EVALUATION OF RAISED PAVEMENT MARKERS

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ABSTRACT

With raised pavement markers of many types coming into widespread usage on the nation's highways, there has been a great need for more standarization in the types of markers which are used for specific purposes, arrangement patterns, and methods of evaluating new markers which become available.

This study was initiated for the purpose of researching all of these areas, but especially for the purpose of developing quality methods for evaluation of performance.

In order to accemplish this, four representative types of markers were chosen for use in this study and remained as "guinea pigs" throughout the program for the sake of uniformity.

Several installations were made on heavily traveled roads in the Baton Rouge area using these four types. Traffic wear and breakdown properties of these markers were carefully observed as well as the effectiveness of various layout patterns on the roadway. Attempts were made in the laboratory to duplicate the types of wear and abuse encountered on these roadway installations.

It was determined that supplementing painted lines by the use of raised pavement markers placed at 40-foot centers is very effective and practical.

An efficient reflectivity measurement system was developed as a result of this study and is now a routine test within the Louisiana Department of Highways.

It was learned that the six different types of epoxies studied for bonding markers to the roadway will all give satisfactory performance when used with any of the four marker types tested. Only two of the marker types tested, the Stimsonite and Ray-O-Lite, will stand up well under traffic and provide adequate reflectivity retention.

A complete rewriting of raised pavement marker specifications within the Louisiana Department of Highways has resulted from work in this study. These new specifications separate markers into four "classes" according to function and/or reflective ability. These new specifications have resulted in better utilization of markers for specific purposes.

A cross-section of other states' durability tests were evaluated and judged to be largely inadequate as far as correlation to roadway durability is concerned.

Although one year of trial roadway service is still required for durability testing, construction of a test facility which may eventually replace this time consuming method of durability testing has been completed, and data from this device is now being evaluated. It is believed that this device has great possibilities for becoming the basis of a standard durability and reflectance deterioration test, and further work is continuing on its development.

IMPLEMENTATION

The findings of the study were being implemented throughout the course of the study.

The first implementation resulted in the adoption by the Department of a procedure whereby painted lines were supplemented with raised pavement markers. All contracts being let by the Department for construction where asphaltic or portland cement concrete surface are used require raised pavement markers be installed by the contractor.

Additional implementation has been the adoption of a standard test procedure for measuring reflectivity of raised pavement markers. This test procedure was developed as a part of this project and has resulted in more realistic values of reflectivity for pavement markers.

Other implementation resulting from the project was the revision of the specifications for raised pavement markers to take into account the requirements of markers needed to function in a satisfactory matter. Markers are now categorized into four classes with each class having certain requirements to meet specific needs. This has resulted in better utilization of markers in performing specific functions.

CHAPTER I

INTRODUCTION

The use of raised pavement markers has become increasingly popular for delineating roadways during the past several years. The popularity is particularly pronouned in areas of heavy traffic where painting of lane lines is extremely hazardous or where high rainfall intensities tend to obscure the painted line when delineation is needed most. The use of raised pavement markers is increasing rapidly in Southern states where there is minimum snowfall and damage to markers from snowplows is practically negligible.

The Louisiana Department of Highways began using raised pavement markers on an experimental basis for replacing painted lines in 1966. The first large scale use was in 1967 when markers were placed under contract on the Mississippi River Bridge on I-10 at Baton Rouge, Louisiana. Louisiana's program was unique in that all raised pavement markes placed were reflectorized and no non-reflectorized markers were used. At the time of this first installation, there was only one marker available that had both daytime and nighttime visibility. Even today there are only two sources of markers that exhibit a satisfactory daytime, nighttime visibility. It is hoped that additional companies will become interested in this market and provide additional sources of markers, as this usually results in a reduction in cost to the consumer through competitive pricing.

Prior to the initiation of this research project a trial installation of raised pavement markers was made on a heavily traveled section of U.S. 61 near Baton Rouge, Louisiana. This test consisted of installing raised pavement markers on 80-foot centers between the painted line of a tangent section of the roadway and on 40-foot centers on curved sections. The normal paint pattern used in Louisiana consists of a 15-foot painted line and a 25-foot skip. Therefore by placing markers on 40-foot or 80-foot centers, we were able to locate the marker in the center of the skip section and eliminate the possibility of having the marker painted over during repainting operations.

The raised marker used in this installation was the Borg-Warner marker which is described in detail later in the report. After observing this installation it was decided that although the 80-foot spacing on tangent sections was adequate under ideal conditions, when one or two markers were lost due to bond failure, etc., the spacing between markers became too great for good delineation. Therefore at the inception of the research project a decision was made to use 40-foot spacing on all installations.

With the initiation of the program for replacing painted lines in urban areas, a research project was also established to study the value of supplementing painted lines in rural areas. It was believed that a raised marker placed in the skip between painted lines would be sufficient to give the motorist a guide to follow during inclement weather when the painted lines were ineffective. This report describes the research conducted in this area.

SCOPE

The scope of this project was to determine the effectiveness of and the properties needed in a raised pavement marker to supplement a painted line in a rural area where overhead lighting is not normally used.

Field test installations were made of all markers to be studied under this project. The installations were to be observed and evaluated for a one year period under traffic. It was believed that after one year a determination could be made as to the durability and effectiveness of the marker. Field observations were made of the markers at various intervals of time during the one year period, including walking the sections and noting condition of the markers and driving the sections at night to determine effectiveness of the markers. Various techniques of measuring reflectivity in the field and of filming the markers were attempted to better evaluate the nighttime visibility of the various markers.

In conjunction with the field installations a laboratory phase of the project was conducted in an attempt to develop test procedures for durability and reflectivity. Although there was a procedure being used in some states to measure reflectivity in the laboratory, it was believed that improvements were needed in the procedure to better identify the properties of the various markers. Also, Louisiana had adopted a one year field installation requirement in order to accept a marker for use on state projects. If a laboratory procedure could be developed that would give a better indication of the durability of a marker then perhaps this one year period could be eliminated or shortened.

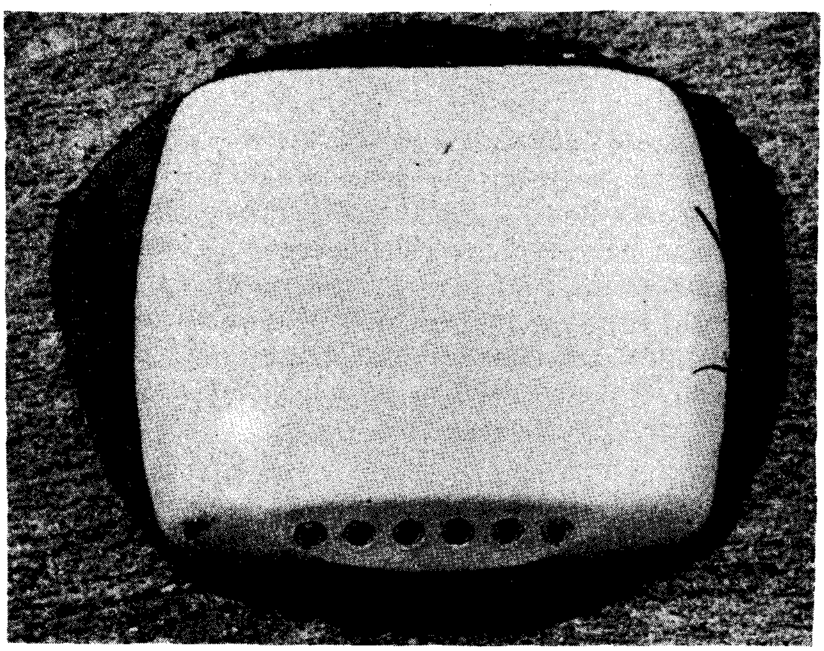
With these three objectives in mind, (1) a better laboratory method of determining durability, (2) a more realistic method of measuring reflectivity and (3) a determination of the properties needed to perform under traffic, the project was begun.

CHAPTER II

METHOD OF PROCEDURE AND DISCUSSION OF RESULTS

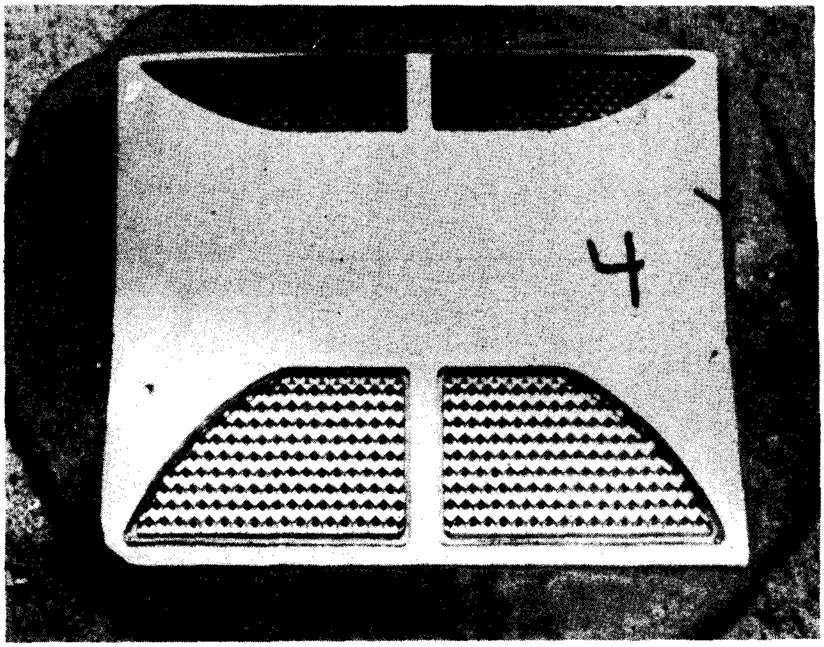
The four raised pavement markers which were evaluated throughout the study are as follows:

1) Borg-Warner Safety Guide
2) Ray-O-Lite Pavement Marker
3) Minnesota Mining and Manufacturing Day/Night Pavement Marker (new design)
4) Stimsonite Pavement Marker



Borg-Warner Marker
FIGURE 1

The Borg-Warner is shown in Figure 1 and is an ABS (acrylonitrile butadiene styrene) body with six glass beads embedded in the plastic matrix for reflectors. The marker is attached to the roadway by means of epoxy which is forced into its waffle-like bottom for increased surface area.

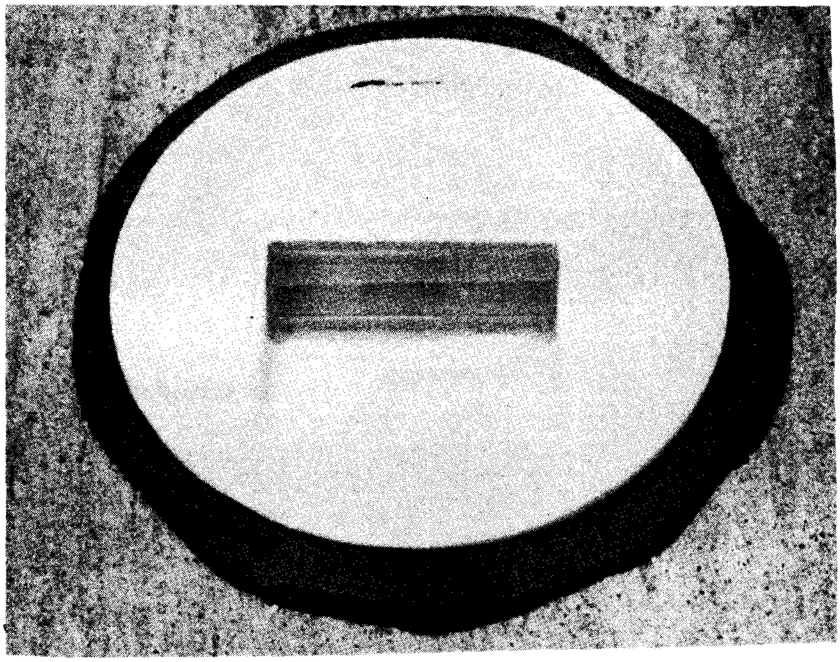


Ray-O-Lite Marker
FIGURE 2

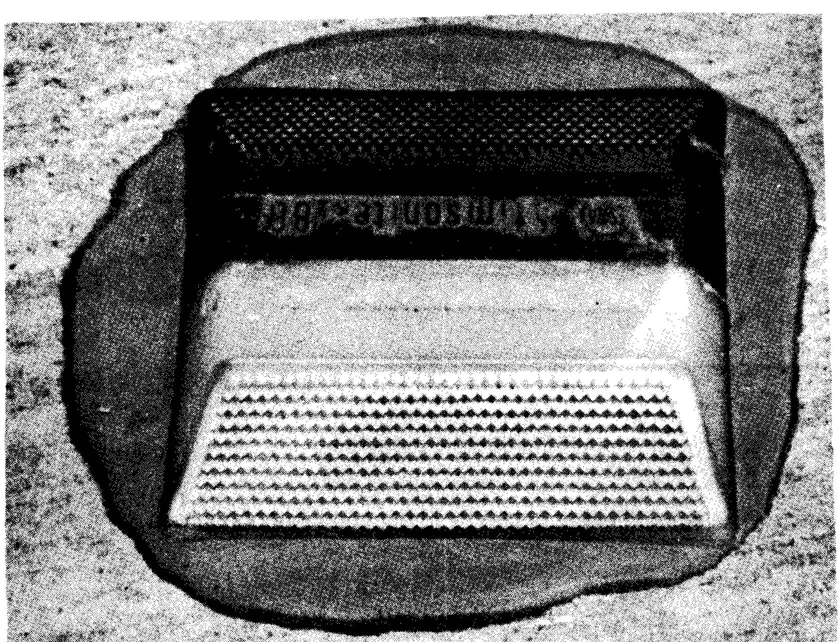
The Ray-O-Lite pavement marker shown in Figure 2 has an ABS plastic shell with a thermosetting resin filler. The reflector is an acrylic cube corner device. Adherence to the pavement is by means of epoxy application to a gritty material which is set into the resin filler on the bottom surface of the marker during manufacture.

The 3M Company's pavement marker shown in Figure 3 is no longer marketed in the form shown, but consisted of a round ceramic base with a recess for a glass rod reflective element. Earlier models were bi-directional with double rods and were used in some of Louisiana's earlier testing. Attachment to the roadway was by means of an epoxy bond between the rough-textured bottom of the ceramic base and the pavement.

The Stimsonite 88 marker consists of a methyl methacrylate body which is bonded to an epoxy base filler. The markers have the same basic wedge shape as the Ray-O-Lite markers, but the cube corner reflector elements make-up an entire side of the marker. (see Figure 4)



3-M Marker
FIGURE 3



Stimsonite Marker
FIGURE 4

Each of these four types of markers had several characteristics in common which were of interest in this study.

1. All had a reflective element for nighttime visibility.
2. All types used a two-part epoxy for roadway attachment.
3. Reflective elements and the main body of the marker were made from two different types of materials.
4. All types of markers were intended for use in a centerline roadway configuratior

The fact that each of the four types tested had these things in common and represented an ideal cross-section of the types of products available from the industry as a whole enabled a comparison and evaluation of the relative merits and weaknesses of the four types. Investigators were able to objectively go about the process of developing laboratory procedures which would best bring out these characteristics without the necessity of marking roadway installations.

Reflectivity Measurements

Laboratory Studies

Throughout the course of this study the largest single effort was put forth for the development of an adequate, efficient method of reflectivity testing for reflective markers. Many approaches were tried before development of an accurate, repeatable system was accomplished.

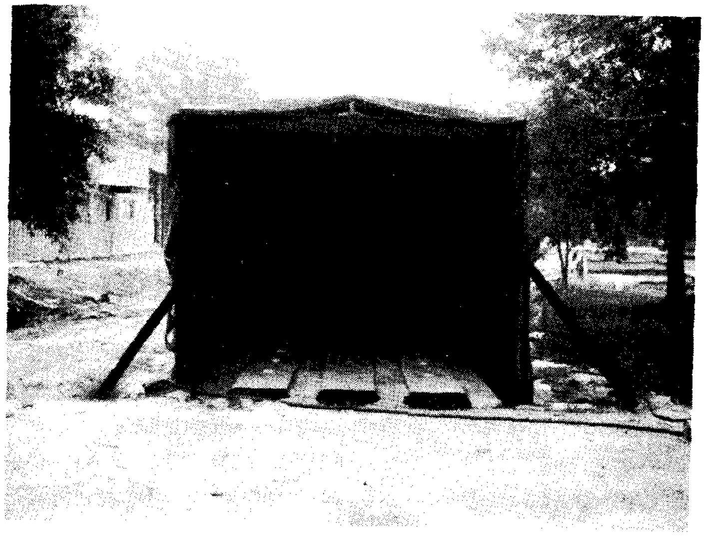
The "Rainmaker"

The first-laboratory type endeavor for reflectivity determination involved construction of a "rain simulator" (see Figure 5, 6 and 7) for comparisons of reflective markers in simulated "rainy night" conditions.

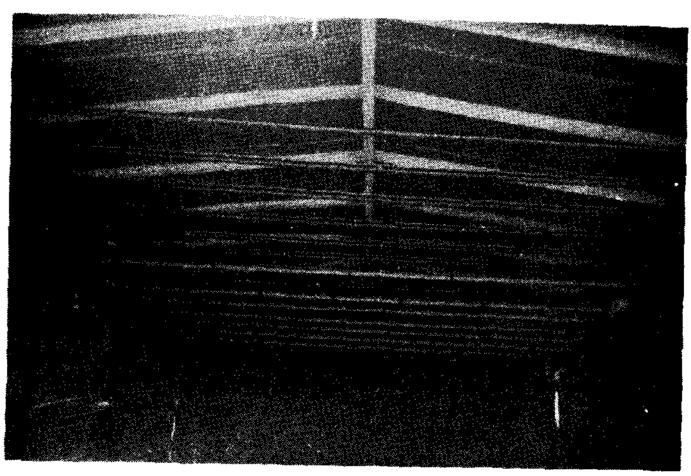
Plans called for three concrete slabs which were two feet wide and eighteen feet in length. Slabs were poured one foot apart and were parallel to one another. Water spray bars were installed six and one half feet above the slabs on two foot centers. The spray holes were positioned on top of the bars one foot apart so that the water would more nearly simulate rain.

Four lawn spray hoses were later used in place of the spray bars, resulting in a better distribution of water and a higher percentage of mist.

This test area was enclosed to prevent outside light and wind from interfering with testing. Only the front end of the area was left open so that light from the light source shown in Figure 8 could enter and observations could be made.

