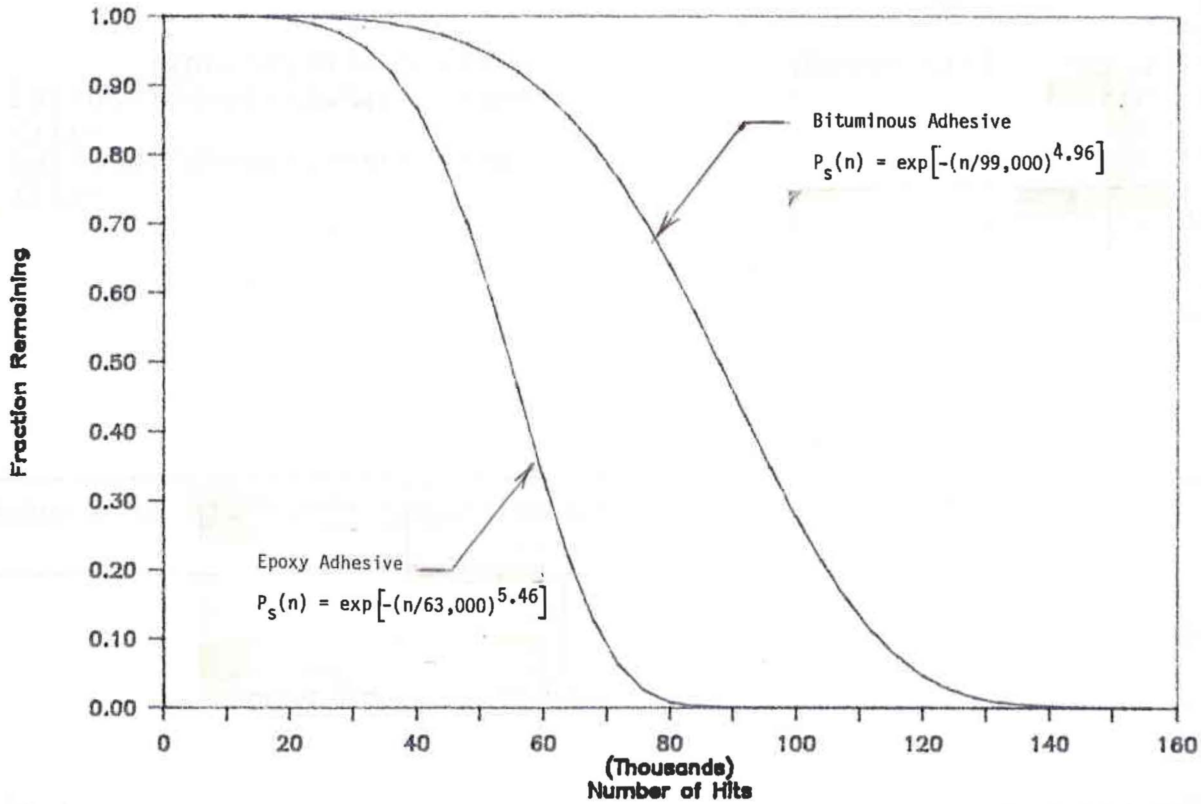


Figure 24. Loss Rate Curves Indicating the Superior Retention Properties of the Bituminous Adhesive

VI. FIELD SURVEYS

EXPERIENCES OF OTHER STATES

Virtually all states use reflective raised pavement markers. However, except for the southern and southwestern States, their use is on a limited basis and is generally restricted to the more expensive snowplowable markers. But their use in the states where snowplowing is not a problem continues to grow both because of their popularity with the driving public and because the technical capability to make and install more durable markers is improving. Oklahoma estimates they have raised pavement markers on 50% of their highways, California has 75%, and Florida is approaching 100%.

But while durability and retention are improving, there remains progress to be made. Many states report that the use of the rubber-like bitumen adhesive improves marker retention on asphalt pavements. But the rapid loss of markers, bonded with any adhesive, installed on uncured asphalt pavement surfaces is unacceptable. All types of reflective markers, including both plastic and porcelain, deteriorate far too rapidly when installed on portland cement concrete pavements. Of course, the truck content of the traffic on such pavements is often very high.

Few if any quantitative tests of the retention and durability of marker systems have been performed by other states. Currently, several states are measuring and reporting the deterioration of marker reflectivity, an important aspect of durability. But the term is used here in the broader structural sense.

RECENT OBSERVATIONS IN TEXAS

Two of these observations will be described. The first is in an informal report of a test of the retention of several types of raised pavement markers on IH20 in Smith County.* The traffic count at the test site is heavy and

*An informal report, prepared by Mr. Joe Graff (D-18), of the results of a Test Section of Raised Pavement Markers on IH20 in Smith County, dated March 10, 1986.

includes a very high (maybe 40 Or 50%) percentage of trucks. After about one year, Joe Graff described the results of using epoxy and bitumen in a side-by-side retention test by summarizing:

"Approximately 8% of all markers placed with bitumen were lost."

"Approximately 47% of all markers place with epoxy were lost."

A glance at Figure 24 indicates that these conclusions are in agreement with the retention curves generated on this project.

Mr. Robert K. Price has made and reported many observations of the performance of reflective pavement markers throughout the state. Some of these counts have been made at sites where the bitumen and epoxy have been installed together to add confidence to comparisons of their performance.

