Research on Raised Pavement Markers

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The results of a study directed toward increasing the retention time of raised pavement markers on asphalt concrete pavement are described. Retention time is believed to be largely limited by fatigue strength of the pavement surface. The kinematics of a tire striking a raised pavement marker were studied by high-speed photography to guide development of a laboratory apparatus that simulates pavement fatigue 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 was also developed during the study. The circuitry is described, and hit count data obtained with instrumented lane line markers are reported. These data, together with the laboratory fatigue data, permit prediction of retention time for a particular application. The paper concludes with an analysis of data from several adhesive test sections on state highways. Data from one 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 alongside it.

The use of raised pavement markers (RPMs) to supplement highway delineations has been well received by road users. At night the reflective marker enhances lane delineation to give the driver an additional feeling of security. Day and night, by a series of tire-marker impacts, the RPM reminds the driver to check his lane position.

RPMs are far more prevalent in southern states than in the north where snow removal equipment restricts their use. Snowplowable markers are available, but their installed cost is high ($15 to $20 per marker). In snow-free areas, the markers are easily attached by adhesive bonding to the pavement surface. The installed cost is then in the neighborhood of $2 per marker. Several million raised markers are currently in service on Texas highways.

Although the RPMs generally perform well and there are no plans to discontinue their use, two distinct maintenance problems—reflectivity and retention—have arisen. The reflectivity problem has been addressed in earlier research (*1*) at the Texas Transportation Institute (TTI), and is the subject of another ongoing project at TTI. The study described in this paper (*2*) focuses on the retention problem.

It has long been recognized that RPMs are generally lost by a failure in the surface of the pavement itself, instead of by failure of the adhesive or breakup of the marker. Missing markers are usually found by the roadside, intact and with a "divot" of pavement attached to the base. They can become a road hazard. A displaced marker thrown through a windshield by a mower resulted in a lawsuit in a Texas highway district.

A distinct shape effect on retention has been observed (*3*). On all pavements, round ceramic markers (traffic buttons) are retained much better than the square-base plastic markers. The retention problem is more serious on asphalt concrete pavement (ACP) than on portland cement concrete (PCC) pavement. Surveys of square-base markers on ACP have found loss rates of up to 80 percent in 18 months. In Texas the loss rates appear to increase during the spring and fall. If the markers survive 18 months, a service life of 3 to 5 years can be expected.

Until recently, all markers were bonded to the pavement surface with a two-part epoxy. Bituminous adhesive, which must be heated before use, is a primary substitute for the various types of epoxy that have been used. A number of highway districts in Texas have laid test sections with bituminous adhesive, some as early as 1983. Inspection reports indicate generally superior performance; in some cases the retention percentage of generally superior performance; in some cases the retention percentage of markers attached with bitumen was twice as high as that of the markers attached with epoxy. Some disadvantages have appeared also; there have been reports of markers sliding and submerging (apparently because of the reaction of bituminous adhesive with bituminous concrete).

RESEARCH METHODOLOGY

The problem of pavement marker retention was approached by studying the fatigue characteristics of asphalt pavements under the repetitive loads imparted by tires striking a pavement marker. The hypothesis is that the 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 that marker retention failure is a fatigue failure is the absence of ductile deformation at the asphalt failure site 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 involved. The failure depends on the number of load cycles (tire hits) and is relatively insensitive to the frequency of the

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loading. The insensitivity to load frequency makes accelerated testing possible.

In order to design a laboratory fatigue experiment, it was necessary to determine the kinematics of a tire striking a marker. This was relatively easy to do with high-speed photography, and the findings are described here. It would also be desirable to determine the marker impact force, namely, the force impulse vector transmitted by the marker to the pavement. For this study, the impact force was estimated from tire ride data provided by a tire company.

To relate the laboratory fatigue data to marker retention time on a highway, a hit-counting pavement marker was developed. The hit count divided by the daily traffic passing the marker allows the laboratory fatigue cycles-to-failure data to be related to highway marker retention time.

Because the 4- by 4-in. square base marker presents a much greater retention problem than the 4-in. diameter round marker, the fatigue study was restricted to square base RPMs.

TIRE-MARKER IMPACT

A tire traveling at 50 mph traverses the 4-in. span of a pavement marker in 4.5 msec. This duration of traverse is too short to visually determine the effect of a marker on the path of a tire. To study the tire-marker impact event, a high-speed motion picture camera was focused on a 4- by 4-in. RPM 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/sec. This gave about four pictures (frames) of the tire traversing the marker at 60 mph. A typical sequence of four frames taken at 60 mph is shown in Figure 1. Regardless of speed (up to 60 mph) or inflation pressure (25, 35, or 45 psi), the tire is seen to

- Hit the marker on 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.

The high-speed photography showed that the tire always stayed in contact with the top surface of the marker instead of bouncing off it as was believed likely to occur with a small high-pressure tire. The passenger car tire was studied because laboratory data (*4*) indicate that a truck tire always envelops a marker. Photographic evidence for a truck tire was not obtained in this study. The assumption that any tire striking a marker will stay in contact during the traverse was used in the design of a laboratory experiment to measure the fatigue strength of asphalt experiencing tire-to-marker impact loads.