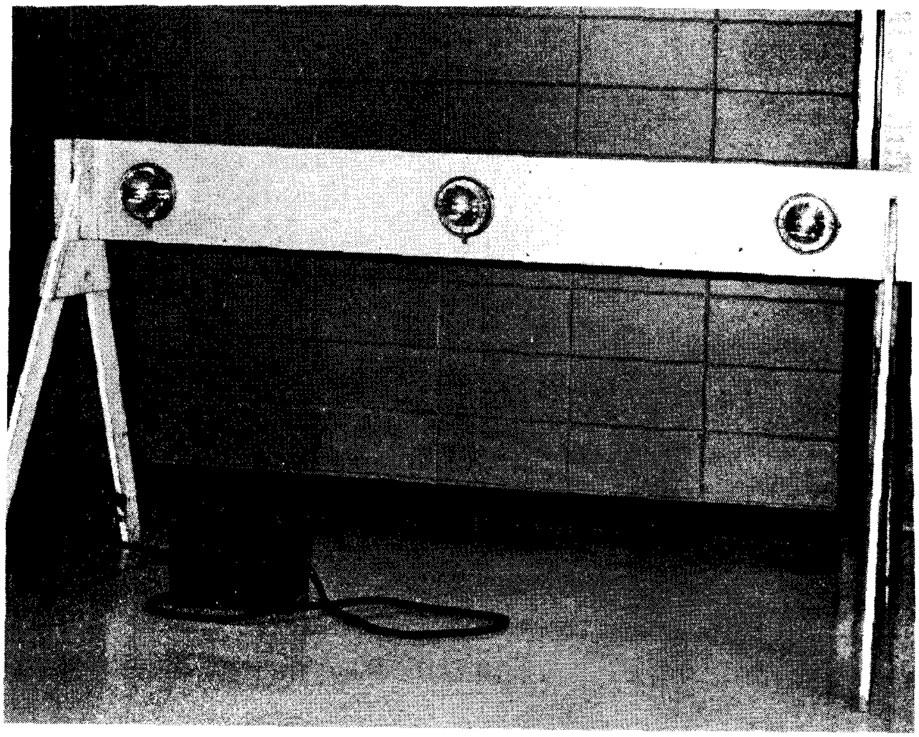


Rain Simulator
FIGURE 5



Rain Simulator - Roof Sprinkler Array
FIGURE 6

Concrete Slab in Rain Simulator Showing Placement of Specimens
FIGURE 7



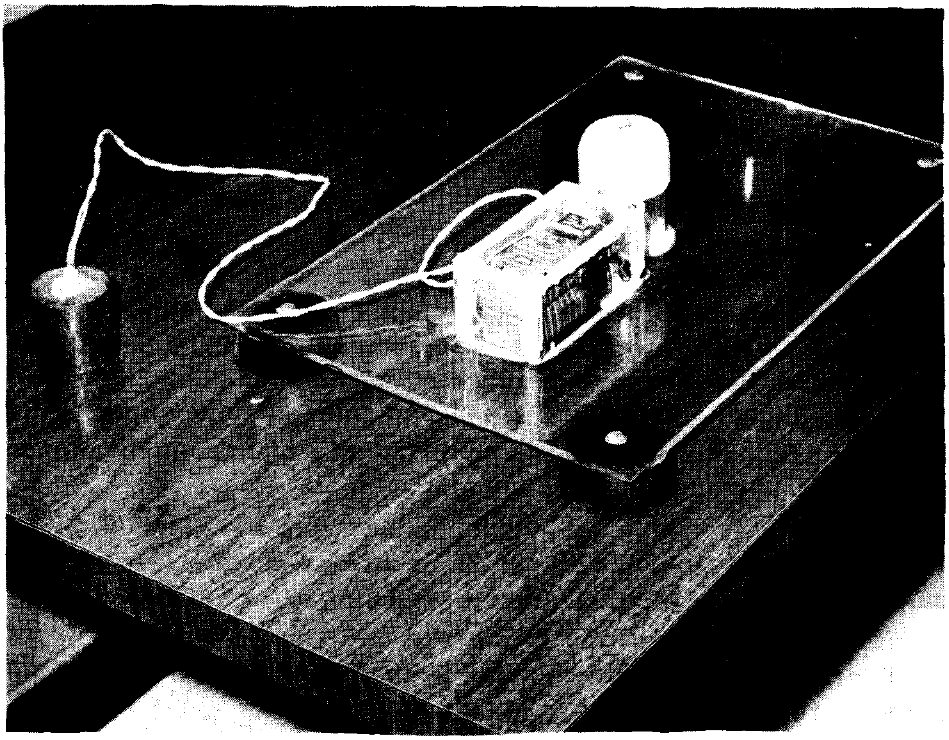
Illumination Source for Rain Simulator
FIGURE 8

The device shown in Figure 9 and 10 was used to gauge the thickness of the rain film accumulation on the surface of the slabs on which the test specimens were placed. Pans were also placed inside the simulator for measurement of rainfall rate, assuming water pressure to be more or less constant over a period of time.

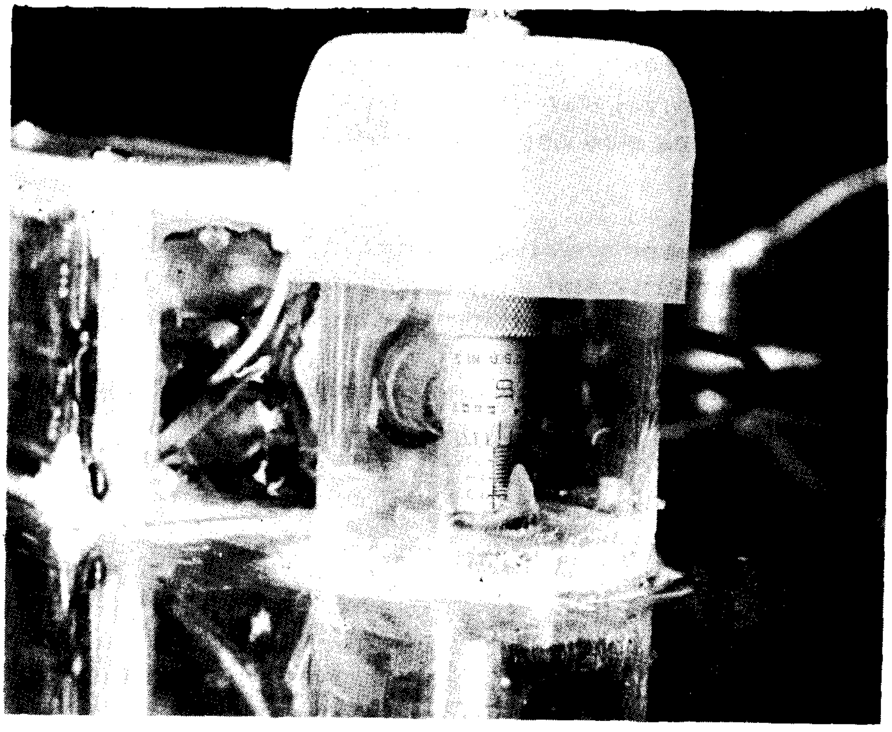
During testing markers were placed on each slab on three foot centers. Rain film accumulation was stabilized at 1/10 inch and a panel of six engineers from the Louisiana Department of Highways was asked to judge relative intensities of the four types of markers. Individual judging tabulation resulted in the following rankings in the order of reflectivity, brightest markers first.

1. Stimsonite
2. Ray-O-Lite
3. Borg-Warner
4. 3-M

Several judgings were carried out, with the positions of the markers changed each time to eliminate as much human error as possible.



Rain Film Thickness Indicator
FIGURE 9



Micrometer Adjustment on Film Thickness Indicator
FIGURE 10

Light Tunnel

Later attempts to develop a system in early 1969 involved construction of a reflectivity measurement device with a light source at one end which directed light onto the marker to be tested. The test specimens were placed at the opposite end of the enclosure which was five feet long by two feet square. Several types of light-sensing devices for measuring reflected light were tried at various positions inside the box,. in some cases with the aid of high-efficiency front-silvered mirrors, all without good results.

Problems were encountered with voltage fluctuations on the lamps, error in placement of the marker during successive readings, non-linearity of sensor elements for different light levels, and erroneous readings possibly resulting from unexpected reflections within the box and/or critical angular relationships which existed because of the short length of the box.

Work went on for several months with the "black box" until it was decided that an entirely new approach utilizing more sophisticated instrumentation was needed. Much was learned from our experimentation with this device even though the overall result was disappointing.

This and other problems which developed during the intermediate stages of the study prompted us to request a change in scope with additional time and monies in July of 1969, three months before the scheduled end of the initial Type B study. Approval was granted by the Federal Highway Administration shortly thereafter, and work was begun on a fifty foot light tunnel for larger scale reflectivity studies.

Information was requested and received from the 3M Company on some of their methods for testing reflectivity and suitable equipment with which we hoped to duplicate and possibly improve upon their testing methods was purchased.

Experimentation was begun with these more sophisticated components in August of 1969.

Basic instrumentation included a Leeds-Northrup light spot galvanometer with an accuracy of .0003 microamperes per millimeter, a shunt accessory for the galvanometer, and a Selenium barrier type photocell which was supposedly very linear with respect to all light levels. The light source which was placed at one end of the tunnel consisted of a modified military surplus 16 MM projector. Its lamp holder was modified so that a 1000 watt quartz filament lamp could be installed. This type of lamp undergoes very little brightness deterioration throughout its life span. The shutter was removed from the projector and a .056 inch carburetor jet was installed in its place. This set-up produced a clearly-defined 16 inch diameter circle of light on a screen at the opposite end of the 50 foot tunnel. Figure 11 shows the basic configuration of the projector-photocell-galvanometer system.

The light receiving device was tried at various mounting positions on the projector end of the tunnel as the experimentation progressed. The photocell was connected to the variable shunt and the light spot galvanometer which was placed on a table near the projector end of the tunnel.

Wiring provisions were made so that the photocell could be placed at either end of the tunnel for light readings, and a removable test rig consisting of a 16 inch diameter disc which rotated about a horizontal axis was used at the specimen end of the tunnel for a "target" in aiming the projector. Provisions were also made on the disc for attachment of the photocell so that the entire assembly could be rotated and the 16 inch circle of light checked for uniform intensity.

It was found that the quartz filament bulb produced a light beam of very uniform intensity. Line voltage variations of as many as four volts caused no significant changes in the intensity of the beam as checked on the "marker" end of the tunnel and it appeared that a good workable system with many of the inherent faults of the old system "designed out" had been developed.

In operation, the marker to be tested was placed on a turntable twelve inches above the floor of the tunnel. Its leading edge was placed on a mark which was exactly fifty feet from the front of the projector lens so that its reflected light was "thrown back" in the direction of the light source.

Several locations of the photocell were tried for the most efficient reception of the reflected light back at the projector end of the tunnel, but it was decided that a duplication of the 3-M Company's 2/10° angle of divergence would be the most appropriate. This meant that the center of the 1 inch diameter photocell would be located about 2 inches to the side of the projector lens.

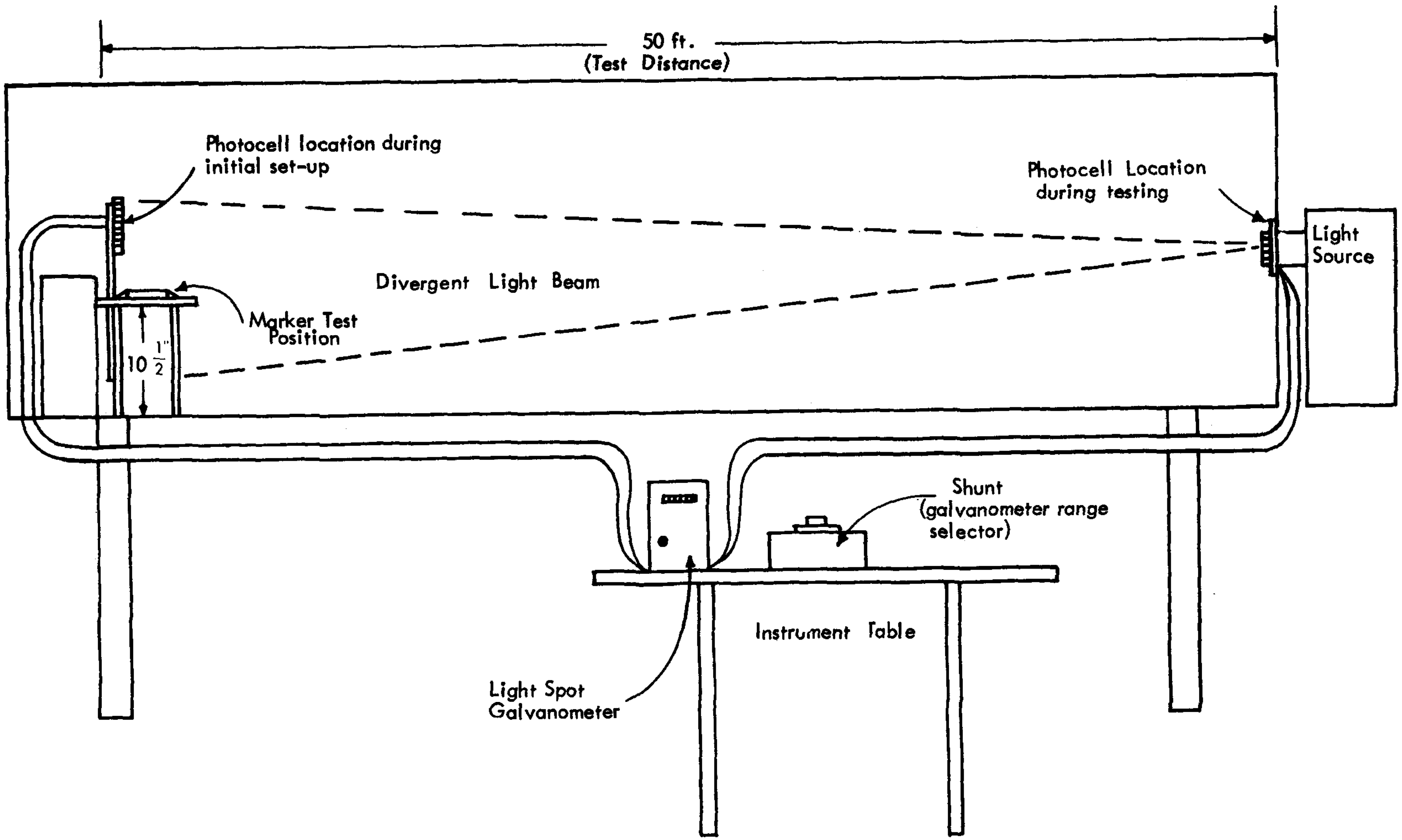
A photographic filter was used in conjunction with the photocell in order to have it respond in a comparable manner to the human eye.

The procedure for testing was as follows:

1. The projector (light source) was turned on.
2. Photocell was attached to the 16 inch disc which was then placed in the center of the tunnel at a 50-foot distance from light source.
3. Light beam was then aimed so that beam exactly covered the outline of the disc.
4. The photocell was hooked to galvanometer shunt circuit and a reading was taken on amount of incident light.

Fig. 11

Light Tunnel Used in Early Reflectivity Tests



5. Disc was then rotated in four 90° increments and a reading was taken at each of these stops.
6. Readings were averaged, and the average recorded for future reference.
7. The disc was removed from the tunnel and the photocell placed in position two inches to the right of the projector.
8. The reflective device to be tested was placed on the 12 inch high platform at a distance of fifty feet from the projector lens.
9. Starting with the least sensitive position, the shunt control was turned until the galvanometer gave as near full-scale reading as was possible without over-scaling.
10. This reading was divided by the reading obtained in step No. 6 in order to derive the "specific intensity" of the device tested i.e., the amount of light incident upon the photocell in the test zone as compared to the amount of light reflected back upon the same photocell in the observer's position.

This system at first appeared to work quite flawlessly. Readings were very repeatable, and correlation checks with the 3-M Company using common specimens showed that similar results were being obtained. It seemed that development of a good, workable system for reflectivity measurement had been accomplished.

The shortcomings of this system began to show up, however, with checks which were made on markers which had been subjected to traffic. Readings showing drop-offs of as much as 90 percent in reflectivity hardly seemed correct for some of the markers which appeared to remain very bright to the eye and had been exposed to traffic for only a few weeks. In short, although the set-up produced very repeatable results, it was felt that the system was not foolproof. Comparative readings did not always agree with what was seen in visual observation of the specimens.

Information on different types of reflectivity measuring equipment available from various manufacturers was acquired, and a search began for suitable instrumentation with which marker reflectivity could be measured. Cintra, Inc. of Mountain View, California seemed to offer the most hope in a telephotometric measurement system for the measurement of brightness in units of Foot-Lamberts. The instrumentation included a readout and control unit and a remote probe with a very small light sensitive pickup area. In operation, the probe was attached to a photographic tripod and the sensitive area was sighted in on the luminous object to be tested.

Arrangements were made with the company to try one of the devices on a thirty day loan basis, during which time its usefulness would be considered.

The device at first appraisal seemed to be well constructed. Having an autorange feature made operation simplicity in itself, and comparative readings on various luminous objects seemed to correlate quite well with visual observation.

It was decided to attempt development of a working brightness measurement procedure which was centered around utilization of this equipment.

Work on this latest endeavor began in July, 1970. We were attempting to develop a system which would accurately measure reflectivity (brightness) of raised pavement markers in much the same way that the eye of a driver would observe and compare them in a night driving situation.

A pair of automobile headlamps removed from the left side of a 1967 Chevrolet was used as the source of illumination. These lights were powered by a regulated power supply and mounted inside the light tunnel. The headlights were aimed according to Louisiana's law for left side (driver's side) headlamps on a standard passenger-size automobile and were placed twelve inches above the floor of the tunnel. The spot probe was located .70 feet above the headlights and positioned inside a hole in the board which supported the headlights. The basic layout of this set-up which is now in official use by the Department is shown in Figure 12.

A copy of the Department's test procedure is also included in Appendix D of this report and may be of interest to the reader.

Typical readings taken from the galvanometer-photocell system and from the spot probe-headlight system are also shown in Tables 1 and 2 of Appendix A.

To help verify the repeatability and accuracy of the new system, as well as determine the amount of reflectivity decrease upon exposure to traffic, a test section consisting of ten each of the four experimental markers was installed on La. 1. Before installation each marker was tested for brightness of reflectivity and marked with a punch so that it could be positively identified later. These markers were then removed in pairs at three month intervals and rechecked for brightness. Results of this testing can be seen in Graphs 1a and 1b of Appendix A in which the original readings are plotted against the 3, 6 and 9 months readings.

The galvanometer-photocell system is still operational within the Department and is being used for checking reflective panels and signs materials. The system has proven to be quite accurate and repeatable for checking reflectivity of these types of materials with large cross-sectional areas approaching that of the 16 inch light circle, but its use in the checking of the relatively small lensed raised pavement markers has been discontinued.

