NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM REPORT 85

DEVELOPMENT OF FORMED-IN-PLACE WET REFLECTIVE PAVEMENT MARKERS

HIGHWAY RESEARCH BOARD
NATIONAL RESEARCH COUNCIL
NATIONAL ACADEMY OF SCIENCES—NATIONAL ACADEMY OF ENGINEERING

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REPORT **85**

DEVELOPMENT OF FORMED-IN-PLACE WET REFLECTIVE PAVEMENT MARKERS

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WITH THE BUREAU OF PUBLIC ROADS

SUBJECT CLASSIFICATION:
- GENERAL MATERIALS
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- TRAFFIC CONTROL AND OPERATIONS

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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Systematic, well-designed research provides the most effective approach to the solution of many problems facing highway administrators and engineers. Often, highway problems are of local interest and can best be studied by highway departments individually or in cooperation with their state universities and others. However, the accelerating growth of highway transportation develops increasingly complex problems of wide interest to highway authorities. These problems are best studied through a coordinated program of cooperative research.

In recognition of these needs, the highway administrators of the American Association of State Highway Officials initiated in 1962 an objective national highway research program employing modern scientific techniques. This program is supported on a continuing basis by funds from participating member states of the Association and it receives the full cooperation and support of the Bureau of Public Roads, United States Department of Transportation.

The Highway Research Board of the National Academy of Sciences-National Research Council was requested by the Association to administer the research program because of the Board's recognized objectivity and understanding of modern research practices. The Board is uniquely suited for this purpose as: it maintains an extensive committee structure from which authorities on any highway transportation subject may be drawn; it possesses avenues of communications and cooperation with federal, state, and local governmental agencies, universities, and industry; its relationship to its parent organization, the National Academy of Sciences, a private, nonprofit institution, is an insurance of objectivity; it maintains a full-time research correlation staff of specialists in highway transportation matters to bring the findings of research directly to those who are in a position to use them.

The program is developed on the basis of research needs identified by chief administrators of the highway departments and by committees of AASHO. Each year, specific areas of research needs to be included in the program are proposed to the Academy and the Board by the American Association of State Highway Officials. Research projects to fulfill these needs are defined by the Board, and qualified research agencies are selected from those that have submitted proposals. Administration and surveillance of research contracts are responsibilities of the Academy and its Highway Research Board.

The needs for highway research are many, and the National Cooperative Highway Research Program can make significant contributions to the solution of highway transportation problems of mutual concern to many responsible groups. The program, however, is intended to complement rather than to substitute for or duplicate other highway research programs.

This report is one of a series of reports issued from a continuing research program conducted under a three-way agreement entered into in June 1962 by and among the National Academy of Sciences-National Research Council, the American Association of State Highway Officials, and the U. S. Bureau of Public Roads. Individual fiscal agreements are executed annually by the Academy-Research Council, the Bureau of Public Roads, and participating state highway departments, members of the American Association of State Highway Officials.

This report was prepared by the contracting research agency. It has been reviewed by the appropriate Advisory Panel for clarity, documentation, and fulfillment of the contract. It has been accepted by the Highway Research Board and published in the interest of an effectual dissemination of findings and their application in the formulation of policies, procedures, and practices in the subject problem area.

NCHRP Project 5-5 FY '67

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FOREWORD

By Staff
Highway Research Board

This report will be of special interest to traffic engineers, materials engineers, and other public officials responsible for the design of highway pavement marking systems having improved safety features. It presents the results of field testing of a low-cost pavement marker that is visible at night during rain and wet pavement conditions. It should be noted that the newly conceived marker, although meritorious, is not recommended on highways where snow removal is carried out using pressure-bearing steel snowplow blades. In addition to this technical report, a 30-minute motion picture film is available showing the marker at night during the rain. Implementation of the concepts presented should provide a more visible pavement marking that will increase the safety aspects of the highway, particularly on rainy nights.