HIT-COUNTING MARKER

Using laboratory fatigue data to predict pavement marker retention time requires knowledge of hit rates for markers in

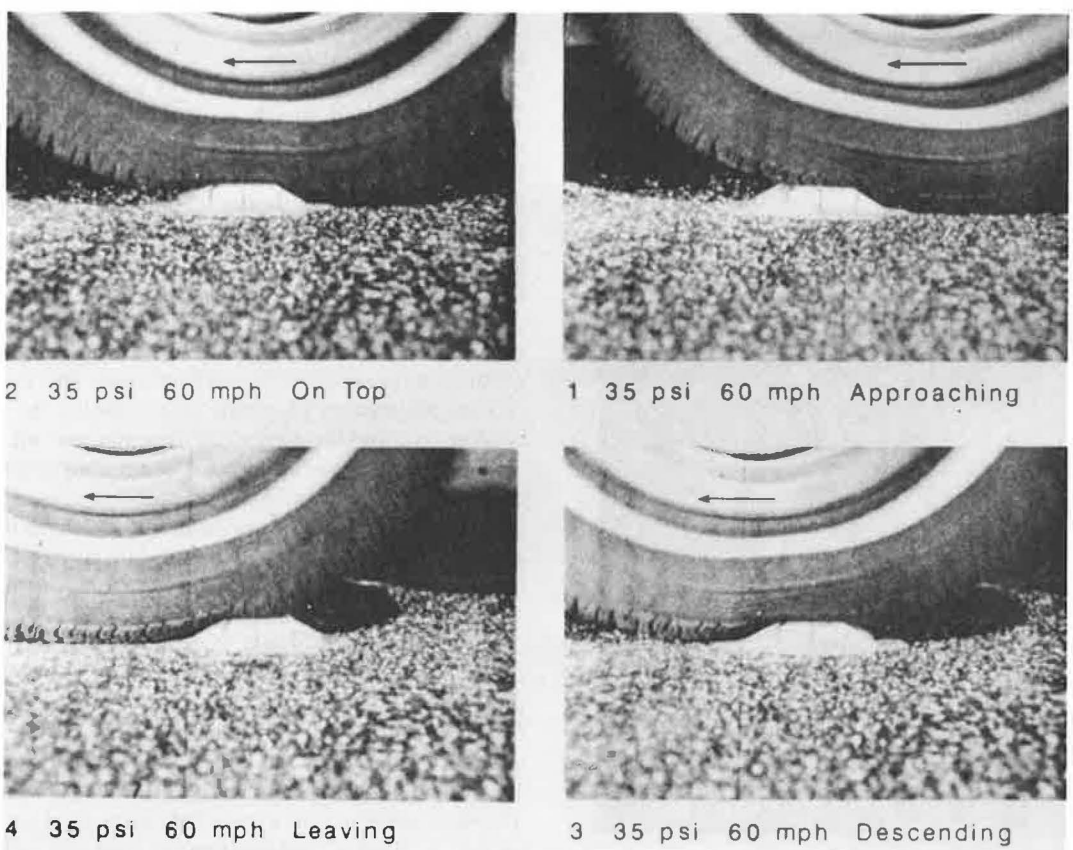

FIGURE 1 Tire-marker impact sequence.

various highway applications. Marker hit rates have been previously estimated by TTI researchers by visual counting during daylight hours. Because it is very difficult to detect when a tire strikes a marker and markers may be hit more often at night than during the day, a means of automatic hit-count data collection is needed.

Instrumentation

A 4- by 4-in. pavement marker was instrumented to record the number of tire hits received. A cavity was milled in the base of the marker to hold a piezoelectric crystal sensor (XDCR), electronic components, and two small 3-volt lithium batteries. A rectangular side opening was cut to hold a 20-pin female connector, flush mounted with epoxy. All of the components were 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. Figure 2 shows an instrumented (hit-counting) lane line marker installed on a pavement. It is completely self-contained and cannot be distinguished from other markers by a vehicle driver.

A hit count is read by plugging a display unit into the connector on the side of the marker. This takes about 3 to 4 sec at the marker location on the highway. The count is held in the digital display until recorded and the display is cleared. A block schematic diagram of the circuitry in both the marker and the display unit is shown in Figure 3.

The lithium batteries power the instrumented marker for about 3 months. The hit-count data reported below were taken near College Station, Texas, during May 1987. There were some very hot days and some rainy days, but weather effects on the instrumented marker could not be detected. The counter was checked by driving a car over it at highway speed.

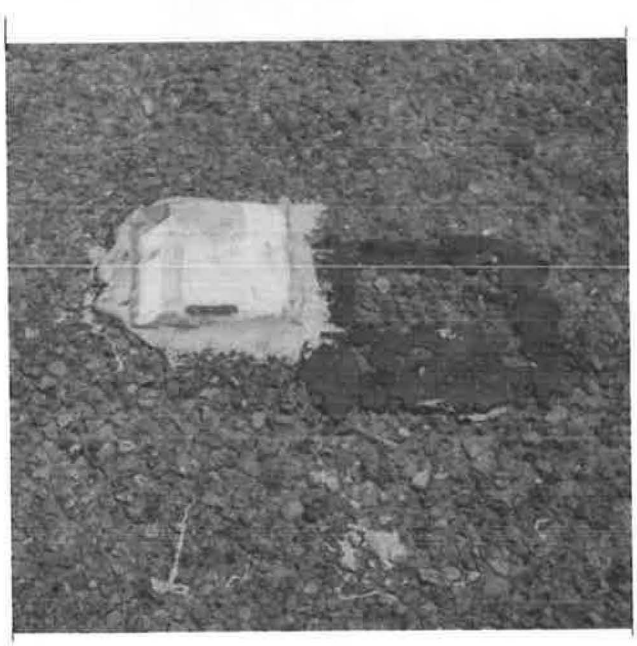

FIGURE 2 Hit-counting pavement marker.