Field Studies

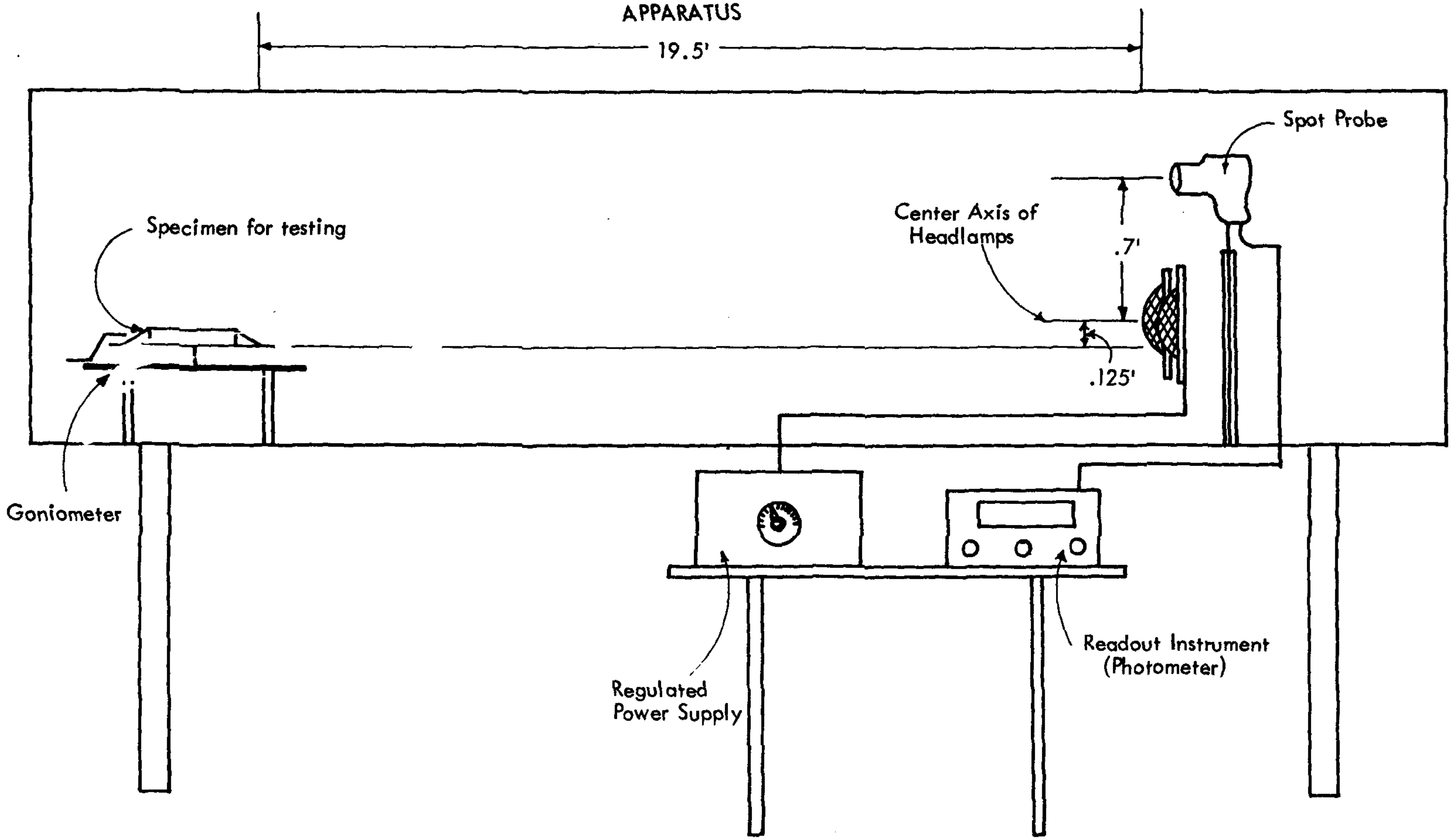
From the beginning of this study it was apparent that there were differences in the amount of reflectivity produced by the various brands and types of reflective markers. Some seemed much better suited to nighttime visibility than others, and all began to lose reflectivity at different rates upon exposure to traffic. The following methods were tried in an effort to document what was obvious to the eye.

Fig. 12

RAISED PAVEMENT MARKER

REFLECTIVITY TESTING

APPARATUS



Filming at Driver eye Level

The first attempts to accurately compare reflectivity in the field involved photographing the different types of markers in the U. S. Highway 61 installation south of the city of Baton Rouge. This was done at night with illumination from automobile headlamps, and the amount of available light necessitated the use of special processing. After pictures were made of each of the sections, it was decided that this method did not show all that needed to be seen from a drivers' point of view, and a system of taking moving pictures was devised for use on these same sections.

Aircraft landing lights were installed at bumper level on a Chevrolet station wagon and a 16 MM movie camera was set up behind the front seat. Pictures were taken while the vehicle was driven at a speed of 40 miles per hour and the movie camera was run at a speed of 16 frames/second. When shown on a projector at 24 frames/second, this camera speed simulated a 60 mile per hour nighttime drive through the test section. The normal filming speed of 24 frames per second would not have provided sufficient light for intelligible movies at night. Movies of the test sections were taken during both fair and rainy weather and seemed to give good indications of the relative reflectivity of the four types of markers present. A hidden advantage of this method is the ease at which a quick inventory of the numbers of markers missing can be made. Instead of slow driving or walking and counting, the film thus acquired can be run at a very slow speed and the markers counted.

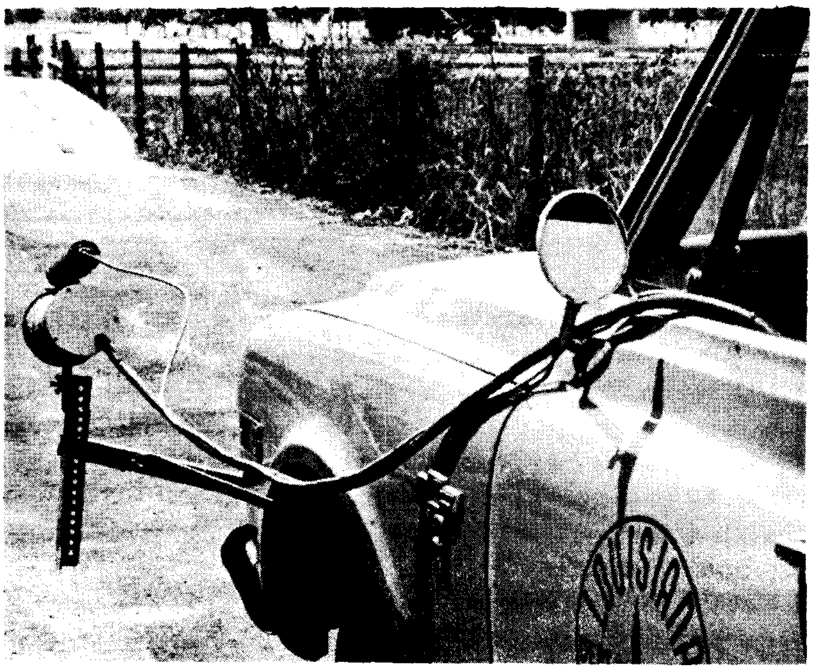
This type of survey provides no way of numerically indexing relative effectiveness of markers, but may well prove to be a good tool in the future for choosing the right marker for use in a given roadway configuration. Much was learned from this filming operation.

Vehicular Mounted Reflectivity-Measurement Device

The device shown in Figures 13a and 13b was constructed for our use in a field evaluation of relative reflectance of markers in place on the roadway. The device consisted of a sealed beam spotlight and photocell assembly, a transistor amplifier, and a recording galvanometer. Before operation, the spotlight was pre-aimed at a spot on the ground about 15 feet in front and 3 feet to the left of the vehicle. It was then locked in-place and the photocell assembly aimed to achieve maximum pickup of reflected light from a luminous object placed on the ground in the brightest part of the light-spot.

With the device set up in this manner, it was possible to record relative reflectivity readings of pavement markers as the vehicle was driven along the roadway. Its major drawback was that extreme care had to be taken in driving the vehicle so that the brightest part of the spot stayed centered over the line of markers that appeared in the roadway.

Vehicle Mounted Reflectivity Testing Device
FIGURE 13a



Vehicle Mounted Reflectivity Testing Device
FIGURE 13b

To do anything less as the light passed over any one marker decreased the amount of light which was available at the marker face for reflection back into the photocell thus producing a low reading.

The device was strictly experimental in nature and was modeled after one which was built by the Colorado State Department of Highways for reflectivity readings on striping material. Further refinement of this prototype was not attempted since additional man hours and materials would have been required at a time when equipment for field evaluation of reflectivity was not needed. Successful development of the laboratory type reflectivity measurement device seemed to fulfill our immediate needs and more nearly coincide with the basic aims of the original research proposal. It is very probable, however, that a good repeatable system for dynamic field evaluation of reflectivity could have been developed from ideas and principles derived from this bit of experimentation.

Physical Testing-Field

Preliminary Installations

The first move toward accomplishing the objective of the raised pavement marker study involved installation of several test sections on U.S. Highway 61, a major traffic artery through the Baton Rouge area known as "Airline Highway." Figure 14 is a strip map of the various installations which were made on this highway from April 11, 1968 to October 16, 1968. All markers were placed on 40-foot centers for the purpose of supplementing the painted center stripe on a hot mix surface.

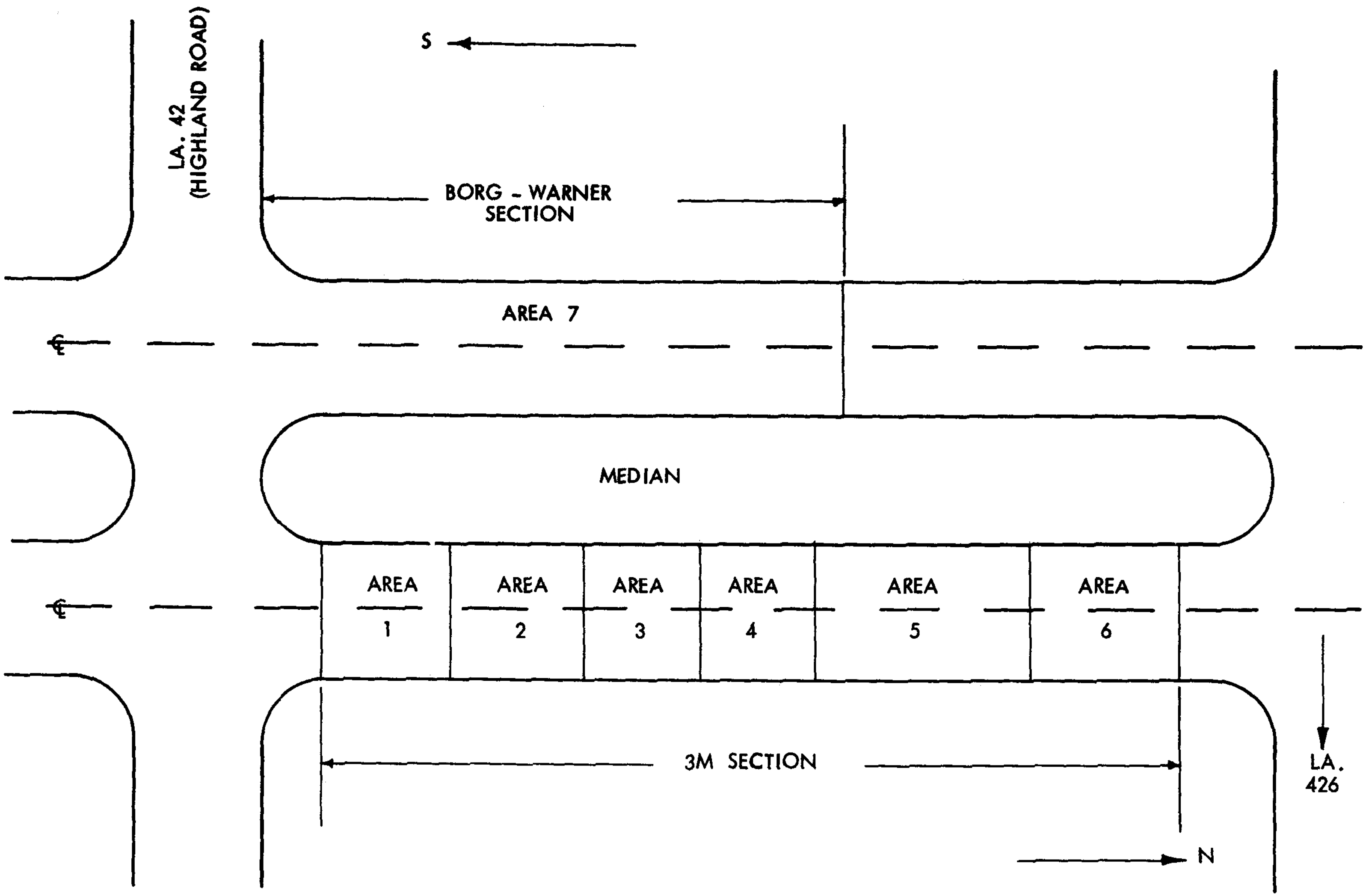
Areas 1 through 4 consisted of bi-directional 3-M glass rods only which normally made up the reflective portion of the regular markers. At the time of these installations, an attempt was being made by the manufacturer to develop a method of attachment for these rods with the use of a white two-part epoxy wherein the ceramic base would be eliminated. In areas No. 1 and 3 a thin layer of epoxy was placed on each point, followed by a piece of fiber glass mesh and another layer of epoxy into which the glass rods were placed. A total of 117 markers were installed in area No. 1 and 101 were installed in area No. 3.

In areas No. 2 and 4, a total of 197 rods were installed using only one layer of the white epoxy without the fiber glass reinforcement.

Areas No. 5 and 6 consisted of installations of the 3-M ceramic markers with glass rods bi-directional reflective elements (see Figure 3). There were 289 markers installed in area No. 5 with a two-part epoxy and 50 were installed in area No. 6 with a newly developed butyl rubber adhesive pad as a substitute for epoxy adhesive.

Fig. 14

RAISED PAVEMENT MARKER TEST SECTIONS ON U.S. 61



Observation of the individual test areas continued for approximately nine months after installation was complete and a summary of the overall condition of each of the six installations is included in Table 3 of Appendix. B.

In summary it can be said that these 3-M markers first submitted to the Department for approval failed for several reasons.

a) Glass reflectors could not withstand physical stresses of roadway traffic.
b) Two-directional glass rods were easily knocked off the ceramic base by traffic.
c) Epoxy used for the base of the marker configuration in which only glass rods were used with epoxy became too rigid after curing and was easily destroyed by roadway traffic.

Area No. 7 of the U.S. Highway 61 installations consisted of 338 Borg-Warner markers (see Figure 1) for supplementation of the white painted centerline of one half of a four-lane highway. Markers were spaced at 80-foot intervals on straight sections of highway and at 40-foot intervals in curves. The roadway surface was again asphaltic hot mix.

Final analysis of the area after one year's service revealed the following:

1) Number of markers missing: 172 or 51 percent
2) Number remaining: 166 or 49 percent
3) Number with one or more beads missing: 34 or 10 percent

The impact of vehicular tires on the beads of these markers seemed to have generally compressed the glass beads into the body of the markers and/or pushed the beads into misalignment with the body of the markers remaining.

Loss of markers from the roadway in most cases seemed to be due to a loss of bond between hot mix and epoxy. Some epoxy "blobs" remained on the roadway however, revealing a loss of bond between the marker and epoxy.

Installations of other brands of markers were also made on the Airline Highway and other roadways in the Baton Rouge area. Although this was not a part of this study a brief report dated March, 1969 is included in Appendix D for information purposes.

Major Study Installation

Beginning about six months after completion of all the installations on U.S. Highway 61, additional test sections were installed on La. Highway 1 in West Baton Rouge Parish across the Mississippi River from the city of Baton Rouge. Inability to obtain sufficient quantities of two marker types planned for inclusion in the study caused a reduction in scope, so that this installation included only the four markers which are introduced at the beginning of this chapter.

This section of La. 1 was chosen because of its rural nature, high traffic density, concrete construction and lack of artifical lighting. It was felt that the concrete pavement would be a much more uniform medium for attachment of the markers that had been provided by the hot mix on La. 61 (variations in densities of the asphalt overlays, especially around the center line area could have resulted in unfair comparisons of bonding strength.)

Absence of artificial lighting was considered to be very important in that return reflections of the various installations could be observed at night with only the light from the observer's automobile headlights as the source of illumination.

Figure 15 is a map of the test area and shows the dates and number of markers involved in each installation.

Each of the sections was inspected after one year and markers which illustrated the various types of deterioration were photographed. Brightness readings were taken from each of the samples removed from the roadway even though equipment was not available for reading brightness before the 1969 installation was begun.

A section-by-section discussion of each of the marker types thus tested follows:

I. Ray-O-Lite

A. Number of markers losing bond to highway:0
B. Number of markers with small chips or small crack on reflector lenses: 67 or 35 percent (see Figure 16).
C. Number of markers with severely damaged reflectors: 3 or 1.5 percent (see Figure 17).
D. Average illumination at time of removal: (markers in good condition) 90.5 Foot Lamberts.