This report stems from NCHRP Project 5-5 entitled, "Nighttime Use of Highway Pavement Delineation Materials." Only the findings of this study that pertain to the development of formed-in-place wet reflective pavement markers are presented herein. The research results dealing with the performance characteristics of conventional marking material and glass beads are presented in *NCHRP Report 45,* "Development of Improved Pavement Marking Materials." During the initial effort the researchers conducted studies of the physical nature of reflective materials, with particular emphasis on performance characteristics under various types of water film.

Based on the initial research efforts, it was determined that a new marker should be developed that would combine the features of being applied like paint and also perform like a raised reflectorized marker. With these thoughts in mind this research was initiated to further develop, optimize, and field test the new marking system that emerged from the initial research effort.

In this research a two-man, self-propelled machine similar to a normal paint machine has been developed, constructed, and tested in the field. The equipment pumps the viscous epoxy material and the fluid catalyst to the applicator gun. One-fourth-inch glass beads are then embedded in the pigmented epoxy binder. Major field testing of the experimental markers throughout the country has been conducted. Experimental markers were placed on highways in California, Oregon, Washington, Wyoming, Illinois, Missouri, Texas, Florida, North Carolina, New Jersey, and Connecticut.

As part of the final report on this project, a film has been produced entitled, "Pavement Marking Materials." The movie describes the low-cost pavement marker that was developed on the project. Scenes are shown of the marker as seen from the vehicle during a severe thunderstorm. The film includes operation of the pavement marking machine, which automatically manufactures and installs the marker directly on the pavement. The film is available for short-term loan on request to the Program Director.

CONTENTS

ACKNOWLEDGMENTS

The study reported herein was conducted in the Process and Product Development Section, Department of Chemistry and Chemical Engineering, Southwest Research Institute, with John M. Dale as Principal Investigator. Other Institute personnel associated with the project include Henry F. Frazier, William B. Pratt, Jr., and Elgin O. Ott.

The author is indebted to the City of San Antonio, and the States of California, Connecticut, Florida, Missouri, New Jersey, North Carolina, Oregon, Texas, Washington, and Wyoming for providing test sites, assistance in placing test markings, and surveillance of the test markings. Area Engineers of the Bureau of Public Roads also participated in inspections of the various test sites. Regretfully, space does not permit naming the many individuals within these organizations for their cooperation and assistance. The primary contacts within these organizations are cited in the field notes shown in Appendix C. Special appreciation is due Philip V. Palmquist and C. F. Tung for the development of the coated 0.25-in.-diameter glass beads of improved reflectance, and to their employer, The 3M Company, for making quantities of these materials available. Special appreciation is also due Charles H. Will, of Varian Associates, for assistance in application of microwave technology in preheating pavements.

DEVELOPMENT OF FORMED-IN-PLACE WET REFLECTIVE PAVEMENT MARKERS

SUMMARY

The information contained in this report offers agencies responsible for highway pavement delineation a new, low-cost technique for marking pavements that provides markings which are visible during periods of darkness and precipitation. It incorporates into one system the ability to be applied like paint and yet perform like raised, reflectorized markers.

Briefly, the system consists of formed-in-place markers approximately 4 in. in diameter by 0.25 in. in height which are applied by a self-propelled machine. A prototype application machine was designed, fabricated, and extensively used during the course of this research program. This machine employs a circular wire brush to clean the pavement surface. Onto the cleaned surface, a pigmented and catalyzed epoxy resin is discharged as a viscous liquid to form the body of the marker. Nineteen 0.25-in.-diameter coated glass beads are dropped into the epoxy and they submerge to just over their horizontal axes. Depending on the environmental conditions, the epoxy normally requires from 10 to 20 min to set or harden. The action of traffic over the markers removes the coating from the exposed portion of the glass beads. The coating on the embedded portion of the glass beads remains in place and serves to make the beads highly retroreflective, and they remain so even during periods of precipitation, where guidance and visibility problems are critical.