Highway	Location	% Retained by Bitumen	Epoxy
SH35*	Abilene	97	94
FM369*	Wichita Falls	60	78
US277*	Wichita Falls	94	60
US90**	San Antonio (east of Castroville)	98	47
US281**	San Antonio	96	54

Except for the results on FM 369 in Wichita Falls, these data all serve to confirm, at least qualitatively, the conclusions supported by the curves of Figure 24.

* Interoffice Memorandum to Mr. Billy R. Neeley, dated 15 April 1986.

**Interoffice Memorandum to Mr. Billy R. Neeley, dated 1 May 1986.

VII. CONCLUSIONS AND RECOMMENDATIONS

This chapter summarizes the contributions of this research project. Recommendations for future research on asphalt concrete-pavement marker compatibility are also presented.

WHAT HAS BEEN LEARNED

The most important contribution of this project is the finding that the adhesive used to attach pavement marker can influence the fatigue strength of asphaltic concrete. This is notable because there is very little penetration of adhesive into the pavement. The fatigue studies show that a softer adhesive (bituminous) will give new asphalt pavement (a more flexible pavement) longer fatigue life in withstanding tire-marker impact loads than a hard adhesive (epoxy) will. This finding indicates that it will eventually be possible to match physical characteristics of an adhesive to those of the pavement, thus making it possible to optimize the marker cost/retention ratio.

The laboratory studies showed clearly that the advantage of bituminous adhesive decreases (a) as pavement stiffness increases and (b) as input stress level increases. These findings indicate that bituminous adhesive will be less effective on high traffic pavements.

In another endeavor during the project, it was learned how a tire impacts a marker at highway speeds. We found that a small high-pressure passenger car tire did not bounce over the marker (as had been suspected) but instead stayed in contact over the entire top surface of the marker, and remained in contact over a portion of the sloping exit surface. The small high pressure tire is considered an extreme case. It is believed that a truck tire is more likely to stay on top of the marker than a passenger car tire is. The assumed kinematics of truck tire impact can be verified or refuted by high-speed motion photography, as was done for the passenger car tire..

Instrumented markers were used to establish the laneline hit rate on a straight section of a highway. Knowledge of the rate at which traffic strikes a marker is needed to relate the laboratory fatigue studies to retention time on a highway.

A seal coated highway test section was used to compare the performance of bituminous adhesive and epoxy adhesive for laneline markers (the most frequently hit markers). At the end of this project, 14 months after installation, none of the 48 markers in the test section had been lost, suggesting the conclusion that the seal coat surface can accept either type of adhesive equally well. However, 6 months later (20 months after installation), 4 of the markers installed with bituminous adhesive were missing. None of the markers installed with epoxy have been lost.

Another test section was used to investigate the possibility of patching the crater left by a missing marker by installation of a new marker directly on top of the failure spot. To date, 22 months after installation, none of the 16 markers in this test section have been lost, indicating that this maintenance technique can be used to simultaneously repair a pavement flaw while replacing a missing marker. Epoxy adhesive was used for this investigation.*

RECOMMENDATIONS FOR FUTURE WORK

It is most important that work be directed toward measurement of marker impact forces. The marker instrumentation developed to simply count pulses generated by tire hits should be extended to record the hit pulse itself, to give a record of the time dependent force developed by a tire going over a marker at highway speed. Some indication of tire-marker forces has been gotten from axle transducer data but, in view of the complicated deformation of the tire by the marker, it is imperative that the impact force be measured at the marker-pavement interface.

The hit counting marker should continue to be used to establish marker hit rates at centerline locations and on curved sections of pavement.

Laboratory fatigue testing should continue, using specimens cut from highway pavements of different ages and materials. Some highway test sections were cut near the end of the present project but the project terminated before data could be obtained from them. The fatigue test program should be expanded to investigate the effect of air voids and pavement surface temperature on fatigue strength, and the effect of load cycle frequency. The cycle frequency effect may be important in view of the "healing" property of ACP.

*A laboratory study of this procedure (reported in Chapter IV) showed that bituminous adhesive does not work as well as epoxy for replacing a marker on a failure cavity in ACP.

The laboratory fatigue apparatus can now be used to evaluate alternative attachment techniques on a comparative basis. This would (a) save the considerable expense of installing highway test sections (rotomilling, etc.) and (b) provide an indication of the viability of new attachment schemes in a relatively short time. For example, the new hybrid adhesives (bituminous-epoxy, bituminous-rubber) now being developed can be easily and realistically tested with the laboratory apparatus developed during this project.

We recommend that another high-speed photography session be planned to determine how a highway truck tire impacts a pavement marker.

VIII. REFERENCES

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November 30, 1987

HPR 0010(11)
Study No. 2-10-65-84

Mr. Raymond E. Stotzer, Jr.
Engineer-Director
State Department of Highways
and Public Transportation
Austin, Texas

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MAR 22 1988

Attention: Mr. Alvin R. Luedecke, Jr.
State Transportation Planning Engineer

Dear Sir:

Submission of Research Report 477-1F

We are submitting to you for your review and approval ten (10) manuscript copies of Research Report 477-1F, " On the Retention of Reflective Raised Pavement Markers," by John T. Tielking and James S. Noel.

This research report emanates from study no. 2-10-86-477.

Sincerely,

C. V. Wootan
Director

we need it for publ. 5-23-88
due 6-15-88 at SDHPT Austin

DATE APPROVED March 15, 1988
REPORTS REQUIRED 125
SUMMARY REPORTS REQUIRED N/A
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B. Hubbard w/FHWA attachment
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