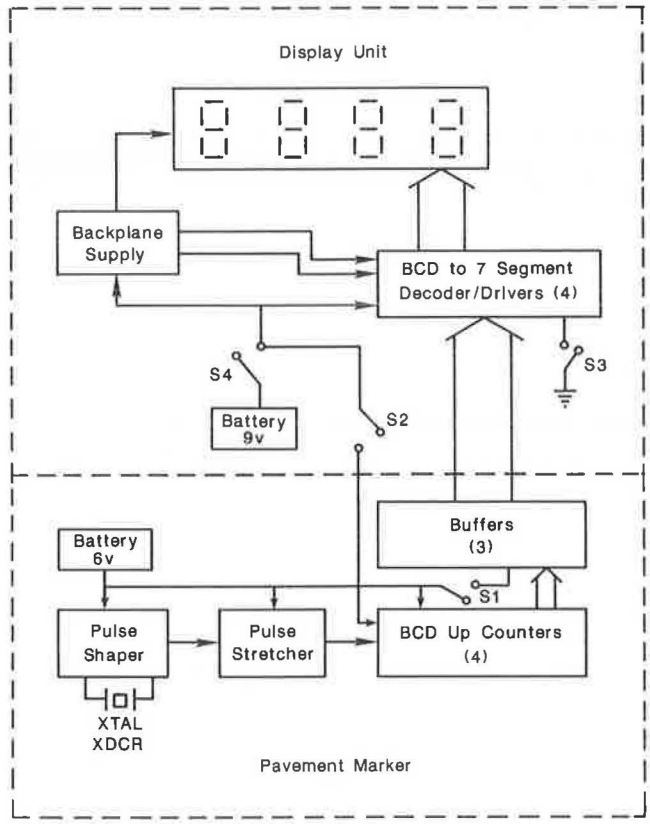

FIGURE 3 Block schematic of pavement marker and display unit electronics.

Highway Hit-Count Data

Two instrumented lane line hit counters were placed on a straight section of eastbound FM 60 near College Station. FM 60 is a four-lane divided highway with a posted speed limit of 50 mph. One counter was installed at location A (see Figure 4) and the other was installed at location B (not shown), 560 ft 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 placed across the two eastbound lanes about 100 ft east of hit-counting marker A (see Figure 4). The traffic counter records the number of vehicle axles crossing the tube, which is taken to equal the number of tires that may hit a pavement marker. Table 1 gives the traffic count data and the daily 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 hit/axle for the 1-week period. Assuming two axles per vehicle, these data imply that 1.16 percent of the traffic will strike a particular lane line marker in this test section. It was estimated in earlier resarch (*3*) that lane line markers are hit three times as often as center line markers on four-lane divided highways. Highway geometrics are clearly a factor in marker hit rates. The data reported here were taken on a no-access straight section of highway, and thus may be considered a lower bound on lane line hit rates for this highway.

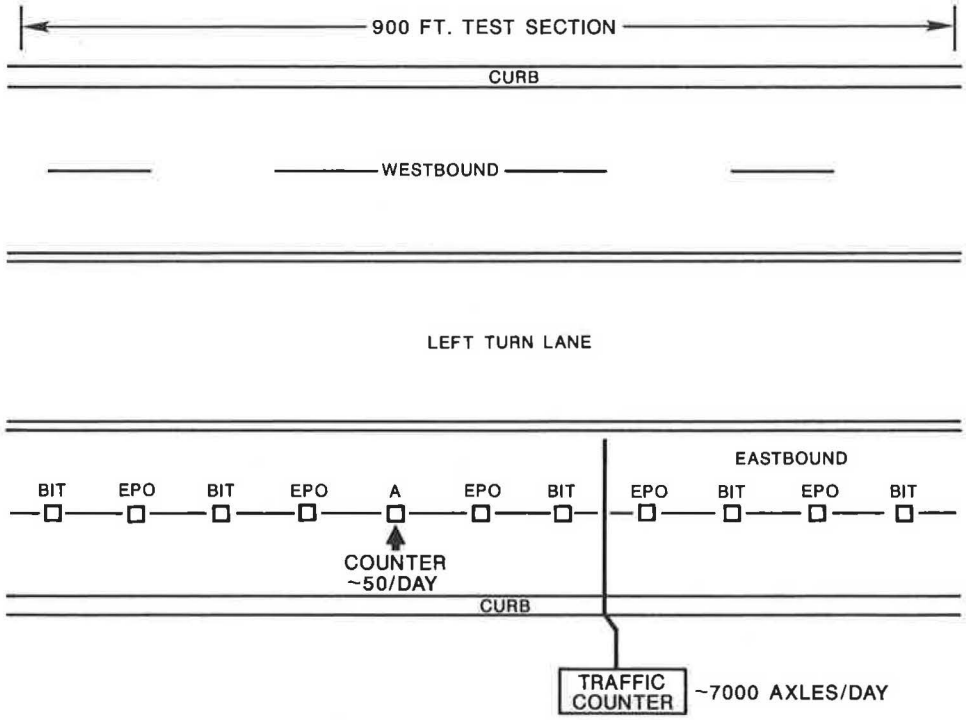

FIGURE 4 Seal coat test section with location of hit-counting marker (*A*) and traffic counter.

TABLE 1 MARKER HIT AND TRAFFIC DATA ON FM 60

	Hit Count		Axle Count	
Date	A	B	Daily	Total
May 18 (Mon.)	70	–	–	–
May 19	34	84	6,791	6,791
May 20	40	64	6,902	13,693
May 21	44	30	7,064	20,757
May 22 (Fri.)	26	94	7,190	27,947