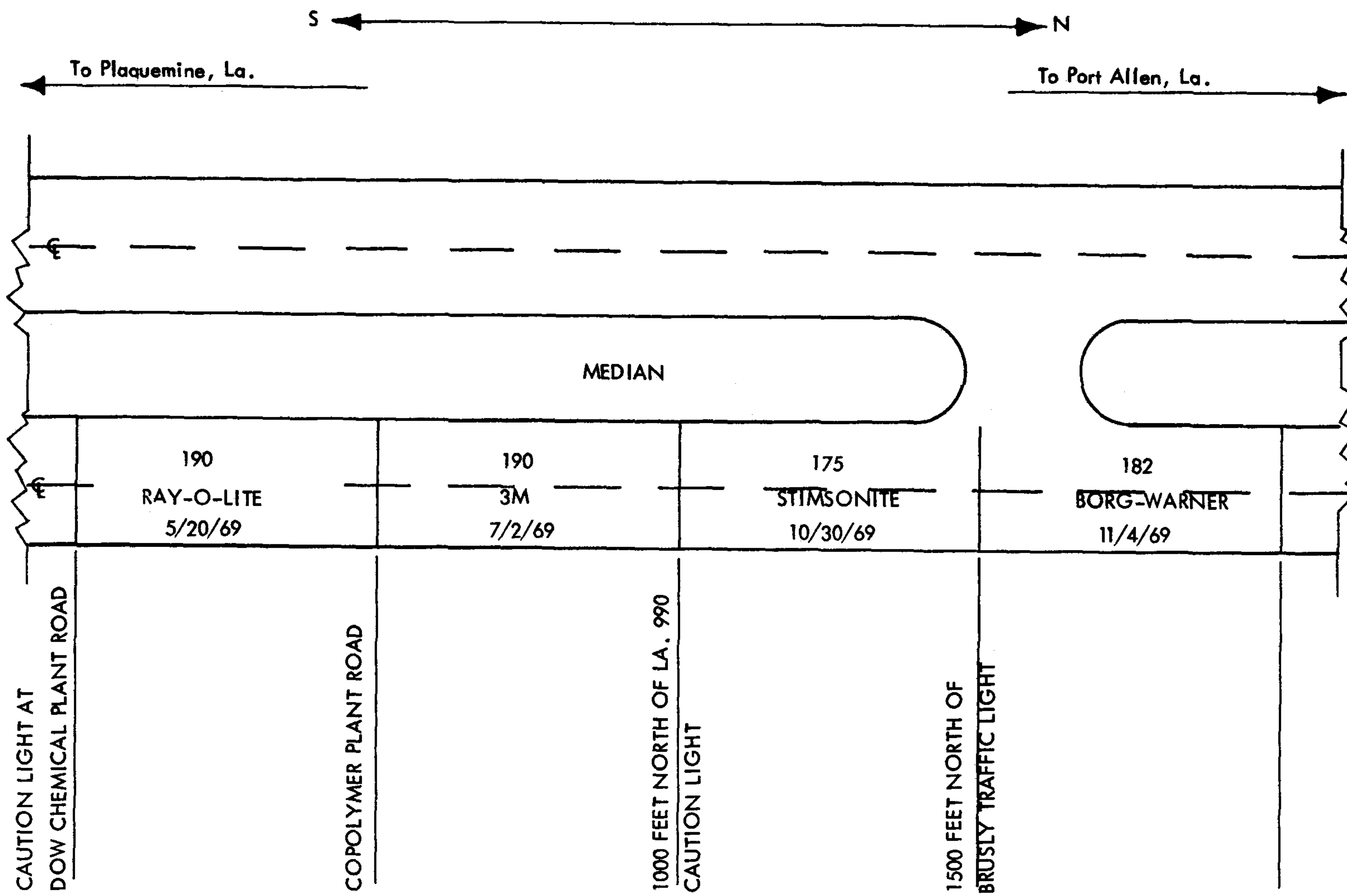
Brightness checks of new markers of this type showed an average of 196 foot lamberts. This would mean that the markers removed showed an average reading of 46.2 percent of the original brightness after one year exposure to heavy traffic.

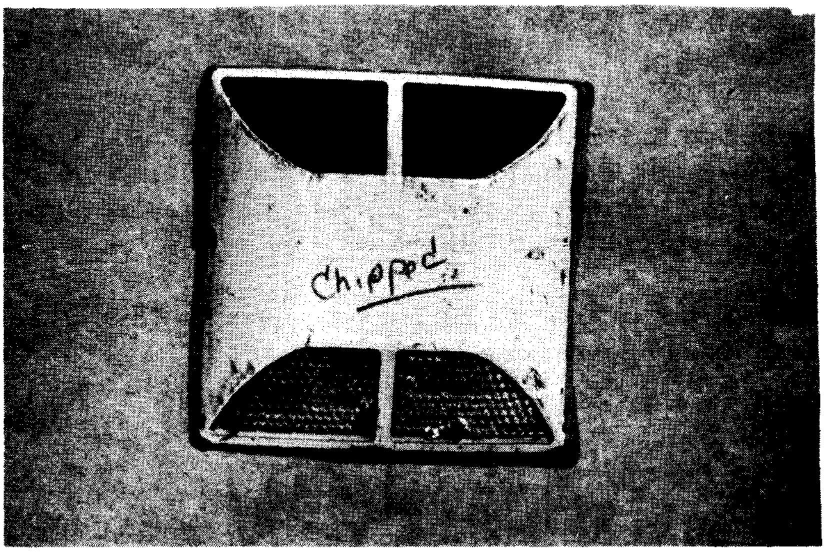
II. 3-M

A. Number of markers losing bond to highway: 0
B. Number of markers with small chip or small crack on reflector lenses: 76 or 40.0 percent (see Figure 18)
C. Number of markers with rods severely damaged or most of glass rod missing: 17 or 8.9 percent (see Figure 19)

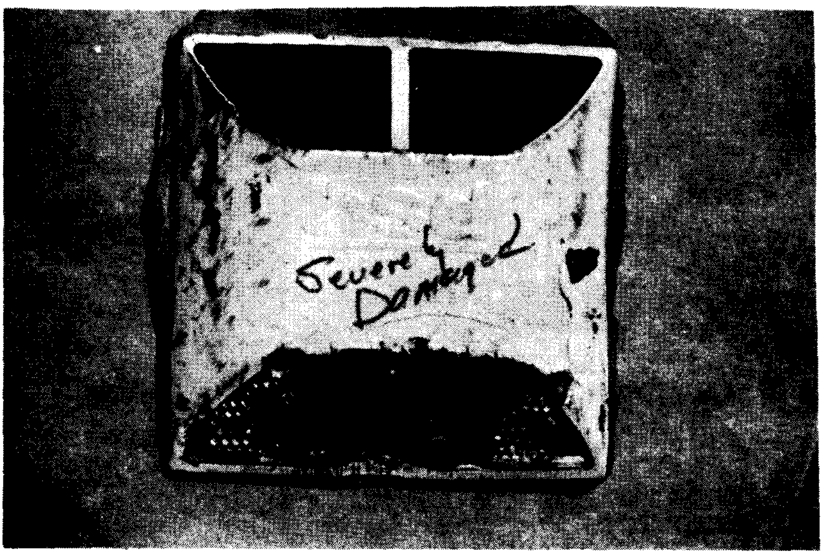
Fig. 15

RAISED PAVEMENT MARKER TEST SECTIONS ON LA. 1





Ray-O-Lite Marker with Chipped Reflector (La. 1)
FIGURE 16

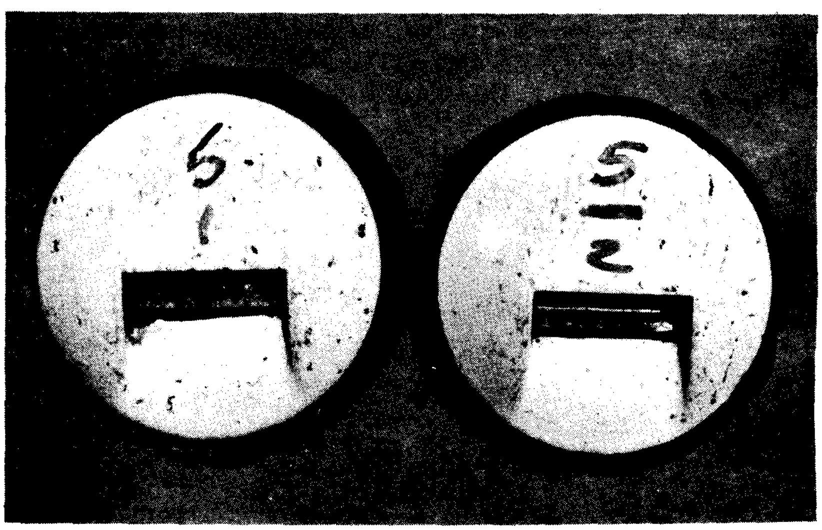


Severely Damaged Ray-O-Lite Marker (La. 1)
FIGURE 17

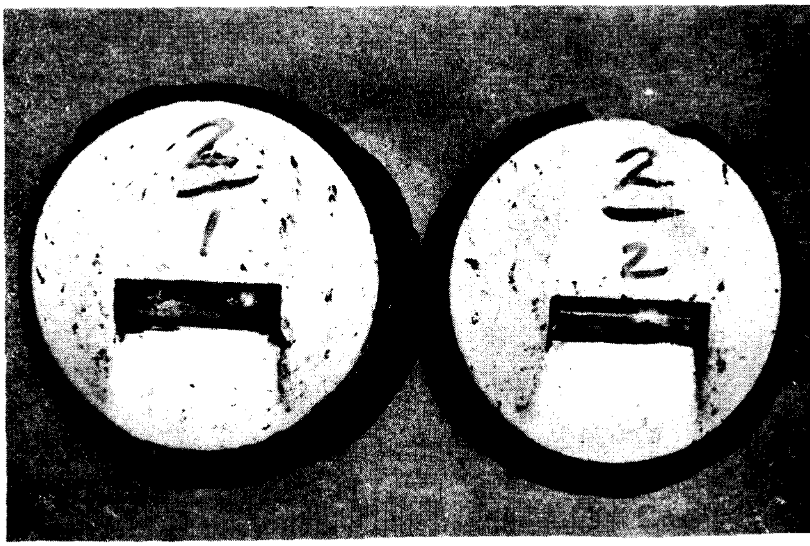
D. Number of markers with ceramic base of marker cracked: 14 or 7.4 percent (note: condition of glass rods included in this figure)

E. Remaining number of rods on ceramic marker with minor pecks or pits: 97 or 51 percent (see Figure 20)

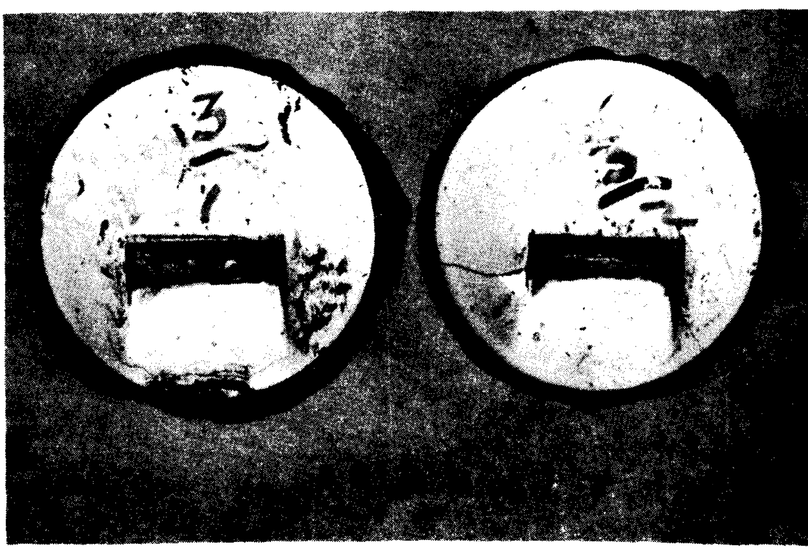
It was felt that glass reflectors of the type used on this marker are not durable enough for use on congested highways.



3-M Markers with Small Cracks or Chips on Reflector Lenses
FIGURE 18



3-M Marker with Severe Reflective Element Damage
FIGURE 19



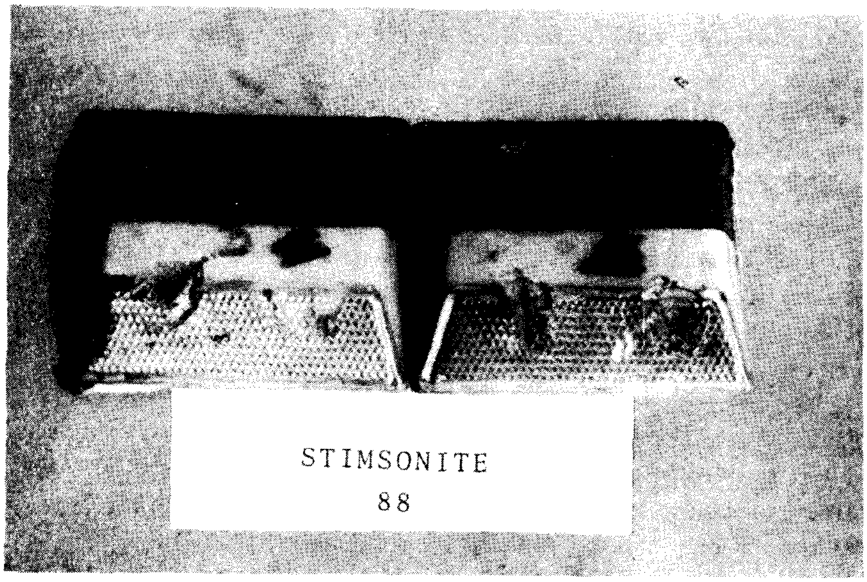
3-M Markers with Ceramic Base and Reflector Damage
FIGURE 20

Brightness readings of new markers of this type not subjected to traffic averaged 18.0 Foot Lamberts. Removed specimens with small pecks or pits showed an average of 80.1 percent of this reading. Markers with chips or cracks in the reflective element yielded an average of 50 percent of this reading, and markers with rod severely damaged or a portion missing yielded an average of 22 percent of the original reading. All markers were cleaned with a boar-bristle brush and water before readings were taken.

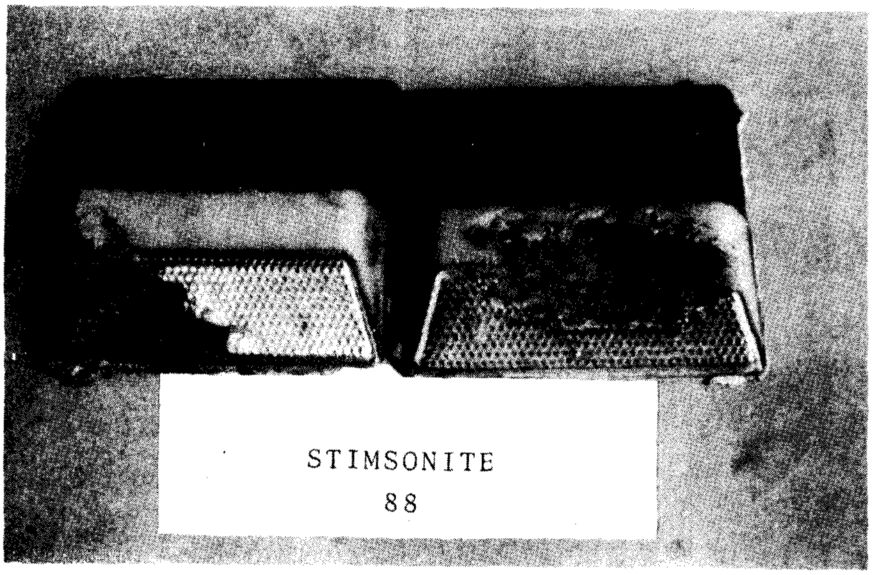
III. Stimsonite 88

A. Number of markers losing bond to highway: 0
B. Number of markers with small chip or crack on reflector: 17 or 9.7 percent (see Figure 21)
C. Number of markers with a part of reflector or marker missing: 18 or 10.3 percent (see Figure 22)
D. Number of markers with severe damage to marker and reflector: 4 or 2.3 percent (see Figure 23)
E. The balance of the markers were in good condition physically (excluding five which were picked up during the year for testing purposes).

Stimsonite Markers from La. 1 Showing Slightly Damaged Lenses
FIGURE 21



Stimsonite Markers from La. 1 with Portion of Lens Broken Away
FIGURE 22



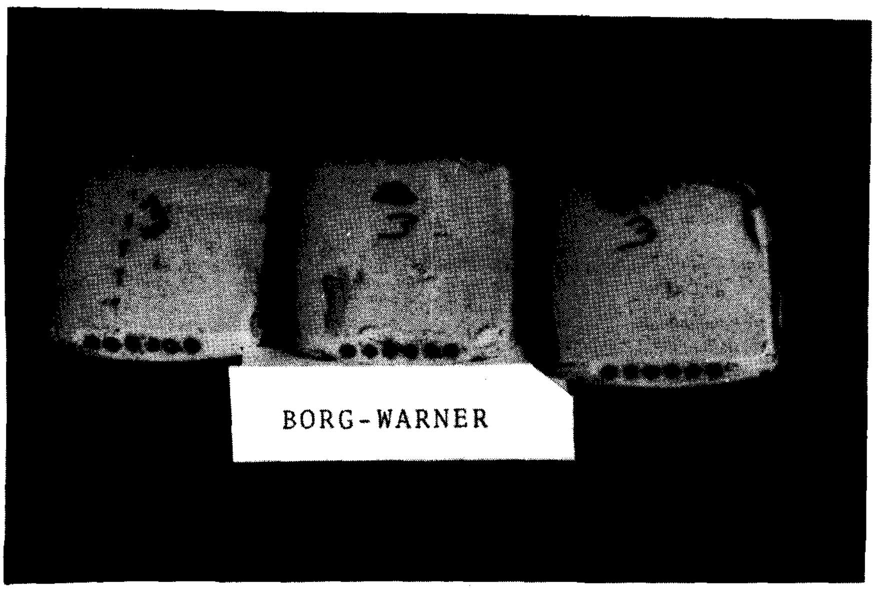
Stimsonite Markers from La. 1 with Severe Reflective Element Damage
FIGURE 23

These markers stood up fairly well to traffic and roadway film accumulation on them was negligible.

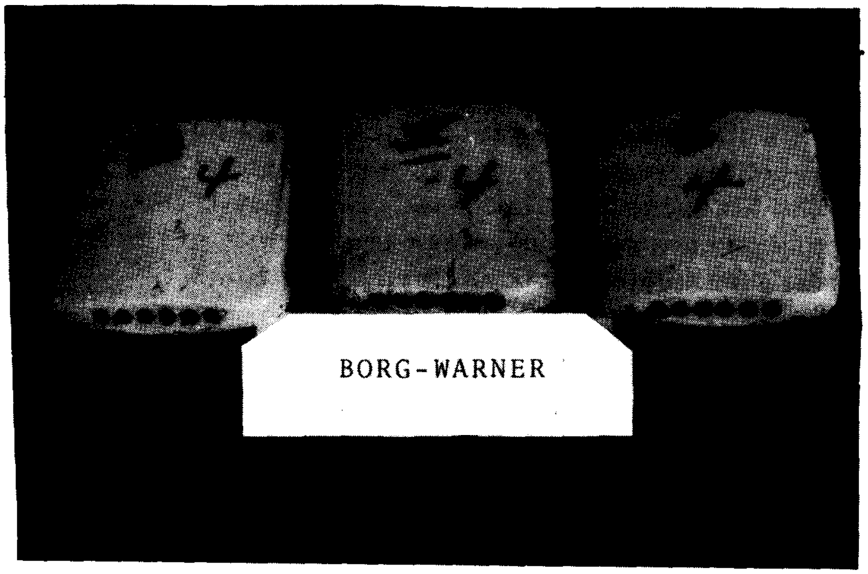
Brightness checks on new markers of this type averaged 176 foot lamberts. Markers in good condition maintained 58 percent of this average while those with severely damaged lenses averaged 32 percent of the hypothetical reading. Again, as with the case of the 3-M rods, the markers were cleaned with a brush and water prior to reflectivity readings being taken.

IV. Borg-Warner

A. Number of markers to lose bond to highway: 0
B. Number of markers with one bead missing: 22 or 12 percent
C. Number of markers with two or more beads missing: 4 or 2.2 percent (see Figure 24)
D. Due to impact of vehicles on the face of the markers the beads were compressed, distorted or cracked. The front part of the markers had a tendency to hold road film and dirt: 156 or 85.9 percent (see Figure 25)



Borg-Warner Marker Displaying Lost Reflective Beads After One Year Exposure to Traffic (La. 1)
FIGURE 24



Reflective Element Distortion and Road Grime
Accumulation in Borg-Warner Samples
FIGURE 25

The bonding of this marker to the road surface was not as good as other types tested. Samples removed for testing revealed a rather poor bonding between the marker and the epoxy as evidenced by complete separation of the marker's waffled base from the epoxy in almost all instances of removal.