The system was field tested at a number of sites across the United States between June 1968 and May 1969. Performance of the markers was found to be outstanding in snow-free areas. In snowfall areas, it was found that the damage from steel snowplow blades was severe, but could be controlled by the use of rubber-tipped snowplow blades or the use of shoes fitted to the blades to raise them above the pavement surface. It was also found that in snowfall areas the action of studded snow tires and chains was most detrimental to the life of the 0.25-in.-diameter glass beads contained in the markers. Beads made from plastic are seen as a promising solution to this problem.

Being a new concept in pavement markings, the developed system is still very much in its infancy. It should be possible for individual authorities to make major improvements in the resin system, reflective materials, equipment, and application procedures, particularly as they relate to specific areas and locations which have individual environmental conditions, service characteristics, and maintenance requirements. In areas where the use of steel snowplow blades is considered essential, the useful life of the developed markings may be reduced to that of paint striping(*1*), which has an average useful life of 1 yr or less. The need for delineation during periods of inclement weather is so great, and the cost of the developed markers is sufficiently low, that their use should be considered at all locations, even those where steel snowplow blades are used.

CHAPTER ONE

INTRODUCTION AND RESEARCH APPROACH

The sensory inputs, decision processing, and motor responses required in high-speed driving can be overwhelming. The visual channel, which is the principal means of conveying information to the driver, can become overloaded during periods of darkness and adverse weather. During these periods, many commonly used pavement marking materials lose their effectiveness, and the visual burden can become critical with regard to the safe operation of a vehicle.

The performance of various pavement marking materials was explored in NCHRP Project 5-5, "Development of Improved Pavement Marking Materials—Laboratory Phase," and documented in *NCHRP Report 45*. In that study, a large number of different markings were evaluated from the standpoint of how they performed under a variety of environmental conditions. Various types of paint and glass beads were examined, as were a large variety of raised, reflectorized and non-reflectorized markers. Water films as encountered on highways were measured and related to the performance of the various types of markings. Glass beads were examined closely with respect to how they function as retroreflective elements when dry and when wet. An analysis of the individual characteristics of the various materials was made and compared to their performance characteristics as observed in the field, citing basic advantages as well as limitations in their use. From this, a systematic approach to decision making with regard to marking of pavements was developed and presented.

Evolving from this study was the concept of the formed-in-place raised marker employing 0.25-in.-diameter glass beads as reflective elements. A small number of these markers were made by hand and were found to have promising performance characteristics, particularly from the standpoint of night, wet-weather visibility. Thus, the second or Field Phase of the study as reported herein was undertaken to further develop, field-test, and determine the feasibility of the conceived system.

RESEARCH APPROACH

The research approach used to fulfill the goals of this study was to gather sufficient information to allow for the design and construction of a prototype marking machine, and, with this machine, to lay field tests of formed-in-place markers at a number of sites around the U.S., each having different environmental conditions, to determine the advantages and disadvantages of the system.

PROJECT ACTIVITIES

The project was initiated in July 1967, and was begun by conducting a number of independent studies which included studying the degree of adhesion that could be obtained with the pavement by using various pavement cleaning techniques, studying the performance of raised markers under the action of a rubber snowplow blade, and studying various resin and reflective systems by testing a large number of markers at test sites on research agency roads.

From these tests, a resin and reflective system was selected in November 1967 which allowed proceeding with the design, fabrication, and placing in operation of the prototype application machine. This machine was completed in May 1968, and was then used to apply the formed-in-place markings at test sites around the U.S. during the months of June, July, and August 1968. Monitoring of the test sites and other related work was pursued over the winter months of 1968-69, with the final inspection and report preparation being done during the Spring of 1969. This work is presented and discussed in Chapter Two.

INTERPRETATION

After all of the work had been completed, reviewed, and analyzed, it was possible to determine the economics of the system and make comparisons with conventional systems. This work is presented and discussed in Chapter Three.