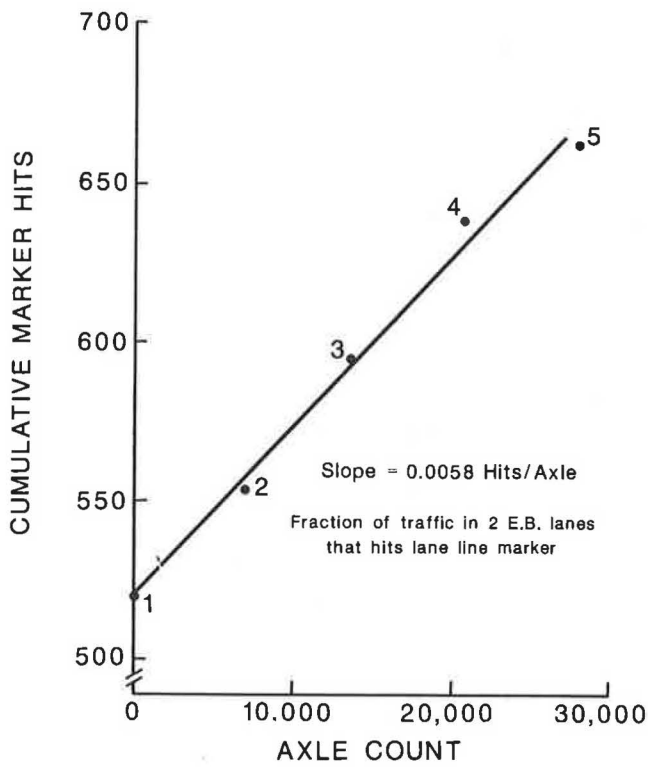

FIGURE 5 One-week accumulation of marker hit data.

PAVEMENT FATIGUE STUDY

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 car or truck tires. The high-speed photography, described above, showed that a tire striking a marker remains in contact during the traverse. Because the center line of a tire seldom passes over the center of the marker, a tire impact imparts a rocking motion to the marker in addition to the vertical load. The repetitive rocking motion from tire impacts on either side of the marker applies a fatigue loading to the pavement surface.

Fatigue Test Apparatus

To simulate pavement marker fatigue loading, the laboratory apparatus shown in Figure 6 was constructed. Here pavement loading is applied by three pneumatic rams acting on a steel beam attached to a 4- by 4-in. steel plate. The steel plate is bonded to the asphalt concrete sample with the same adhesive that would be used to attach a pavement marker. The purpose of these experiments was to study pavement surface failure and any effects an adhesive may have on the fatigue life of a pavement surface. The 5-in. ram at the center of the beam

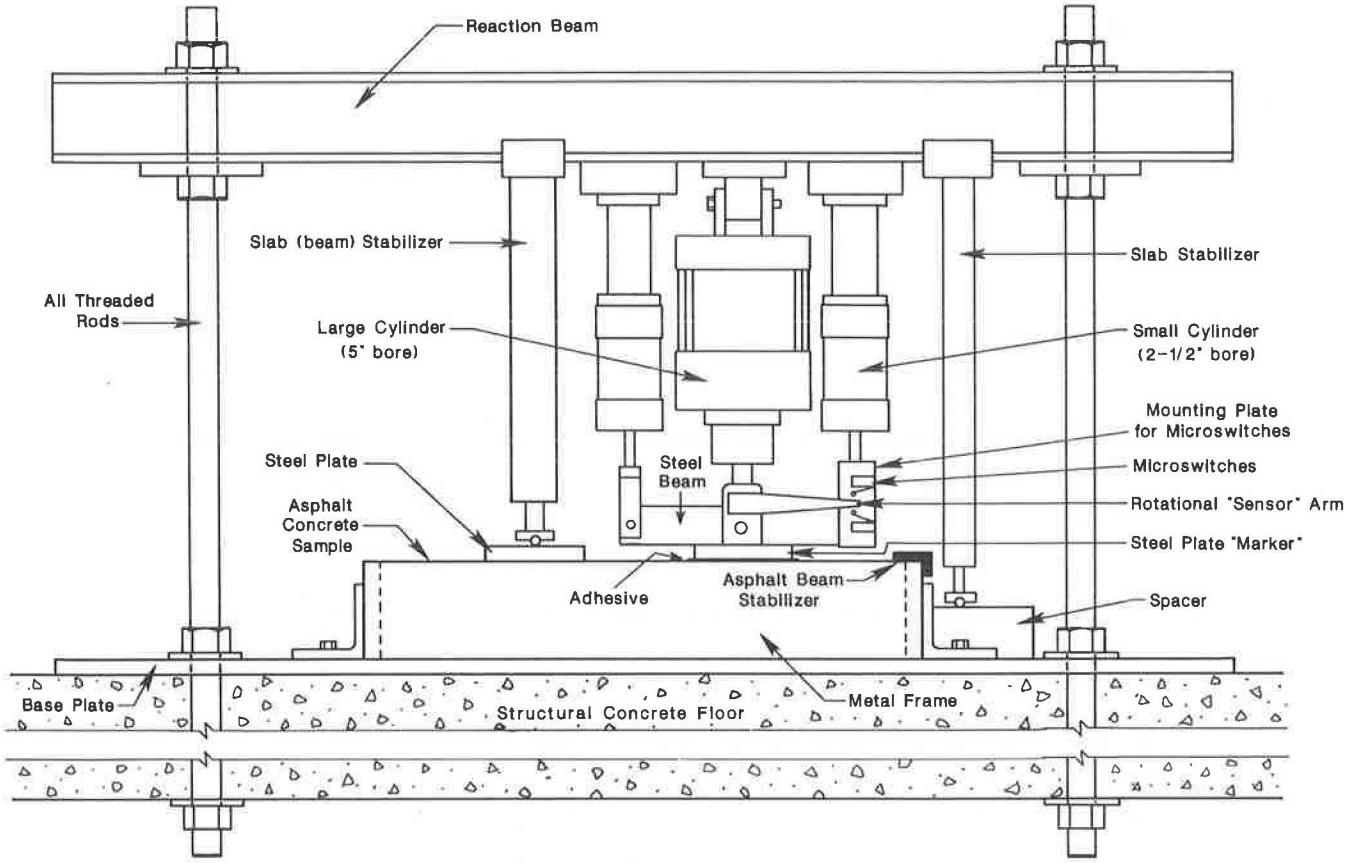

FIGURE 6 Fatigue test apparatus.

applies a pulsating vertical load on the center of the marker, whereas the two 2.5-in. rams at the ends of the beam apply an alternating moment to the marker plate. The control system timing the rams is completely pneumatic, and the entire apparatus runs on a very small volume of the laboratory air supply at 100 psi. The fatigue test is performed under load control, with the load frequency fixed at 1 cycle/sec.