The average reflectivity reading of a random sample of unused markers of this type was 35 foot lamberts.

Markers with one bead missing averaged 59 percent of this reading while markers with half or more of their beads missing averaged 41 percent after one year.

Physical Testing-Laboratory

Other States' Heating and Loading Requirements

In order to preclude the tentative evaluation requirement of one year on a major traffic artery, it was necessary to develop laboratory test methods which would accelerate the types of wear and deterioration incurred on a highway in a controlled manner.

Roadway installations put markers to the "acid test" but the number of wheel paths, gravel in tires, dragging chains, severe braking and smeared rubber across any given point in a string of markers during a given day was far from uniform and predictable. This fact was very vividly seen in many instances such as those shown in the preceding topic. Impartial comparisons on this basis were often impossible; if the markers held up; fine. But what if they did not? Was it due to bad design or to extreme physical abuse from some of the action mentioned above, and were all markers subjected to uniform condition?

Our first attempts at development of these laboratory procedures involved a review of physical testing methods in use by various other state highway departments. Among those examined were:

1) Alabama strength requirement
2) Texas load bearing test
3) Texas heat resistance criteria
4) Alabama method of heat resistance
5) Louisiana Department of Highways Supplemental Specifications

The Alabama strength requirement (Special Provision 967(2)) involved the placement of a 2000 pound load in the center of the marker through a one inch diameter plug. In doing this the marker was placed over a three inch diameter ring having a wall thickness of 1/4 inch. Three of the four candidate markers passed this test; The 3-M marker with the ceramic base failed at 1600 pounds.

The Texas load bearing test (TM Texas 849B) involved application of a 9000 pound load directly to the markers without breakage or significant deformation. All four of the marker types tested easily passed this test.

The Texas heat resistance test (TM Texas 846-B) involved placing markers in a vertical position in an air circulating oven at a temperature of 140°F for four hours. All four of the types tested survived the test with no noticeable deformation or change in appearance.

The Alabama Method of heat resistance (Special Provision 967(2)) called for placing markers in a horizontal position for four hours in an air circulating oven at a temperature of 175°F. Again, all markers tested passed with no change in appearance.

The Louisiana Department of Highways Supplemental Specifications which called for placing a one inch thick neoprene pad on top of the markers in conjunction with an 18,000 pound load were then reviewed. The 3-M ceramic was the only one of the four to break, but the use of the rubber cushion and large contact area enabled the 3-M marker to withstand 8000 pounds of pressure before failure occurred.

After review and discussion of these test results, it was felt that none of these tests singly or collectively could be depended upon to provide much more than guidelines for weeding out very poor specimens. Reliability was not necessarily brought out by this type of testing; in fact, the 3-M marker had one of the most durable types of bases for adherence to and durability on the highway, but failed to pass either of the two "loading" tests which were reviewed.

Epoxy Bonding Tests

Each manufacturer of the markers examined during this study recommended a certain brand/type of two-part epoxy for installation of his respective markers. In most cases the epoxy was marketed under the same brand name as the marker and was supposedly ideal for its installation.

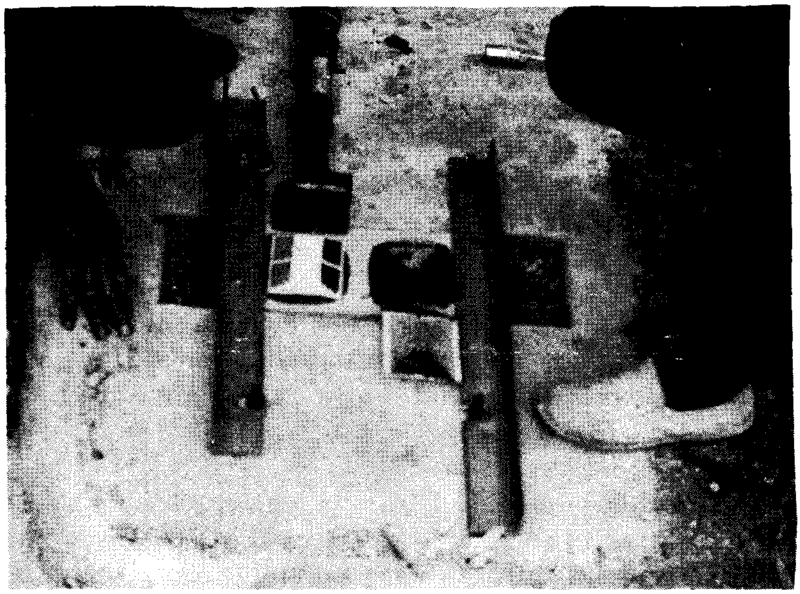
Noticeable similarities between the different epoxy types and the newly-marketed types which were designed for use with all types of pavement markers prompted us to conduct an investigation into exactly what, if any, differences existed between the various epoxies.

The primary property which was tested was the bonding strength of the markers to concrete. A hydraulic ram assembly was used in the testing. The device consisted of a hand operated hydraulic pump which was connected by a flexible hose to a slave cylinder which could apply force to the side of the markers. The pump had a calibrated pressure meter to monitor the number of pounds required to shear the marker from the block.

The jig pictured in Figure 26 was used in the testing program. A form was made for holding the standard 6 by 12 by 2 inch concrete blocks to which the markers were attached. Two pieces of angle iron were used as shown to secure the blocks for testing.

Graphs No. 2a through 2d in Appendix C are displays of the shear forces required to separate the marker from the concrete blocks in each test situation. Six epoxies were tested in conjunction with four types of markers. Six samples of each of the 24 resulting possible combinations were made from these six samples. Two were tested 24 hours after the epoxy was mixed and four were tested at 28 days. Bar graph readings reflect averages of these multiple tests.

For field testing of problem areas in marker installations in the field, a heavy stake-body truck was modified to provide a "backstop" for the shear testing device. The device in operation can be seen in Figure 27. No systematic research was ever carried out involving use of this set up as its main use was that of a troubleshooting tool.



Hydraulic Ram Assembly and Jig Used in Epoxy Bonding Tests
FIGURE 26

Rig Used for Field Testing of Epoxy Bonding
FIGURE 27

Test Track

In attempts to more nearly duplicate roadway wear in a laboratory - type environment, a rotary test track for application of simulated roadway stresses was built near the Highway Department's Central Laboratory building. Plans were quite courteously donated by Republic Steel Corporation who had themselves constructed such a track for use in development of raised pavement markers.

Figure 28 and 29 are photographs of the Louisiana Department of Highways version which is presently in operation.

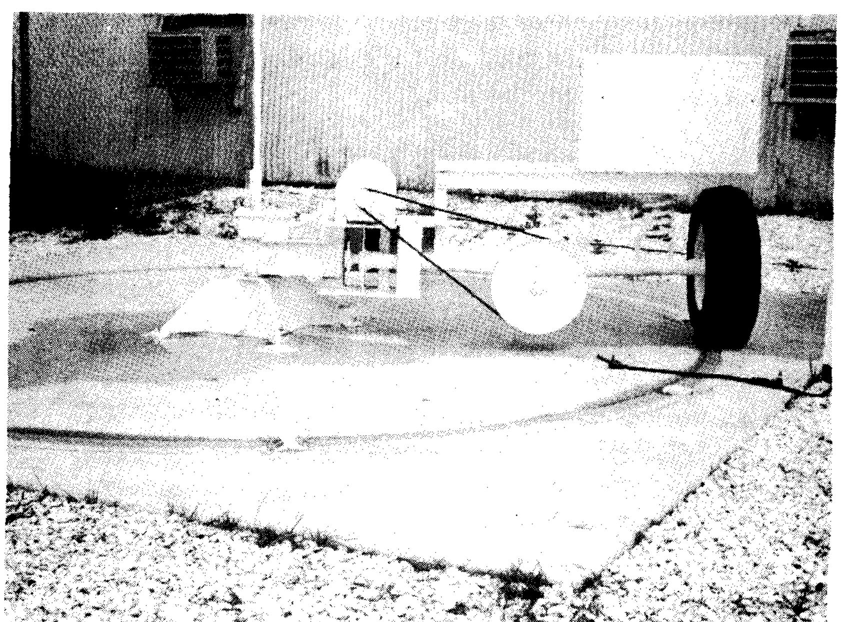
The apparatus basically consists of an automobile differential which is mounted to a pivot assembly at one end. A standard-size automobile tire is used on one axle of the differential. Weights which add a total of 1000 pounds to the tire are suspended by means of a spring and shock absorber assembly above the tire. The entire mechanism is driven by a 1 1/2 h.p. electric motor in a counter-clockwise direction at a speed of approximately ten miles per hour or twenty r.p.m. over a circular configuration. Test specimens are attached to the concrete slab, and a traffic counter for recording the number of revolutions and hence the number of impacts per marker is installed on the perimeter of the circle.

Problems with lubrication of the main pivot bearing and excess tire wear had to be solved before sustained operation was possible, but the addition of a brass bushing to the pivot assembly and a change in the toe-out angle of the tire has to this date alleviated these problems, and upwards of 200,000 revolutions have been completed with the first test specimens.

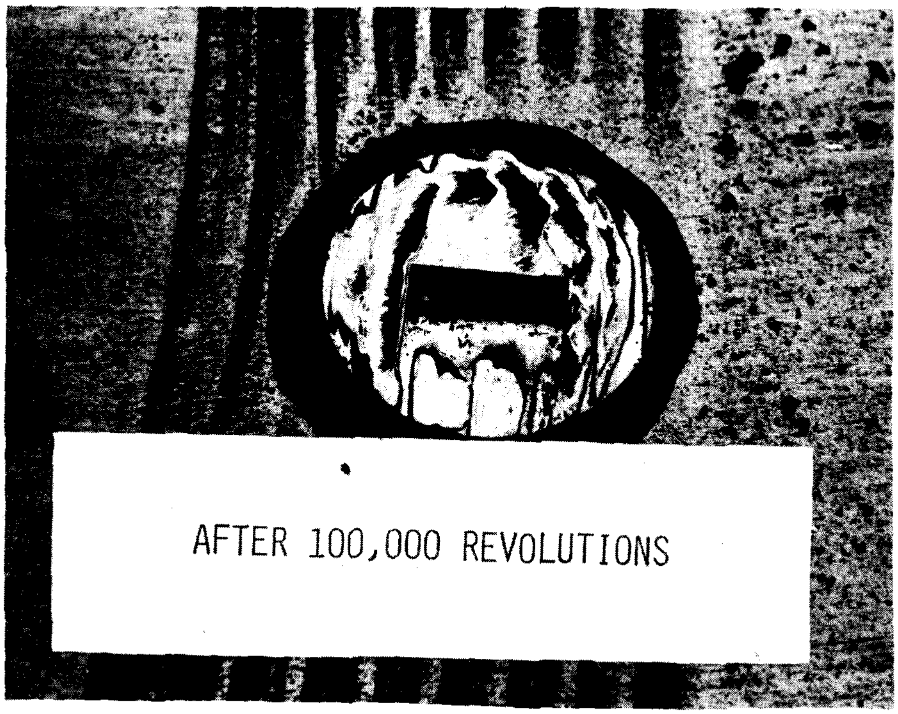
Figures 30, 31, 32 and 33 show the four types of markers studied after the indicated number of revolutions. As can be seen from these photographs, the most severe damage seems to be a result of the raking action of the tire across the markers in the direction of the inside of the circle.

Further refinements will probably be made on the facility in the near future. These will include safety features to cut power to the motor if a malfunction occurs, and a grit and water feed to add an abrasion factor to the testing. The slight toe-in error which causes the raking action of the tires across the markers is probably desirable since it is somewhat analagous to the effect of lane-changing and braking in a roadway situation.

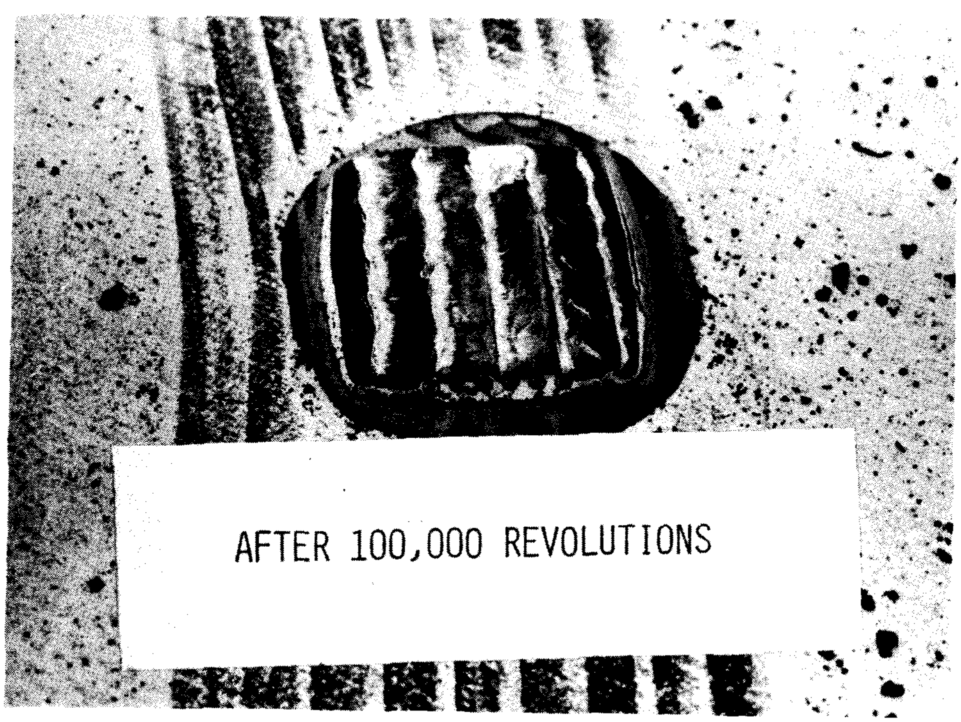
Test Track Facility Used for Durability Testing of Markers
FIGURE 28



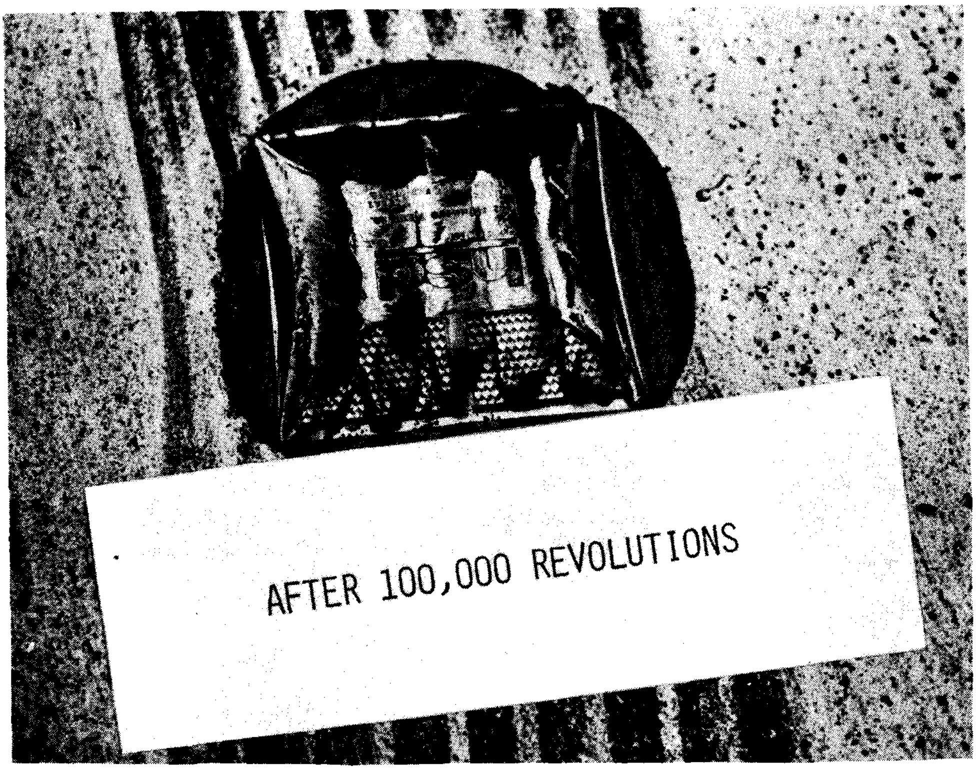
View of Test Track Pivot Assembly and Loadings Components
FIGURE 29



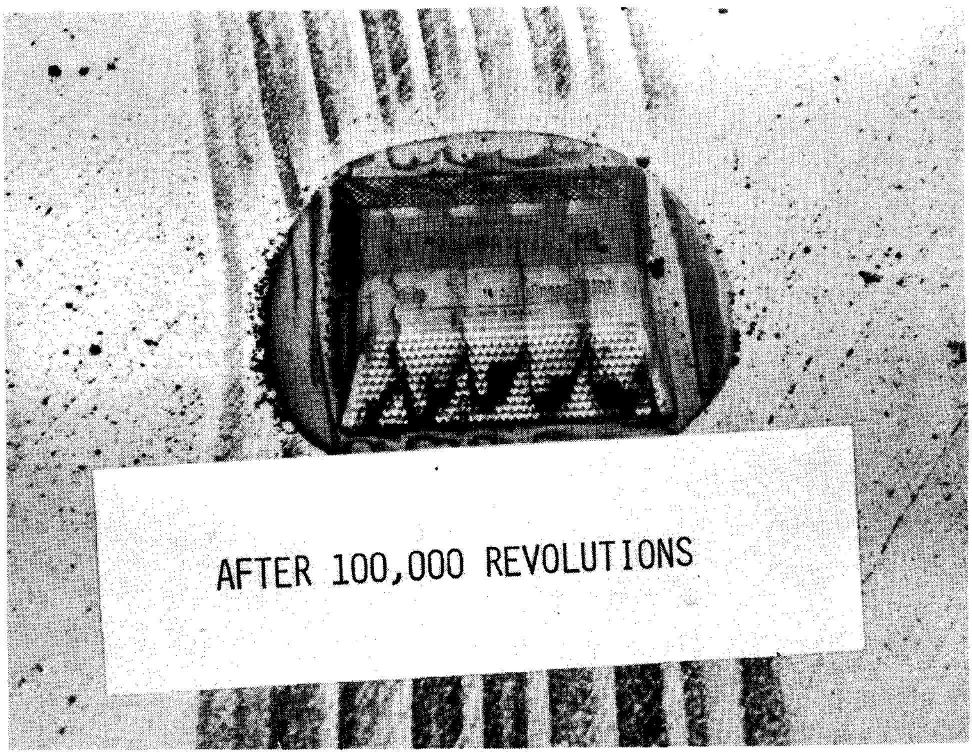
3-M Marker after 100,000 Revolutions
FIGURE 30



Borg-Warner Safety Guide Marker after 100,000 Revolutions
FIGURE 31



Ray-O-Lite Marker after 100, 000 Revolutions
FIGURE 32



Stimsonite Marker after 100, 000 Revolutions
FIGURE 33

CHAPTER III

SPECIFICATION REVISIONS

As a result of this study, specification changes were recommended concerning reflectivity of raised pavement markers. With the adoption of the newly developed test procedure for measuring reflectivity, it was believed that a more flexible system of using raised pavement markers would result if different levels of reflectivity were required for markers. The suggested changes in the specifications would establish four classes or categories of raised pavement markers. The four classes are as follows:

Class I Markers: Class I markers shall be non-reflectorized and shall be used primarily for traffic rumble strips.