APPLICATION

In Chapter Four, consideration is given to where and how the concept conceived and developed on this project can be put to practical application. To assist those interested in the application of the developed system, a 16-mm sound movie was prepared and submitted to the Highway Research Board. Every effort has been made to include in this report sufficient information so that anyone so interested should be able to duplicate, if not improve on, what has already been done.

CHAPTER TWO

RESEARCH FINDINGS

This chapter is divided into four parts and contains the principal findings of the study. The first part covers the preliminary field work that was necessary before equipment design could be undertaken. The second part covers the design, fabrication, and operation of the prototype marking machine. The third part covers the conduct of the field tests at the various sites across the U.S., and the fourth part covers the performance of the markers at the field test sites.

PRELIMINARY FIELD WORK

Pavement Surface Preparation

The service life of any delineation system is a direct function of the bond or adhesion between the delineation material and the road surface. Ideally, the bond strength between the two should be equal to or greater than the strength of the pavement itself. The physical strengths of the epoxy resins are in excess of the physical strengths of portland cement concrete and asphalt pavements. However, road films, oil, grease, laitance in concrete, old paint films, and other conditions encountered in the field often deny a delineation material such as epoxy resin access to the main structure of the pavement surface and require that consideration be given to some type of preparation of the surface.

To determine which pavement preparation method might give the best field performance, a number of 3.5-in.-square by 0.125-in.-thick steel plates were cut and drilled with four 0 5-in.-diameter holes in their respective corners. A 0.25-in.-diameter eyebolt was welded to the center of each of these plates. An epoxy composition consisting of 4 parts of Shell's Epon 828 epoxy resin, 4 parts of Titanium Pigment Corporation's RA-45 titanium dioxide pigment, and 1 part of Shell's Curing Agent U was applied to areas of asphaltic and portland cement concrete pavement which were unprepared and prepared by acid etching, wire brushing, grinding, and sandblasting. The plates were then forced into the epoxy and, after the epoxy was set, the adhesive bond with the pavement was determined by measuring the force required to pull the plates from the surface. Figure 1 shows a portion of the plates on a portland cement concrete pavement and the device employed to measure adhesive bond.

Table 1 gives the surface preparation identification code which was used in Figure 1 and the average pullup strength of those specimens tested after 5 days and those tested after 500 days. There was considerable similarity of results despite the difference of age and pretreatment, suggesting that where one could be assured of a good clean aged surface, as was the case in the test section, surface preparation might not be necessary.

It was found that on asphaltic concrete pavement, pretreatment of the surface other than removal of the road or paint films had very little influence on the adhesion, because, in every case, failure occurred in the pavement substrate and not at or near the interface. The load at failure on a well-aged asphaltic concrete pavement was found to be approximately 60 psi.

Figure 2 shows the bottom portion of two plates after they were pulled, the one on the left having been affixed to an asphaltic concrete pavement, and the one on the right having been affixed to a portland cement concrete pavement, both of which had received a wire brush preparation. In both instances, failures occurred in the pavement substrate and not in the epoxy or at the interface between the epoxy and the pavement surface.

The bond strengths are also a function of the strength of the particular pavement type and its age. The portland cement concrete section on which the test specimens were applied was several years old. On new portland cement concrete, bond strengths would be expected to be lower than those found, due to the presence of unhydrated constituents in the cement. Likewise, bond strengths on new asphaltic concrete would be expected to be lower than those found. Whereas strengths comparable with wire brushing were obtained with acid etching, the operational requirements of acid etching, which involved applying an acid, allowing it time to react, flushing the surface with water, and allowing time for the surface to dry, added considerable time and expense to the application.

In view of these findings and an appreciation of the wide variations in surface conditions that could be expected at the field test sites, the decision was made to employ wire brushing as a pretreatment to the pavement surface, and this feature was included in the design of the application equipment.