As the load cycle count builds up, the small angular motion of the marker plate bonded to the asphalt begins to increase in amplitude. This is an indication that fatigue failure of the asphalt is imminent. The point at which fatigue failure has actually occurred is arbitrary. It was defined in these experiments as occurring at a rotation angle of 1.55 degrees. This value ensures that the asphalt under the edges of the marker plate has separated but is small enough for the test to be stopped before total failure occurs. The test is halted by tripping either one of the microswitches with the rotational sensor arm (see Figure 6).

When a fatigue test is completed, the cycle counter is read and the rocker beam is disconnected from the markerplate. The plate itself can then (usually) be tugged away from the asphalt and the failure examined. The asphalt failure surface produced by the laboratory fatigue test is remarkably similar to the failure surface seen when a marker has been lost from a highway pavement. Adhesive failure does not occur in this test. Further details of the fatigue test apparatus and data obtained from it are given in a marker-pavement compatibility study by Fernandez (*5*).

Test Results

Although little is known about the forces involved when a tire strikes a raised pavement marker, the impact is believed to generate asphalt stress levels in the range of 100 to 1,000 psi at the marker edges. The pneumatic rams were designed to apply alternating tensile stresses in this range for the fatigue study.

To study the possible interaction of adhesive and asphalt, laboratory test pavements were prepared with crushed limestone and two different grades of asphalt cement (AC-5 and AC-20). Two basically different marker adhesives (bituminous and epoxy) were used to attach the marker plates to these pavements for fatigue testing.

The fatigue test results shown in Figures 7–10 give the number of cycles to failure (N) for a test run at a certain tensile stress amplitude of the cyclic load. Each data point represents one surface failure. At the laboratory load frequency of 1 cycle/sec, a data point at $N = 10^4$ cycles was acquired in 2.8 hr. From the highway hit rate found by a hit-counting marker, this data point corresponds to 200 days of lane line life, indicated on the horizontal axis of Figure 7.

Although there is considerable data scatter, as is common in fatigue testing, it is possible to distinguish trends in the data when log-log plots are made as shown in Figures 7–10. The straight lines in these figures represent the power equation $\sigma = AN^B$ with A and B determined by the least-squares curve-fitting procedure.

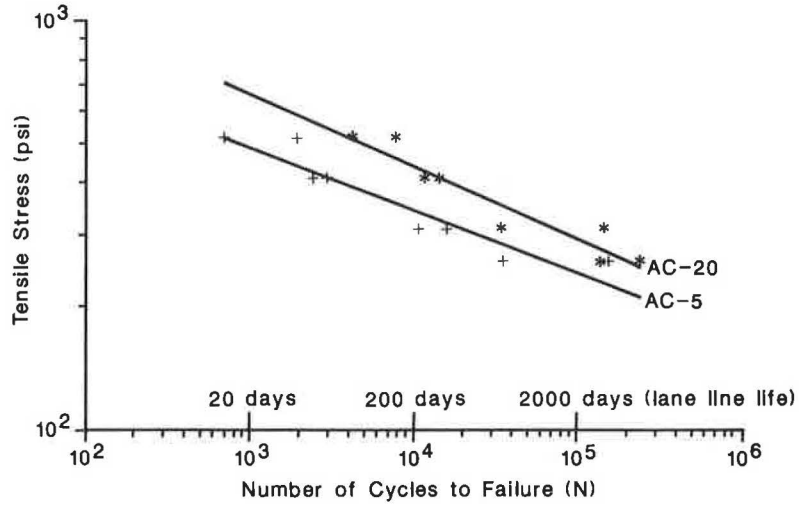

FIGURE 7 Fatigue failure of ACP by pavement marker load cycles: test pavements prepared with AC-5 and AC-20 binders, epoxy adhesive.

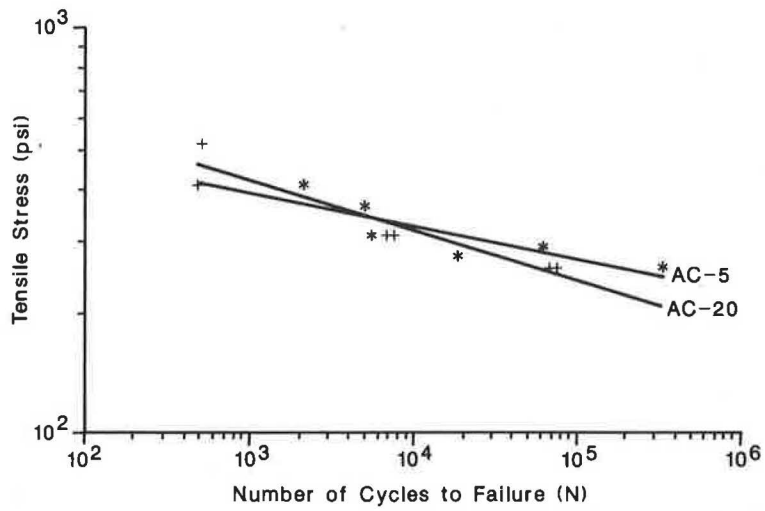

FIGURE 8 Fatigue failure of ACP by pavement marker load cycles: test pavements prepared with AC-5 and AC-20 binders, bituminous adhesive.