Class II Markers: Class II markers shall be reflectorized and shall have both daytime and nighttime visibility. Class II markers shall be used only for replacing a painted line.

Class III Markers: Class III markers shall be highly reflectorized and shall have both daytime and nighttime visibility. Class III markers shall be used for replacing or supplementing a painted line.

Class IV Markers: Class IV markers shall conform to all requirements of Class III markers with the exception that daytime visibility shall not be required. Class IV markers shall be used for supplementing painted lines only.

The two levels of reflectorized markers were established in order to allow the Traffic Engineer a choice in deciding what level of reflectivity a particular roadway needed. There has been considerable discussion concerning driver eye fatigue associated with hours of nighttime driving on roadways using very highly reflectorized pavement markers. It was therefore decided to allow the Traffic Engineer the option of requiring a highly reflectorized marker or one with a lower level of reflectivity. These recommendations have been adopted in the specification and are now in use by the Department.

A copy of this specification can be found in Appendix D for reference purposes.

CHAPTER IV

CONCLUSIONS

The following conclusions can be made based on the findings of this study.

1. Supplementing painted lines by using raised pavement markers placed on 40-foot centers is a very practical and effective procedure.

2. Laboratory procedures used to accept or reject markers, namely load tests and heat resistance, do not give a true picture of the performance of a raised pavement marker.

3. The six different epoxies studied for bonding markers to the roadway will all give satisfactory performance.

4. The laboratory procedure developed for this study for measuring reflectivity results in more realistic values of the actual reflectivity observed in the field.

5. Only two of the four markers studied are satisfactory for the purpose of supplementing painted lines. The Ray-O-Lite and Stimsonite Markers exhibited excellent performance after one year under traffic. The 3-M and Borg-Warner (6 bead unit) either did not have sufficient reflectivity or would not stand up under traffic conditions.

6. Further development of the test track as a tool for predicting life of pavement markers should be pursued.

RECOMMENDATIONS

It has been recommended that raised pavement markers be used to supplement painted lines in rural areas. This recommendation has been adopted by the Department and is now in practice. It is further recommended that more research be conducted using the test track to develop a method of evaluating durability of raised pavement markers.

CHAPTER V

ADDITIONAL ROADWAY MARKERS UNDER EVALUATION

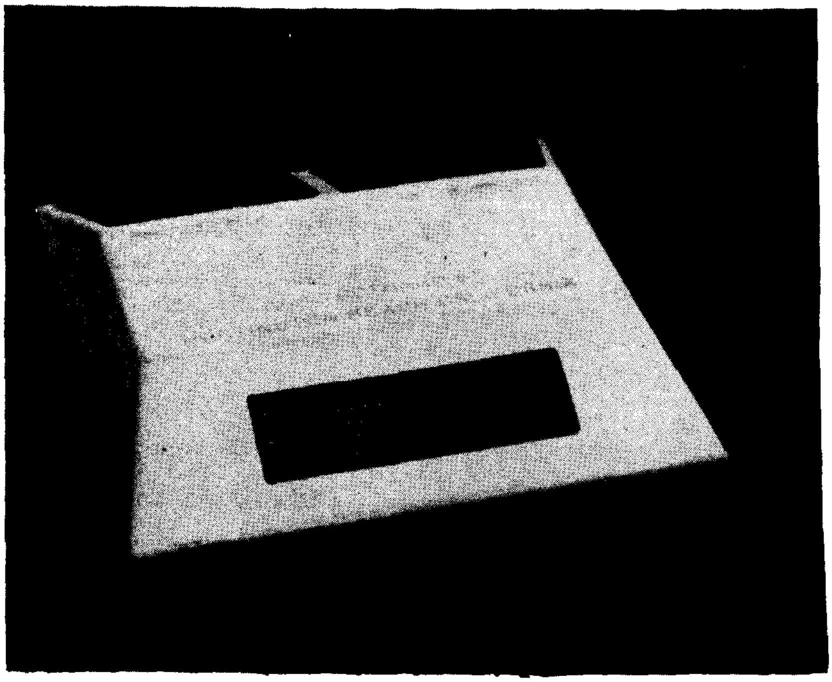
Although the following information was not gathered for this project, it is pertinent to the overall raised pavement marker program throughout the United States and is being included to make this report as complete and up-to-date as possible.

As mentioned earlier in this report at the inception of the raised pavement marker use in Louisiana, there was only one source of supply for a day/night marker. This was the Borg-Warner marker consisting of an ABS plastic body and six glass beads for reflectivity. An attempt was made to use the Ray-O-Lite marker for a day/night marker but the daytime visibility was very bad and this practice was discontinued.

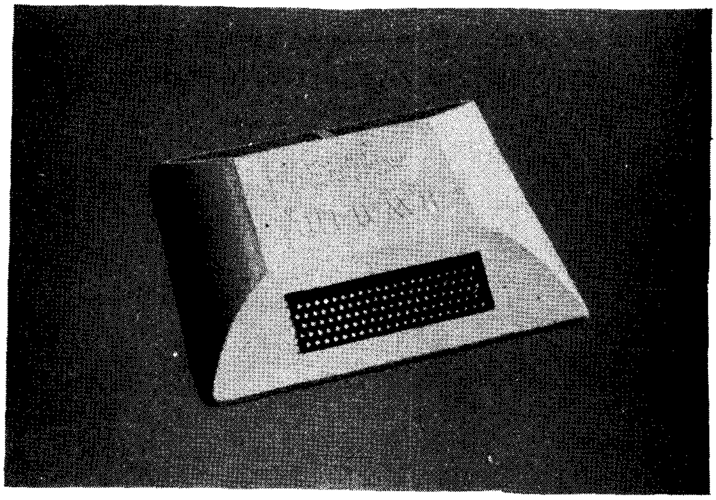
The Ray-O-Lite representative was informed of our problem and a new marker was designed for our evaluation. This new design is shown in Figure 34. As can be seen the daytime visibility was increased by using a smaller reflective surface and making the remainder of the front face white plastic. This provided good daytime visibility although the nighttime visibility was somewhat reduced. A test section of these markers was installed and after initial problems of improper filling of the shells were resolved, the field performance has been satisfactory. Figure 35 shows a modified version of the same marker. Both versions have been accepted by the Department for use as a Class II marker.

The Borg-Warner marker was also redesigned to eliminate problems associated with loss of reflectivity by abrasion and loss of the glass beads. Figure 36 shows the new design of the Safety Guide marker. The marker was increased in height approximately one-fourth inch to allow the glass beads to be moved vertically upward in the face of the marker. In addition, 10 beads were used for reflectivity and the beads were recessed to prevent abrasion from traffic. This marker has also been field evaluated and accepted by the Department for use as a Class II marker.

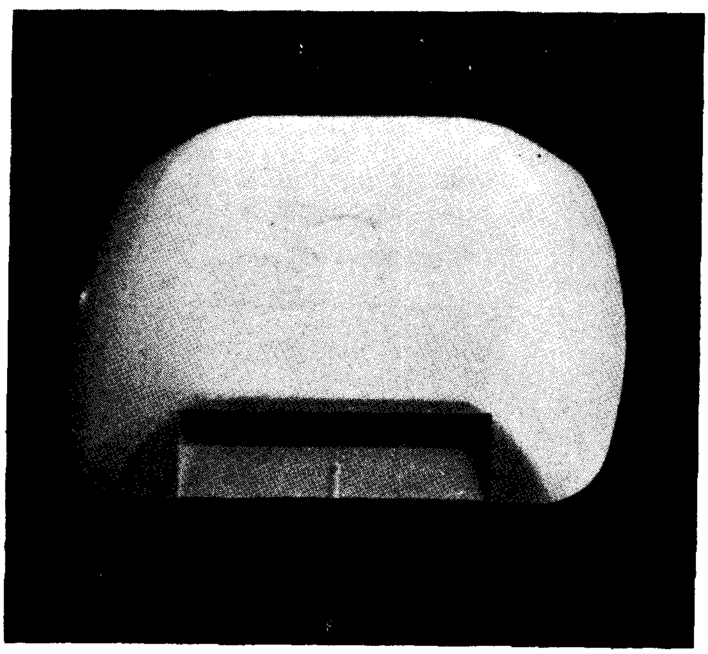
Three additonal raised pavement markers are either under field tests or will shortly be under field tests by the Department. Two of the markers, namely Borg-Warner and Ray-O-Lite shown in Figures 37 and 38 respectively, are being evaluated for acceptance as a Class III marker. To date we have no acceptable Class III marker and it is hoped that the two under consideration will perform in a satisfactory manner. The third marker shown in Figure 39 is manufactured by Permark Corporation of Tyler, Texas. This is a redesign of the 3-M marker except that an acyrlic rod is used instead of glass. No information is available at this time on the performance of these markers.



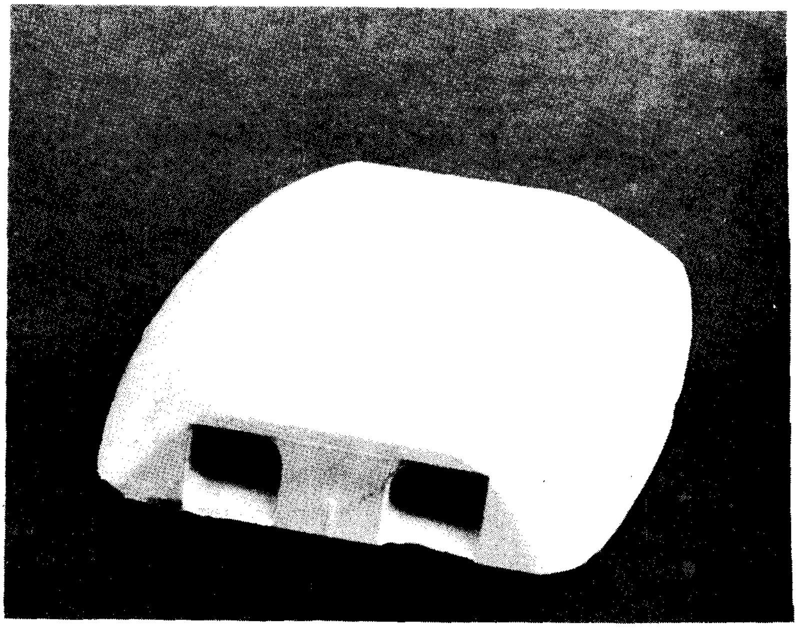
Ray-O-Lite Marker Designed for Increased Daytime Visibility
FIGURE 34



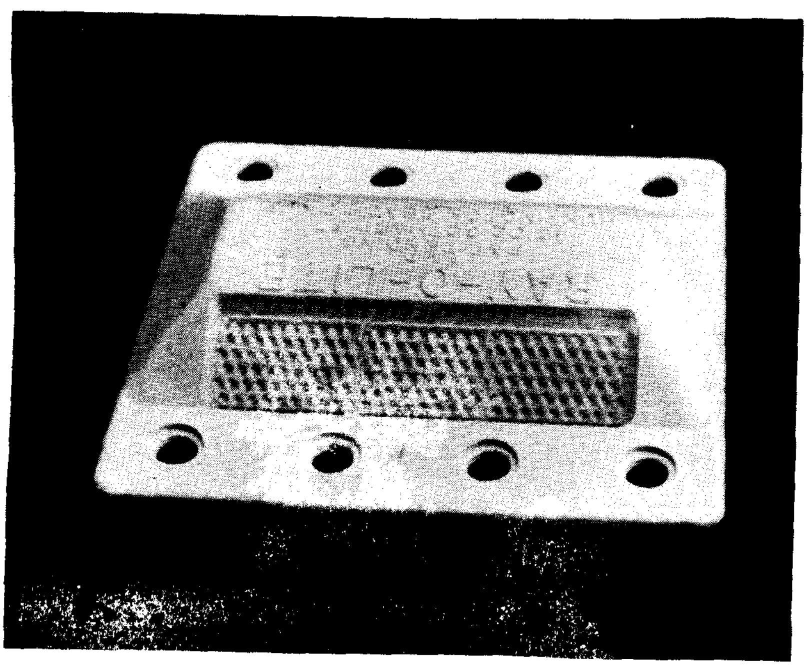
Modified Marker for Increased Daytime Visibility by Ray-O-Lite
FIGURE 35



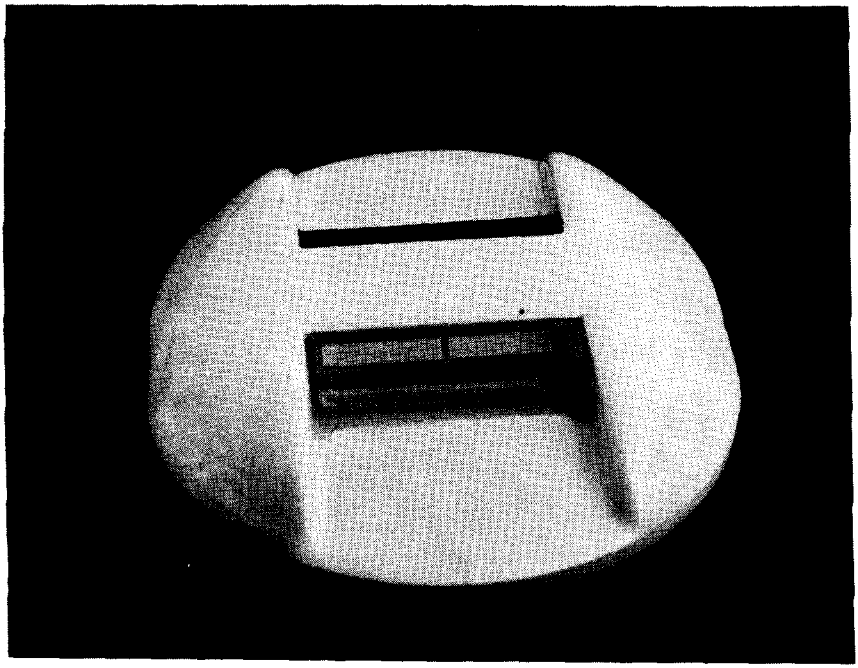
New Design 10 Bead Borg-Warner Marker
FIGURE 36



Prospective Class III (LDH Specifications) Marker by Borg-Warner
FIGURE 37



Ray-O-Lite Marker Submitted for Class III Acceptance
FIGURE 38



Permark Pavement Marker
FIGURE 39

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7. Special Provisions (967(2)) Alabama State Highway Department.

APPENDIX "A"

REFLECTIVITY READINGS OF TWO MEASUREMENTS SYSTEMS ON FOUR MARKER TYPES

REFLECTIVITY READINGS OF FOUR MARKER TYPES AT 3, 6, AND 9 MONTHS INCLUDING BOTH CLEAR AND RED LENSES

TABLE 1
TYPICAL "SPECIFIC INTENSITY" READINGS
FROM GALVANOMETER-PHOTOCELL SYSTEM

(Readings are at 0° incidence angle from markers which were sampled randomly)

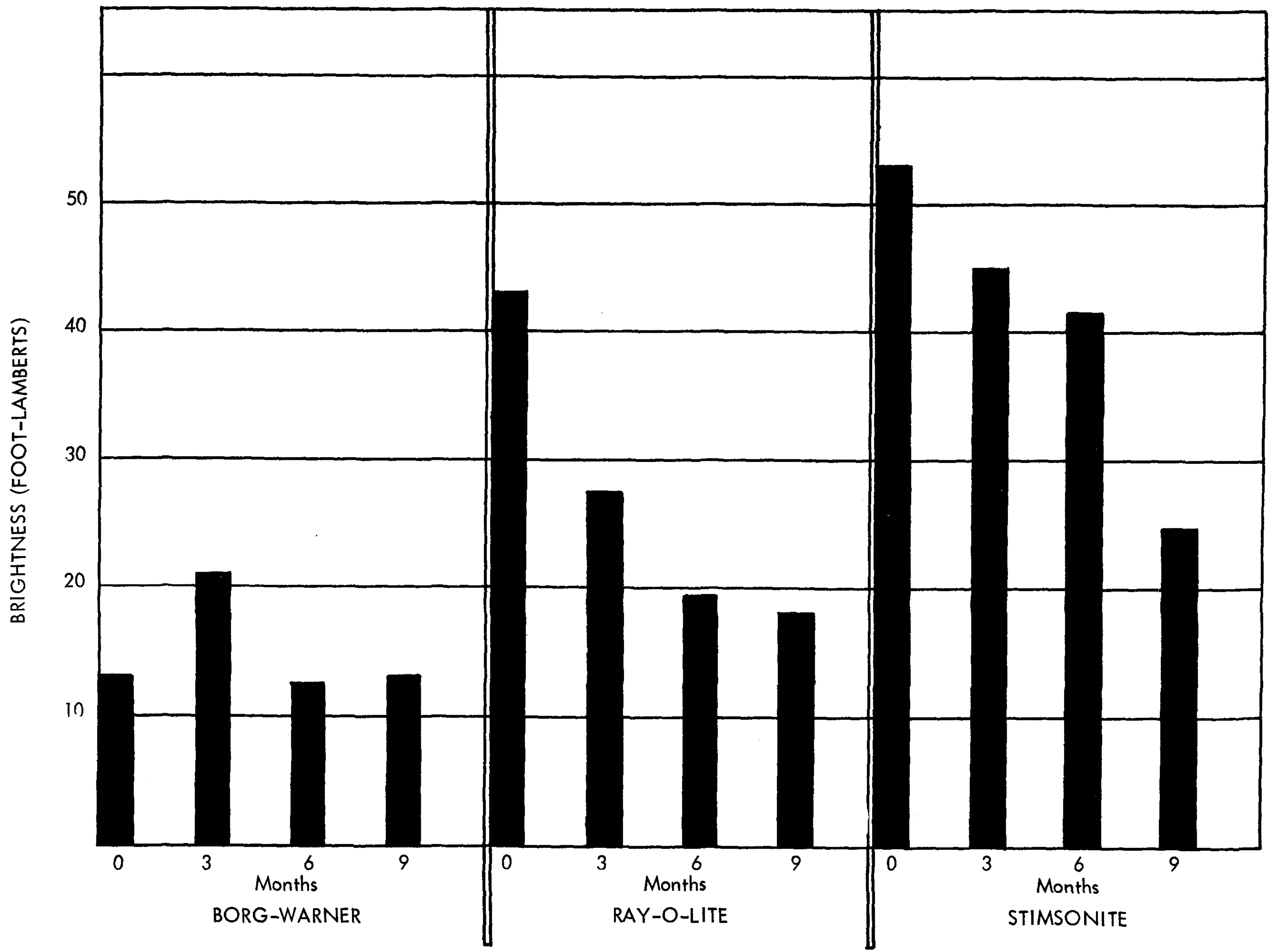
	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5
Stimsonite	3.79	3.81	3.80	3.41	3.76
Ray-O-Lite	1.07	1.08	1.11	1.02	1.93
3-M	1.15	1.16	1.14	1.27	1.15
Borg-Warner	.44	.43	.40	.39	.28