Binder Development

The requirements of a binder for the subject application were that it yield to pigmentation and be of such a viscosity and surface tension as to hold a film thickness of just over 0.125 in. and allow 0.25-in.-diameter glass beads, when dropped on, to sink and embed to just over their horizontal axes. In addition, the binder had to have the many other required performance features of marking materials, such as acceptable impact strength, flexural strength, hardness, abrasion resistance, and cure time. Previous consideration of potential binder materials indicated that the epoxy resins came close to meeting the specific requirements.

Binder development was initiated by contacting representatives of different epoxy resin manufacturers. Samples of a large variety of resins, modifiers, fillers, and curing agents were obtained and studied in the laboratory, particularly from the standpoint of their final or mixed viscosity, film holding capability, and set or cure times.

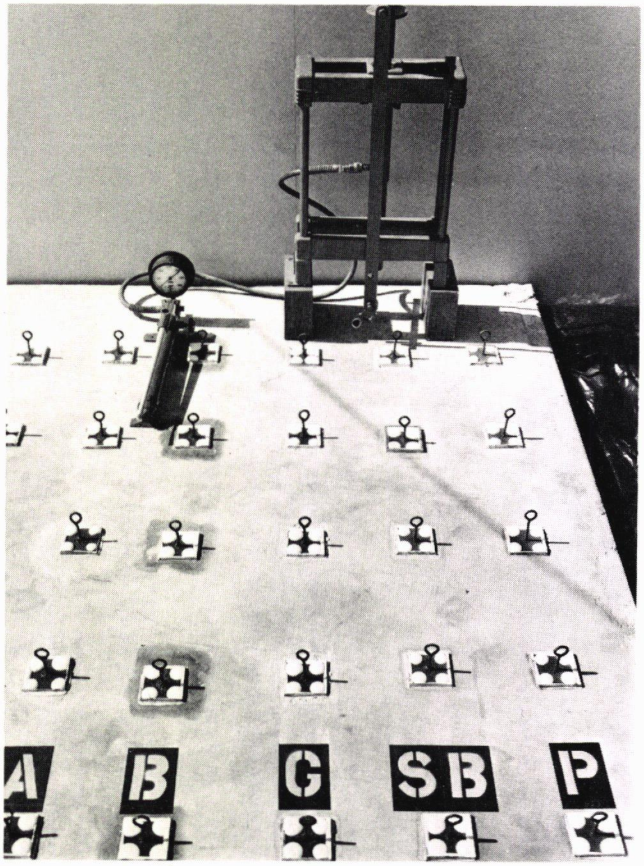

Figure 1. Test specimens and loading device.

TABLE 1

BOND STRENGTH AS A FUNCTION OF SURFACE PREPARATION AND AGE ON PORTLAND CEMENT CONCRETE

IDENT. CODE	SURFACE PRETREATMENT	3 SPECIMENS, AVERAGE BOND STRENGTH (PSI)	
		5 DAYS	500 DAYS
A	Acid etching—50% HCI	87	63
B	Wire brushing	89	82
G	Grinding	71	72
SB	Sandblasting	73	68
P	Plain or none	67	75

From these materials, a number of formulations (Appendix A) were selected for placement in field tests on research agency roads. Resin-curing agent systems with extremely rapid set times were purposely avoided because of anticipated complications that would be encountered in development of the application equipment. Their use was further viewed as a logical followup study if the basic system proved attractive.

It was found that placement of warning cones directly over the newly made markers serves the useful purpose of keeping blowing dirt, grass, and other trash off the wet resin until it has set.