Discussion of Results

From the data in Figure 7, it is seen that fatigue failure occurs sooner for the AC-5 concrete than for the AC-20 concrete when epoxy adhesive is used. These pavements differ mainly in stiffness, with the AC-20 binder giving the stiffer surface. When the markers are attached with bituminous adhesive, the distinction between binder grades is not as clear (see Figure 8) and is seen to depend on stress level. In order to use the laboratory results in a comparative analysis of adhesives, Figures 9 and 10 were made to show the effect of the two adhesives used with each asphalt cement grade. These plots clearly show that marker retention time is affected by the adhesive used. This result is notable because very little adhesive appears to penetrate the pavement surface. For the lower-grade binder (AC-5) pavement the retention time is less at higher stress levels when bituminous adhesive is used (see Figure 9). When a higher-grade binder (AC-20) is used, giving a stiffer pavement, there is a consistent difference between the retention times obtained with the different adhesives. The retention on the stiffer laboratory pavement is better at all stress levels when epoxy adhesive is used (see Figure 10).

These results are supported by the fact that, in the field, better retention has been obtained with bituminous adhesive. During the service life of an asphalt pavement, its stiffness increases with aging and traffic. In the early life of an ACP, when its stiffness is lower, the retention time of markers using bituminous adhesive may be expected to exceed that of markers placed with epoxy adhesive. With time, the advantage of the bituminous adhesive over the epoxy adhesive is predicted (by the laboratory findings) to decrease until, on an aged

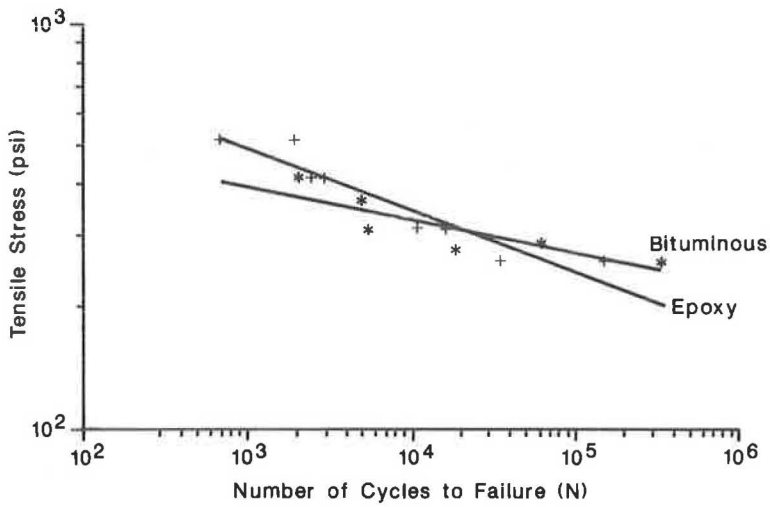

FIGURE 9 Fatigue failure of ACP by pavement marker load cycles: marker plates attached with bituminous and epoxy adhesives, test pavements prepared with AC-5 binder.

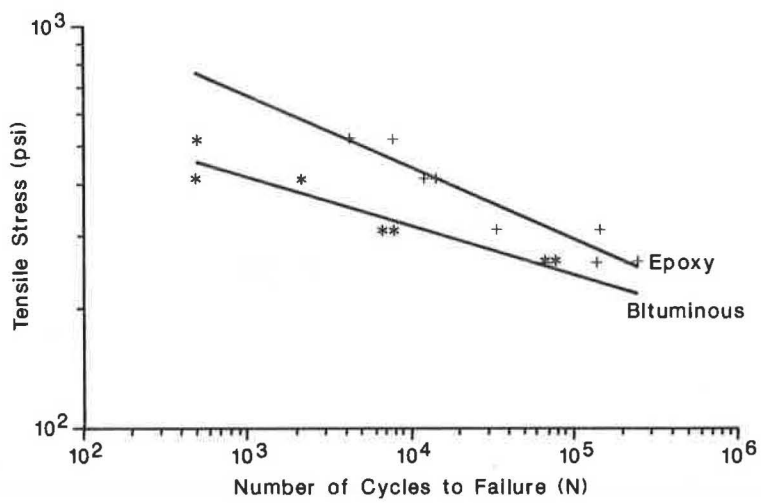

FIGURE 10 Fatigue failure of ACP by pavement marker load cycles: marker plates attached with bituminous and epoxy adhesives, test pavements prepared with AC-20 binder.

pavement, the retention of markers attached with epoxy may become comparable or exceed the retention of markers attached with bituminous adhesive.

HIGHWAY TEST SECTIONS

The survivability of a variety of test marker systems has been monitored since the inception of this study. It was determined that the Weibull distribution function reflects the marker loss rates reasonably well. This two- (sometimes three-) parameter statistical distribution function was first proposed in the early 1950s (*6*). The function has been found to be particularly well suited to characterization of the fatigue failure rates of large numbers of identical parts subjected to similar or identical load histories. Algebraically, 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 tire hits. 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.

A systematic procedure was used to pick the constants b and c to represent observed marker loss rates. The constants were selected to minimize the sum of the squares of the differences between the observed loss rates and the loss rates predicted by the survival function. This made it possible to compare the retention performance of different marker systems either by comparing cumulative distribution curves or by comparing the values of the shape and characteristic life parameters.

Markers Placed with Epoxy Adhesive

As an example of the applicability of the Weibull distribution, consider the results of a 2-year study of the retention of raised RPMs placed with epoxy adhesive. This study was conducted by the Texas State Department of Highways and Public Transportation (SDHPT) in the late 1970s. The observations were made on three major highways: one in Dallas and two in San Antonio. The location in Dallas was on a six-lane divided highway (SH 183 from Mockingbird Lane to near International Place) where the markers 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 the single lane lines. Several types of markers are represented and were systematically placed so that similar numbers of each type faced traffic in each direction at each location. At four time intervals (3, 6, 12, and 24 months after the test began), counts of the markers remaining in place were made by SDHPT personnel. The complete results have been reported elsewhere (*3*). The condensed data shown in Table 2 give the results of the count for 4- by 4-in. RPMs.