TABLE 2
TYPICAL BRIGHTNESS (FOOT LAMBERTS) READINGS
FROM LDH REFLECTIVITY TEST SET-UP

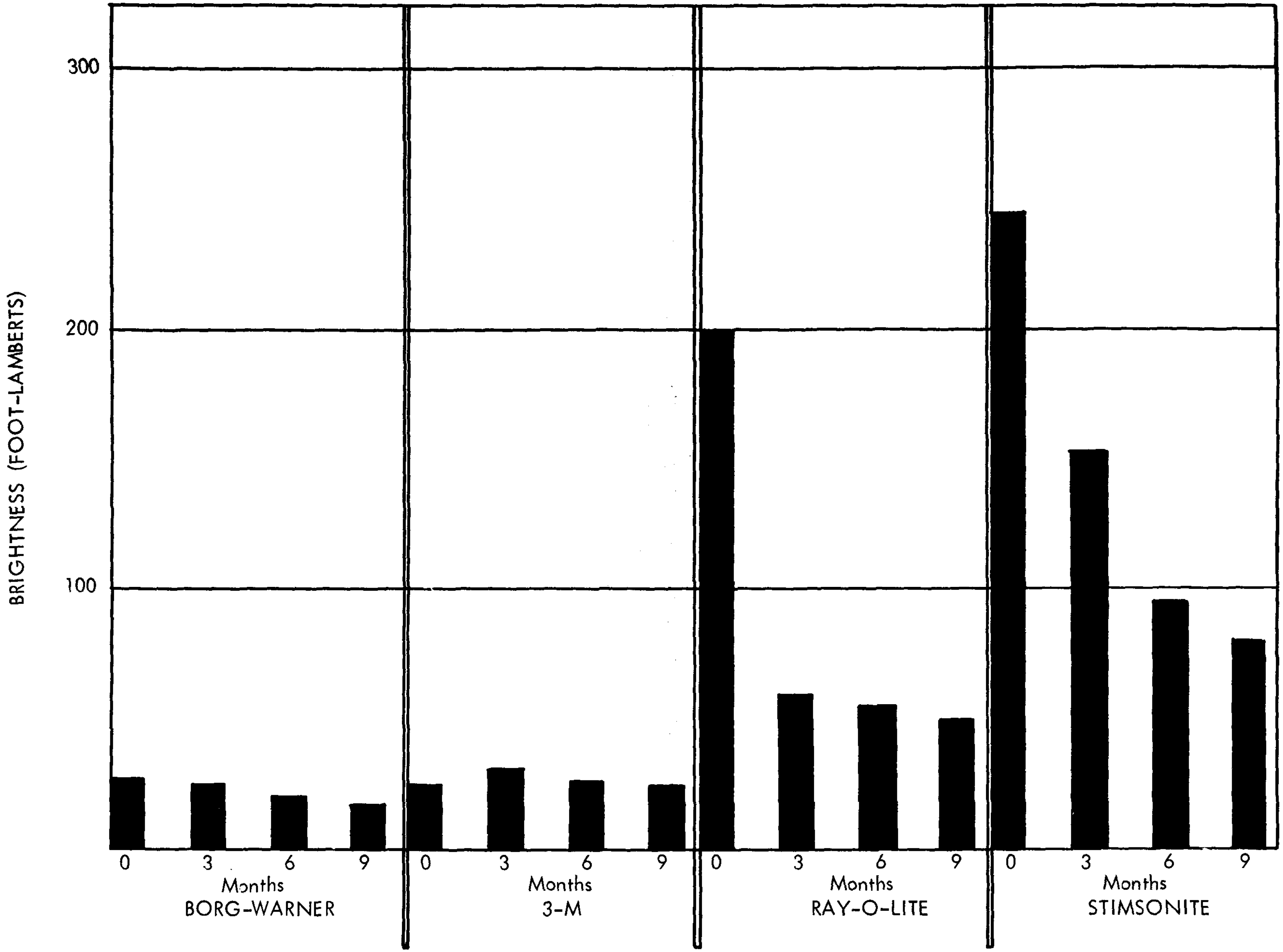
(Readings are at 0° incidence angle from markers which were sampled randomly)

	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5
Stimsonite	133	185	159	252	278
Ray-O-Lite	77	84	135	95	103
3-M	17	16	16	19	15
Borg-Warner	19	21	30	31	40

GRAPH 1a -- REFLECTIVITY VS. ROADWAY SERVICE TIME - RED LENS SIDE



GRAPH 1b -- REFLECTIVITY VS. ROADWAY SERVICE TIME - CLEAR LENS SIDE



APPENDIX "B"

NINE MONTH DURABILITY OBSERVATION RESULTS FROM U.S. 61 INSTALLATIONS

TABLE 3
NINE MONTH OBSERVATIONS OF U.S. 61 TEST SECTION

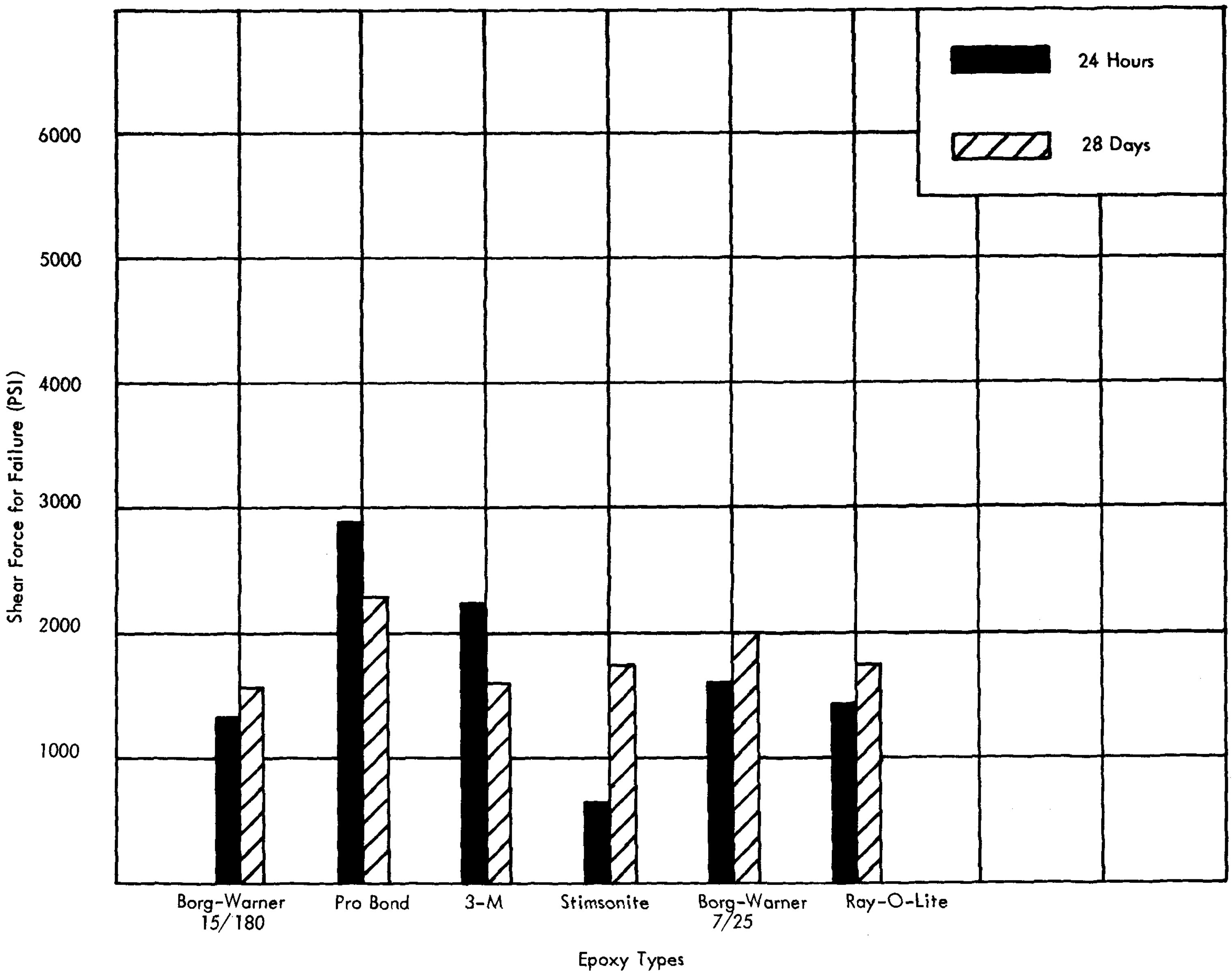
	Glass Reflective Elements (Areas 1 - 4)							
	Area 1 117 Placed		Area 2 100 Placed		Area 3 101 Placed		Area 4 97 Placed	
	Qty	%	Qty	%	Qty	%	Qty	%
Glass rod missing	31	26	6	6	8	8	7	7
Portion of glass rod missing	10	9	10	10	10	10	4	4
Severely cracked rods	30	26	30	30	30	30	31	32
Small crack or chip	38	32	38	38	44	43	35	36
No Damage	8	7	16	16	9	9	20	21

	Ceramic Base (Areas 5 and 6)		
	Area 5 289 Placed		Area 6 50 Placed
	Qty	%	All markers originally placed were either shifted in position or completely removed from the roadway by traffic action due to failure of Butyl pads.
Markers missing	1	1/2	
Glass rods missing	125	43	
Glass rods chipped or cracked	78	27	
Ceramic Bases chipped or cracked	26	9	
No Damage	59	20 1/2	

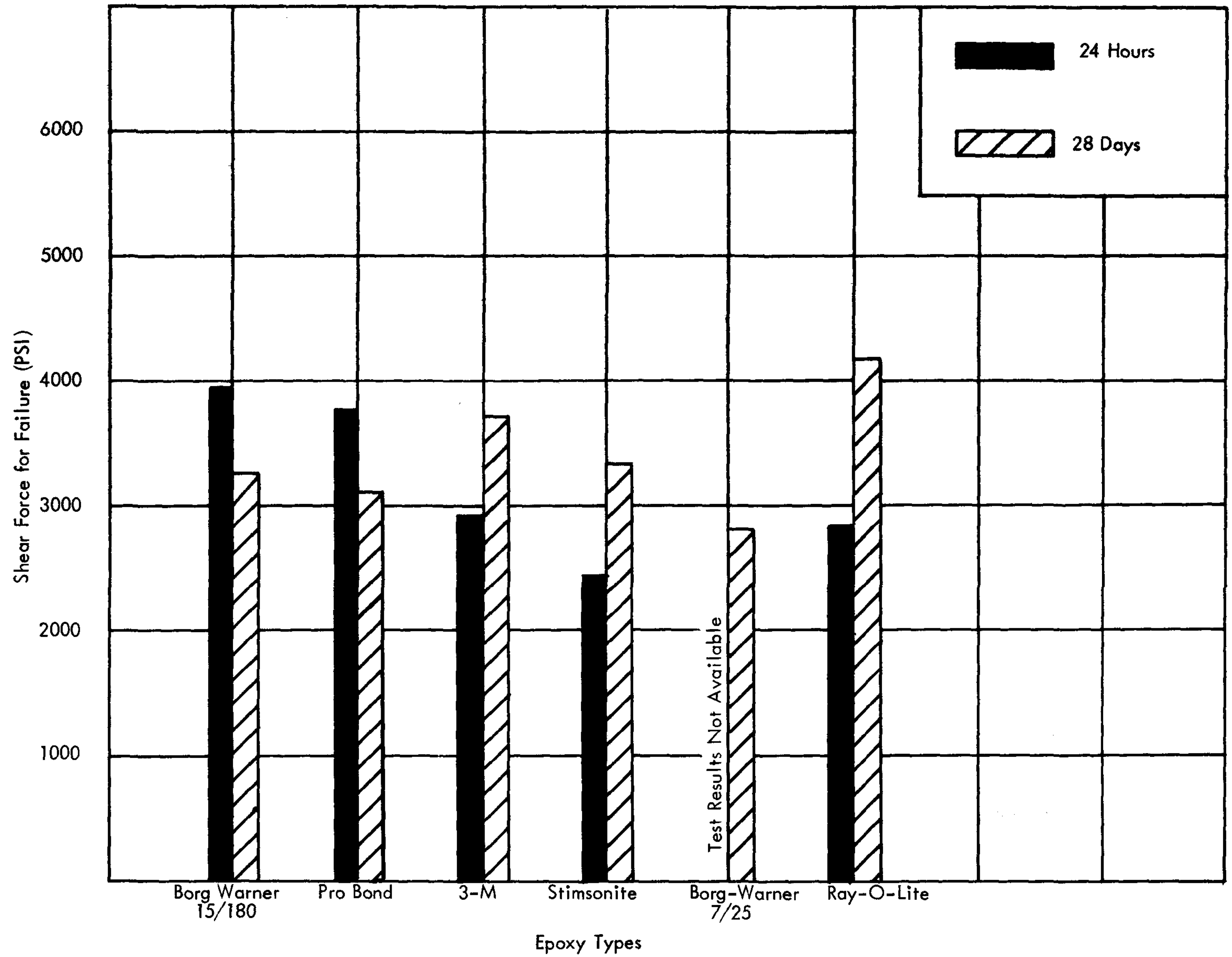
APPENDIX "C"