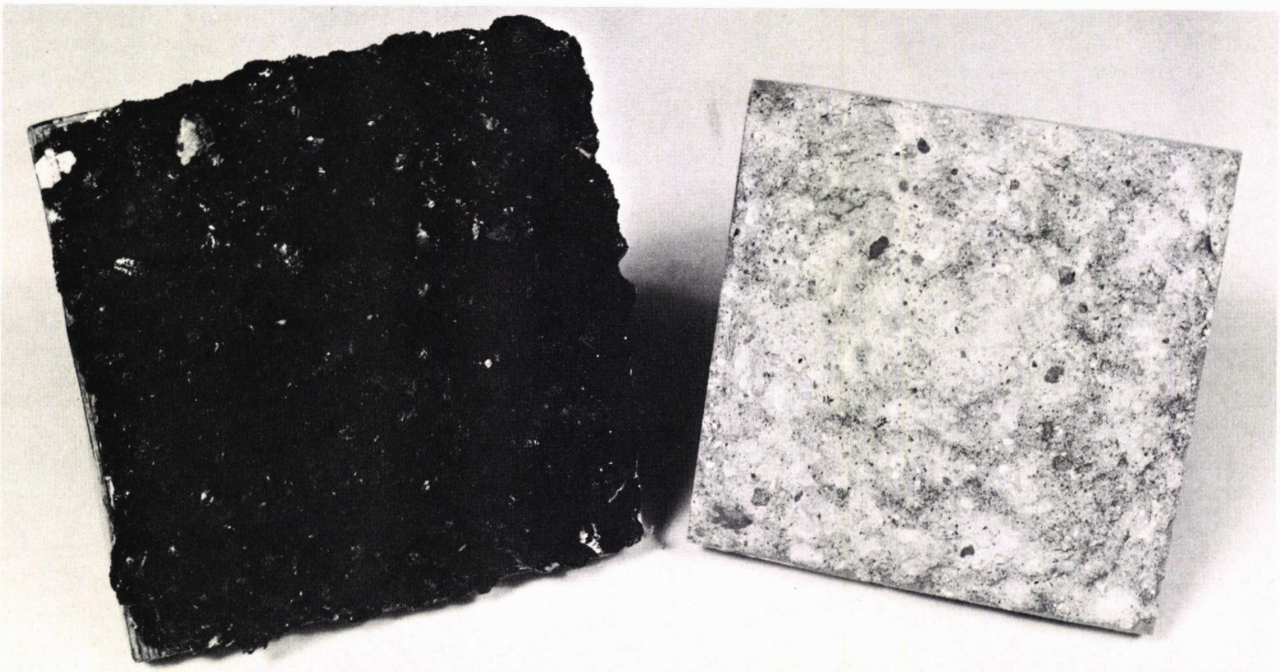

Figure 2. Characteristic adhesion failures on asphaltic concrete and portland cement concrete pavements.

Reflective Materials Development

In the laboratory phase of this program, it was concluded that for a glass bead to be effective during periods of precipitation, it should be approximately 0.25 in. in diameter or larger. The retroreflective characteristics of beads smaller than this, when embedded in a binder to above their horizontal axes and subjected to water films as encountered on roadways, are either completely overcome or greatly impaired. The only source of glass beads of this diameter was found to be the Industrial Products Division of Corning Glass Works. Beads from this source were obtained and found to perform adequately. The glass from which these beads were made was a glass having a refractive index of 1.55, and its efficiency in terms of retroreflection was a point for potential improvement.

Rather than focus the major emphasis of this program on the development of an improved bead, a number of glass-bead manufacturing firms were contacted. Trips were made to the research and development laboratories of a number of these companies. On these visits, the objectives of the program and the need for a 0.25-in. bead of improved retroreflective intensity were described in detail. As a result of these contacts, The 3M Company responded by providing, over the course of this project, 0.25-in.-diameter glass beads to which they had applied a reflective coating. This coating is rapidly abraded away on the exposed portion of the beads, but remains as a backing on the embedded portion of the beads and contributes very substantially to their retroreflectance. Reflective measurements made with a Gamma Scientific Corporation Model 2000 Telephotometer at an equivalent distance of 300 ft for markers of the same configuration and containing the same number of beads, but with different coatings on the beads, are given in Table 2.