To get a broad overview of the test results, the retained fraction of the 4- by 4-in. pavement markers was plotted as a function of the number of tires estimated to have hit each marker. This estimate was made using the 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 earlier. The Weibull distributions were then fit to the observations with the results shown in Figures 11–13, where the solid curve is the prediction given by $P_s(n)$. In this particular study, the asphalt concrete pavement of IH 10 (see

TABLE 2 FRACTION OF MARKERS REMAINING IN SAN ANTONIO AND DALLAS RETENTION STUDIES

Location	Total No. of Markers Installed	At 3 Months		At 6 Months		At 12 Months		At 24 Months	
		Fraction Remaining	Est. Hits	Fraction Remaining	Est. Hits	Fraction Remaining	Est. Hits	Fraction Remaining	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 (PCC pavement)	360	0.997	12,600	0.989	25,200	0.931	50,400	0.737	100,800

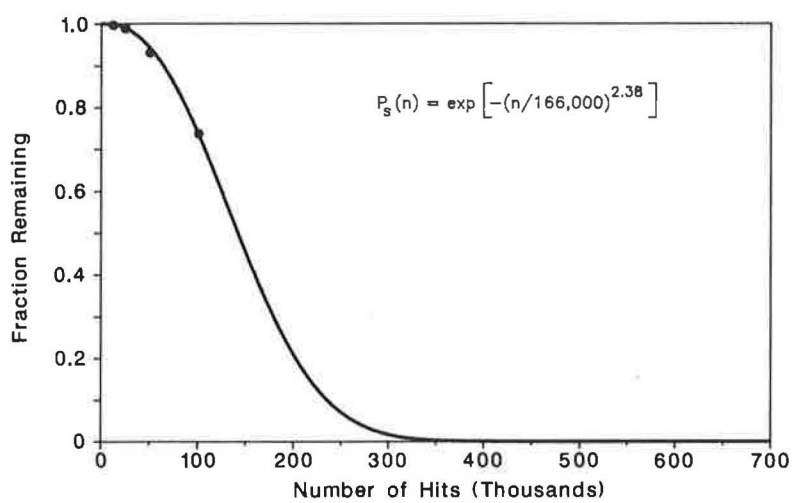

FIGURE 11 Loss rate curves for 4- by 4-in. markers using epoxy adhesive: SH 183 in Dallas (portland cement concrete).

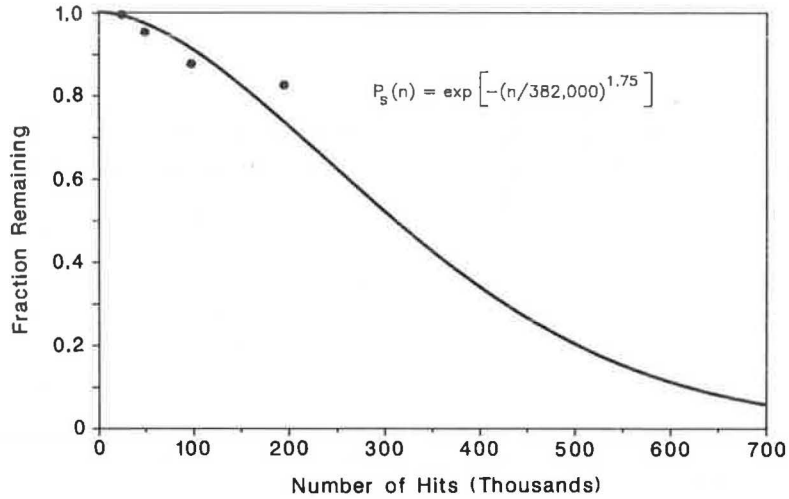

FIGURE 12 Loss rate curves for 4- by 4-in. markers using epoxy adhesive: IH 10 in San Antonio (asphalt concrete).

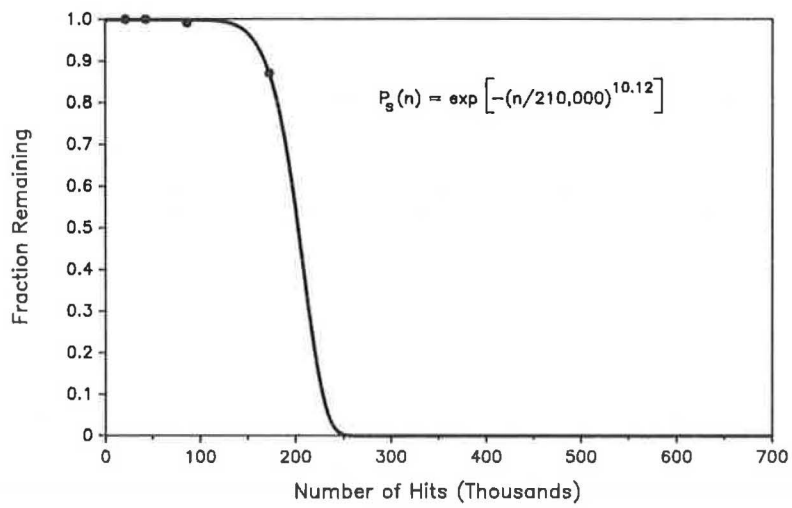

FIGURE 13 Loss rate curves for 4- by 4-in. markers using epoxy adhesive: IH 35 in San Antonio (asphalt concrete).

Figure 12) retained the markers better than the PCC pavement of SH 183 (Figure 11). However, the latter retained the markers longer than the asphalt concrete of IH 35 (see Figure 13).

Bituminous Adhesive Versus Epoxy Adhesive

An alternative adhesive (to epoxy) first suggested by the Stimsonite Company and recommended by Roger McNees of TTI is a black, solid, bituminous adhesive marketed specifically for raised markers. This single-component material must be heated to nearly 400°F (200°C) for use. This temperature is slightly above the softening point of asphalt, which may account for its success on asphalt pavements.

Several hundred of the low-profile (2- by 4-in.) reflective markers were installed using bituminous adhesive and a like number using conventional epoxy. These tests were all in District 16 of the Texas SDHPT near Corpus Christi. As shown in Figure 14, the superiority of the bituminous adhesive over epoxy was found to be pronounced.