EPOXY BONDING TEST RESULTS

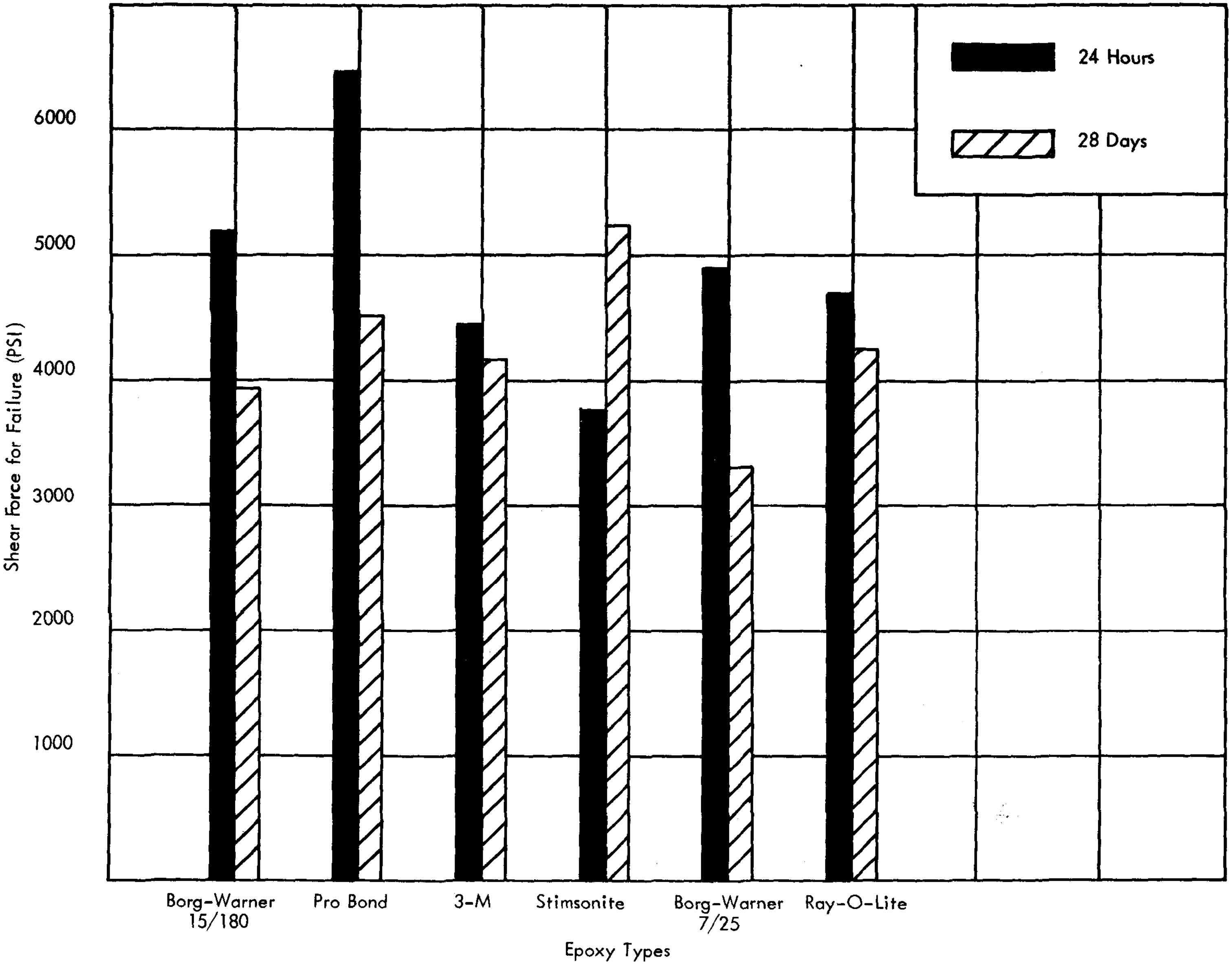
GRAPH NO. 2a -- BONDING STRENGTH OF BORG-WARNER MARKER



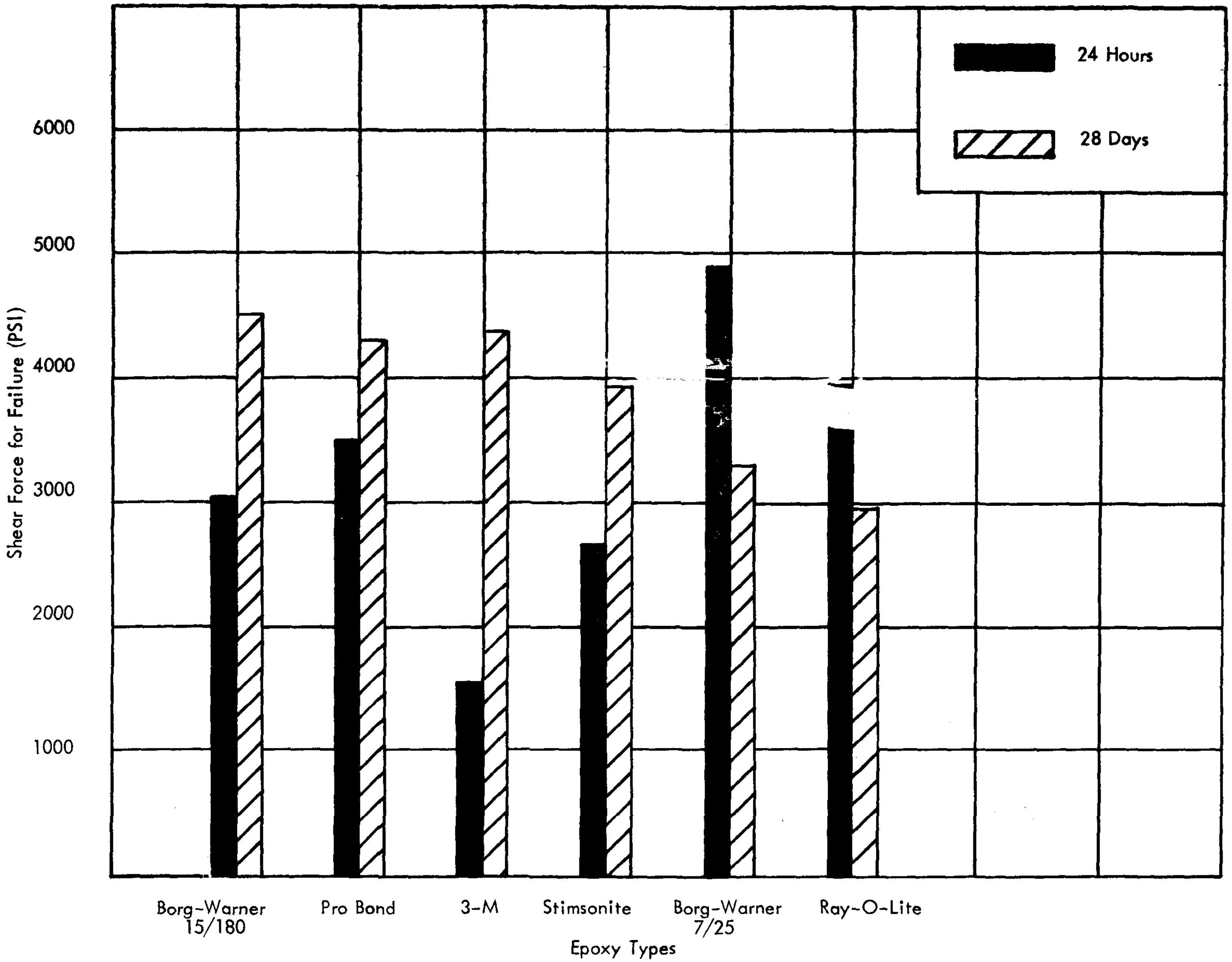
GRAPH NO. 2b -- BONDING STRENGTH OF RAY-O-LITE MARKER



GRAPH NO. 2c -- BONDING STRENGTH OF 3-M MARKER



GRAPH NO. 2d -- BONDING STRENGTH OF STIMSONITE MARKER



APPENDIX "D"

EARLIER SUMMARY REPORT

REFLECTIVITY TEST PROCEDURE

NEW RAISED PAVEMENT MARKER SPECIFICATIONS

HIGHWAY RESEARCH REPORT

March, 1969

The Research and Development Section has been evaluating various raised pavement markers for the past two years.

During this time some twelve different markers have been evaluated either by installation of test sections, or by observing installations placed by others. The following is a listing of the various markers, with a general description and a brief summary of observed performance to date.

Manufacturer or Supplier	Description of Marker	Performance
1. Cataphote Corporation	Pigmented epoxy resin with high index glass beads for reflectivity	The markers will not perform satisfactorily under adverse weather conditions. (Unsatisfactory)
2. Slip-Pruf Service Corporation (Little Jewel)	Pigmented epoxy resin with high index glass beads for reflectivity	Same comments as for No. 1 except durability is not as good. (Unsatisfactory)
3. Reflex International Sales (Ray-O-Lite)	ABS plastic shell with a thermosetting resin filler. The reflector is an acrylic cube corner device	Durability appears to be good but reflective surface is scratched and cracked by traffic.
4. Minnesota Mining and Mfg. Company (Glass Rod)	Glass rod with reflective sheeting inside for reflectance	Good reflectance under all conditions but durability of glass rod is questionable.

Manufacturer of Supplier	Description of Marker	Performance
5. Minnesota Mining and Mfg. Company (Day/Night Pavement Markers)	Ceramic base with glass rod mounted on base	Ceramic base appears to have durability, but glass rods are being destroyed by traffic. (Unsatisfactory)
6. Borg-Warner, Safety Guide Division (Safety Guide Roadway Markers)	ABS plastic marker with six glass beads embedded in plastic for reflectors	Durability of the marker is good. Some glass beads being lost due to traffic impacts.
7. Borg-Warner, Safety Guide Division (Safety Guide Berm Marker)	Same as No. 6	Same as No. 6
8. Slip-Pruf Service (Little Jewel)	ABS plastic marker with acrylic reflector	Insufficient time on test installation to (approximately 2 months)
9. Stimsonite Signal Products (Stimsonite 88)	Methyl methacrylate bonded to an epoxy base filler cube, corner reflex element for reflectivity	Durability of marker is generally good, although the reflective surface gets scratched and broken by traffic with resulting loss of initial reflectivity level.
10. Stimsonite Signal Products (Stimsonite 89)	ABS plastic shell with an epoxy filler. Same type reflective element as No. 9 only smaller	Plastic shell becomes unbonded due to traffic and day time visibility is lost. Same comments as No. 9 on reflector. (Unsatisfactory)

Manufacturer or Supplier	Description of Marker	Performance
11. American Clay Forming (Permark)	Ceramic disc non reflectorized	Durability is good. Must be used in conjunction with some type of reflective marker for nighttime visibility.
12. Trans-World Miss. Ltd.	White epoxy applied to roadway surface and large glass beads placed in epoxy for reflectivity	Uneffective in rain to low profile. (Unsatisfactory)

Of these twelve markers, Nos. 1, 2, 5, 10 and 12 have been classified as unsuitable. However, No. 5 is being redesigned by Minnesota Mining and Mfg. Company in an attempt to prevent the glass rod from being destroyed. When samples of the new design are received, a test installation will be made for evaluation. Of the remaining markers, only Nos. 3, 6 and 8 have both daytime and nighttime visibility and therefore could be used to replace a painted line. Nos. 3, 4, 6, 7, 8 and 9 could be used to supplement a painted line. No. 11 must be used in conjunction with reflective markers to replace a painted line and are not usable as a supplement to a painted line.

Our evaluation of these various markers indicates that a minimum of one year is needed under field conditions before a decision can be made as to the durability and effectiveness of a marker. In some cases less time is needed to eliminate unsatisfactory markers. Of the markers still under consideration, only No. 6 has been observed by the Research and Development Section for longer than one year. The remainder have been under traffic from two months to nine months. After the one year period is completed, a more meaningful evaluation can be completed.

to be tested is perpendicular to the line running through the angle indicator on the platform. The angle indicator shall then be set to the desired angle (usually 0°), and the doors on the shielded enclosure closed. After allowing approximately 3 seconds for readings to stabilize, the brightness reading may be obtained from the photometer and multiplied by 10^{+3} to obtain brightness of the specimen in foot lamberts. The brightness measurement on the standard reflective marker should be rechecked once every fifteen minutes during brightness measurement operations. A variation of more than 0.1 X 10^{-1} readout units requires that an adjustment be made in the power supply voltage to obtain the proper reading.

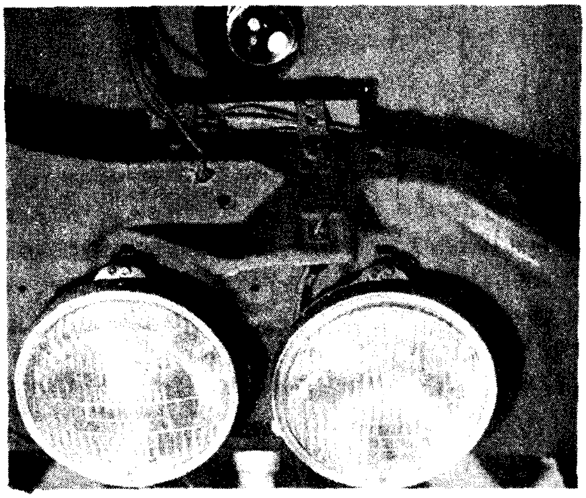


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FIGURE 3

Headlight Assembly with Spot Probe Attached

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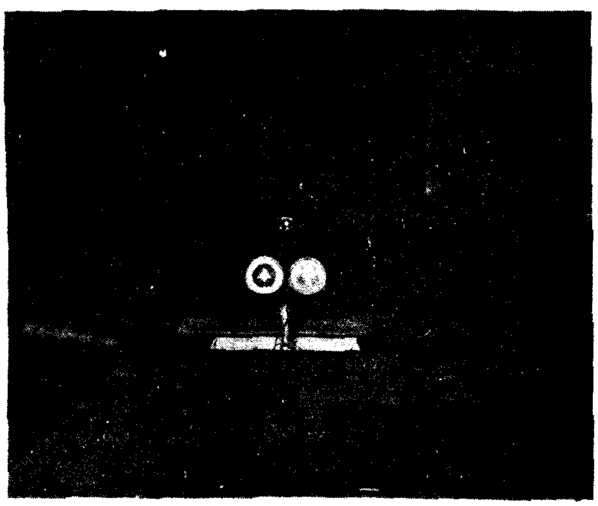

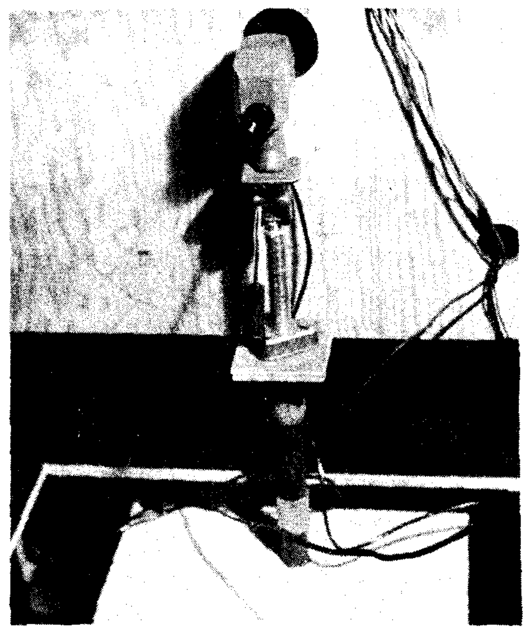

FIGURE 4

Spot Probe and Supporting Assembly

SUPPLEMENTAL SPECIFICATIONS FOR REFLECTORIZED AND NONREFLECTORIZED RAISED TRAFFIC MARKERS

DESCRIPTION: This work shall consist of furnishing and placing raised pavement markers at the locations shown on the plans or where directed by the engineer.

Raised markers shall conform to the requirements for either Class I, Class II, Class III or Class IV markers and must be one which has been approved for use by the Department. Any changes in design or materials of a previously approved marker will require a re-evaluation prior to use.

Unless otherwise specified or approved in writing by the engineer, one brand of markers must be used throughout the project for each Class of marker required.

REQUIREMENTS: Markers will be classified as Class I, Class II, Class III or Class IV and shall conform to the applicable requirements for the particular Class of marker.

Class I Markers: Class I markers shall be *non-reflectorized* and shall be used primarily for traffic rumble strips. The marker shall be of the type, and shape shown on the plans or specified in the special provisions.

The material for Class I markers shall be Acrilonitrile Butadiene Styrene Polymer, injection molded. Colors shall be as specified on the plans and shall be integral and uniform through the material.

A. Physical Requirement:

1. Heat Resistance. The marker shall show no significant change in shape or general appearance when subjected to the heat test. The heat test shall consist of placing the rumble strip in a vertical position in a circulating air oven set at 140°F. After an exposure period of four hours, the unit shall be removed from the oven and permitted to cool in air to room temperature. The unit shall then be compared to corresponding unexposed control standards.

2. Impact Resistance. The marker shall not break, chip or crack when subjected to the impact of a steel ball, 1-7/8 inches in diameter, falling freely from a height of 2 feet. Impact tests shall be performed at room temperature (70°F to 80°F). The marker shall rest, topside up, on a steel plate not less than 1/2 inch thick. The marker shall not be held or restrained in any manner. The steel ball shall strike at the approximate center of the marker.

3. Load Resistance. The marker shall withstand a load of 18,000 pounds without breaking or being significantly deformed when subjected to the load bearing test. The load bearing test consists of placing the marker, topside up, one a steel plate not less than 1/2 inch thick. A neoprene pad, cut to the size of the marker and meeting the specifications listed below, is placed on top of the unit and a load is uniformly applied at the rate of 20 to 50 psi per second. After reaching the specified load, the load is removed and the unit is inspected for evidence of cracking, deformation or breaking.

Neoprene Pad Specifications:

Thickness	1"±1/8"
Shore A Hardness (Durometer) ASTM: D676	70±5
Composition	100% Virgin Neoprene
Tensile Strength ASTM D 412	2,500 PSI (Min.)

Class II Markers: Class II markers shall be reflectorized and shall have both daytime and nighttime visibility. Class II.markers shall be used only for replacing a painted line.

The Class II marker shall consist of an acrilonitrile butadiene styrene body with a spherical reflecting system using biconvex glass elements or an acrilonitrile butadience styrene shell filled with a mixture of an inert thermosetting compound and filler material with prismatic reflector lens or other approved materials. The infra-red curves of the materials used in the markers shall match approved curves on file at the Materials and Testing Laboratory Colors shall be as specified on the plans.

A. Physical Requirements. Class II markers shall conform to the same physical requirements as provided for Class I markers except that the load shall be 9,000 pounds for the load resistance test.

B. Optical Requirements. Class II markers shall conform to the following requirements when tested in accordance with LDH Designation: TR 604.

Color	Footlamberts Angle of Incidence			
	0°		20°	
	Average	Minimum	Average	Minimum
Crystal	40	30	24	18
Amber	25	20	15	12
Red	14	10	8	6

The reflectivity of the marker shall be not less than 80% of the above minimum values after being subjected to the heat test required elsewhere herein.

Class III Markers: Class III markers shall be highly reflectorized and shall have both daytime and nighttime visibility. Class III markers shall be used for replacing or supplementing a painted line.

Materials and physical requirements shall be the same as outlined under Class II markers.

A. Optical Requirements. Class III markers shall conform to the following requirements when tested in accordance with LDH Designation: TR 604.

Color	Footlamberts Angle of Incidence			
	0°		20°	
	Average	Minimum	Average	Minimum
Crystal	125	110	75	65
Amber	80	70	48	40
Red	40	35	25	20

Class IV Markers: Class IV markers shall conform to all requirements of Class III markers with the exception that daytime visibility shall not be required. Class IV markers shall be used for supplementing painted lines only.

Sampling: Markers of each Class specified and proposed for use by the contractor will be selected at random for testing and submitted to the Department's Laboratory. Ten (10) markers shall be sampled per 1000 markers or portion thereof for each Class of marker. All ten markers representing a lot of 1000 markers shall be subjected to the reflectivity test outlined under Optical Requirements. At the completion of the reflectivity tests, three of the markers shall be tested for heat resistance, three for impact resistance and four for load resistance. Failure to conform to the requirements of any of the four tests shall constitute failure for the 1000 markers represented by the 10 samples.

Adhesive:

A. General: The adhesive shall be a two-component system consisting of the epoxy resin and hardener. Equal parts, by volume, of the epoxy resin and hardner components must be mixed together to obtain the finished adhesive.

B. Adhesive Properties:

1. Pot Life at 77°F, Minutes, Minimum	13
2. Set Time 77°F, Minutes, Maximum	200
3. Adhesive Shear Strength, Minimum	
Steel to Steel	2,000 psi
Aluminum to Aluminum	2,000 psi
4. Viscosity, 77°F	
Resin	42,000 cps
Hardener	20,000 cps

1. Pot Life at 77°F: The initial temperature of the adhesive components and the ambient temperature is 77±2 degrees F for this test. Equal parts, by volume; of the resin and hardener are measured into a six-ounce cup to give a 100 gram total mass. The two components are stirred with a spatula for 60±5 seconds

to assure a good mix. After the initial mixing, the adhesive is checked at two to three minute intervals for lumps or other signs of curing. When the first signs of lumps appear, the time elapsed is recorded as pot life.

2. Adhesive Shear Strength: The procedure followed is as outlined in ASTM Designation: D1002. Steel and aluminum specimens are used. The surfaces of the steel panels are prepared by grit blasting with 80-mesh sand using a Pangborn vapor-type sandblaster. The blasted surfaces are degreased with trichloroethylene and allowed to dry before applying the adhesive.

The surfaces of the aluminum panels are prepared by etching with the following solution:

10 parts sodium dichromate
30 parts sulfuric acid
90 parts demineralized water

Etch time is ten minutes at 140°F - 165°F followed by a tap water rinse. The specimens are dried immediately and must be used within 24 hours.

3. Viscosity: The viscosity of the individual components is measured with a Brookfield viscometer, Model LVF. The viscometer is equipped with a No. 4 spindle and tests are conducted at 12 RPM. Component and ambient temperature is to be 77°F±3°F at the time of measurement. The test sample consists of 400 grams of the component placed in a one-pint paint can.

CONSTRUCTION METHODS: The markers shall be cemented to the pavement with adhesive as described under heading entitled "Adhesive". All adhesive shall be mixed and dispensed by machine.

The markers shall be installed and pavement surfaces shall be prepared according to the manufacturer's recommendations and the following requirements. The portion of the pavement surface to which the marker is attached by the adhesive shall be cleaned or dirt, grease, oil, loose or unsound layers, and any other material which would reduce the bond of the adhesive. Cleaning shall be done by blast cleaning or other approved methods on portland cement concrete surfaces. On asphalt surfaces, blast cleaning shall not be used. The wet adhesive applications shall be of sufficient thickness so that when the markers are pressed into the adhesive, excess adhesive shall be forced out around the entire perimeter of the marker.

METHOD OF MEASUREMENT: Raised traffic markers will be measured by the marker and the number of markers permanently placed and accepted will be counted.

BASIS OF PAYMENT: The number of markers placed and accepted will be paid for at the contract unit price per each complete in place.

Payment will be made under:

Item S - , Nonreflectorized Raised Traffic Markers (Class I), per each.
Item S - , Reflectorized Raised Traffic Markers (Class II), per each.
Item S - , Reflectorized Raised Traffic Markers (Class III), per each.
Item S - , Reflectorized Rasied Traffic Markers (Class IV), per each.