Several engineers with experience using the bituminous adhesive on Texas roads report similar results, suggesting that the service life of markers bonded to asphalt with this adhesive is significantly increased. Specifically, two side-by-side comparisons of the bituminous and epoxy adhesives are known to have been made on Texas highways. The first was made by Joe Graff, a maintenance engineer in the Texas SDHPT, in 1985–1986 on IH 20 in Smith County. The traffic count at this site was very high and included an especially high percentage of trucks (estimated to be nearly 50 percent). After about 1 year in place, Graff reported that approximately 8 percent of all markers placed with bitumen and 47 percent of all markers placed with epoxy had been lost.

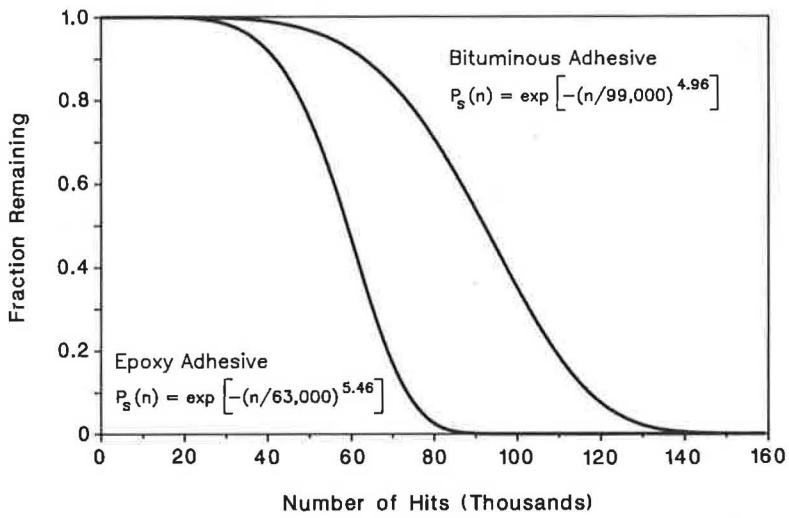

FIGURE 14 Loss rate curves comparing the retention properties of bituminous and epoxy adhesives.

TABLE 3 FIELD TEST RESULTS FOR BITUMEN AND EPOXY ADHESIVES COMPARED ON THE SAME HIGHWAY AFTER 30 MONTHS

Highway	Location	Initial Number	Percent Retained by Bitumen	Percent Retained by Epoxy
FM 369	Wichita Falls	283	60	78
US 279	Wichita Falls	118	94	60
US 90	San Antonio	242	98	47
US 281	San Antonio	183	96	54

In the second comparison, Robert K. Price, a materials and test engineer in the Texas SDHPT, made several counts of the relative performance of bituminous and epoxy adhesives on test sections with low-profile markers (*7*). A representative selection of Price's findings is given in Table 3. Of a total of 10 highway test sections in five districts, the only low-profile markers retained longer by epoxy were found on FM 369 (Table 3).

Seal Coat Test Section

A test section to compare bituminous and epoxy adhesives on seal coat was placed on a high-speed (50-mph) straight section of FM 60 in College Station, Texas. This is a four-lane divided highway that had been seal coated about 3 months before the markers were installed. Lane line markers (4- by 4-in.) were placed in skip stripe gaps alternatively with epoxy and bituminous adhesive, as shown in Figure 4. Twelve markers were placed with epoxy and 12 with bituminous adhesive in both the eastbound and the westbound lane lines, giving a 900-ft test section in each direction of traffic. A count taken 14 months after installation found all 48 markers intact. However, 6 months later (20 months after installation) four of the markers attached with bituminous adhesive were missing. None of the markers attached with epoxy were lost.

Replacement Marker Test Section

Replacement markers are ordinarily placed adjacent to the surface failure left by the missing marker. The exposed failure is then subject to further deterioration by traffic and weather. Installing a replacement marker on the failure spot would appear to be advantageous in (a) using the slightly larger surface depression area for adhesive bonding and (b) sealing the surface failure left by the missing marker. However, the perceived advantages may be outweighed by other effects such as the susceptibility of the surface failure to additional failure.

A replacement marker test section of 16-lane line markers (4- by 4-in.) was placed on FM 60 in a high traffic area that had lost all of its markers. The markers were placed with epoxy, alternately in front of and on top of the failure spots in the skip stripe gaps. A shot of compressed air was used to blow debris out of the failure depression before filling it with epoxy and placing a marker on top. When the test section was driven at night, the 640-ft illuminated marker string gave no indication of any difference in marker placement. This test section was installed on July 17, 1986. Twenty-two months later, all 16 markers were still in place. Although the test section was resurfaced a month later (in 1988), terminating the test, it appears that this maintenance technique can be used to simultaneously repair a pavement flaw and replace a missing marker.

CONCLUSIONS

Perhaps the most significant finding of this research is that the adhesive material used to bond the markers to the pavement surface can influence the fatigue strength of asphaltic concrete. This is true even though there is very little penetration of the adhesive into the pavement. The fatigue studies show that a more compliant adhesive (e.g., bituminous) gives a new asphalt pavement, the more compliant pavement, a longer fatigue life than a stiffer adhesive such as epoxy. Osten-

sibly, a longer fatigue life means that the marker stays in place for a greater number of tire impacts.

The laboratory studies indicated that for stiffer asphaltic concrete surfaces the advantage of the bituminous adhesive decreased. The advantage of bituminous adhesive also decreased as the force level increased. Thus, it is concluded that for older pavement surfaces and for pavements with heavier (truck) traffic, the advantage the bitumen exhibits over epoxy is largely lost. These findings imply that it may some day be possible to tailor the properties of the adhesive to match the pavement surface properties and thereby optimize the retention lives of the markers.

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