The degree of improvement in the visibility of the markers using The 3M Company's No. 722 coated beads is every bit as dramatic as the measured values indicate. The beads with The 3M Company's No. 722 coating became available toward the end of the project, and thus it was possible to use them only in the latter part of the field work.

Another approach to improving the reflectance of the developed marker system is the use of higher refractive index glass in making the 0.25-in.-diameter beads. A source for beads of this type was not developed during the course of the project. If it had been developed, a question would have arisen with regard to the physical integrity of the beads, inasmuch as high refractive index glass is reportedly less chemically and wear resistant than low refractive index glass. Thus, the concept of the coated low refractive index glass bead is attractive because it provides the physical integrity of the low refractive index glass and the retroreflective intensities comparable to high refractive index glass.

For those interested in the colored markings, several possibilities exist. The resin binder can be colored by pigmentation, the glass beads can be given colored coatings, or the glass in the beads themselves can be colored. These are variations to the central theme of the project. Samples of 0.25-in.-diameter glass beads with high-intensity reflective coatings in red, green, and blue were also supplied by The 3M Company. When one employs the coated bead principal, then the color of the binder in which the bead is embedded does not influence the color of the light reflected. One of the reasons an epoxy binder was selected is that epoxy resins are clear and capable of being easily pigmented various colors. With the advent of the coated bead, it is reasonable to consider employing other lower-cost binders, such as asphalt materials and certain thermoplastics, because their color would not determine the color or amount of light reflected.

TABLE 2

REFLECTANCE OF MARKERS WITH DIFFERENT 3M COATINGS ON 1.55 REFRACTIVE INDEX, 0.25-IN.-DIAMETER GLASS BEADS [a]

3M COATING DESIGNATION	REFLECTANCE (FOOTLAMBERTS)
Uncoated	0.40
Coating 700	1.95
Coating 709	2.23
Coating 722	7.70

[a] All markers same design, 4 in. in diameter with 19 beads.

The reflective area in the viewing direction of commercial raised markers varies from 0.12 to as much as 2.0 sq in. for 4-in.-wide markers. The reflective area of the formed-in-place marker varies from 0.25 to 0.44 sq in., depending on the manner in which the beads are applied. The retroreflective intensity and visibility of some of the markers with the smallest reflective areas are, in some cases, greater than other markers with much larger reflective areas. Also, there is a considerable variation in the retroreflective intensity and visibility of markers as a function of the angle at which they are viewed. In the case of a vehicle traveling down the road, this angle is constantly changing. The reflective intensity of the formed-in-place markers having The 3M Company's No. 722 coated beads has been found to be more than adequate. A very distinct characteristic of the formed-in-place marker is that it provides equal retroreflective intensity in all directions, whereas many raised markers are highly directional. This allows side-approaching vehicles to easily distinguish the delineations. This could be used to advantage in the construction of directional and one-way arrows.

A useful design feature of the formed-in-place marker is that the reflective element is not a single element, but 19 separate lenses. Therefore, single large impacts (such as from a stone in a tire tread) may shatter one bead, but there are still 18 which are active.

Snow Removal

The highest elevation of the formed-in-place marker is the top of the glass bead which protrudes approximately 0.25 in. above the road surface. Although this height is less than that of conventional raised markers (for which elevations range from 0.50 to 0.75 in.) it is sufficiently above the road surface contour that it is subject to damage by snow-removal equipment. A steel snowplow blade was run over a series of the experimental markers applied to research agency roads; it was found that the blade had a tendency, because of the form of the marker, to ride over the epoxy, but in doing so, to damage the epoxy and fracture all of the 0.25-in.-diameter glass beads. The destructive force of the steel blade to the 0.25-in. glass beads was clearly evident and easily discernible to the naked eye.

The detrimental effect of steel snowplow blades on pavement markings has recently been documented (*1*) by the Bureau of Public Roads, particularly as related to the use of thermoplastics. A recent development which presents itself as a potential solution for conducting snow-removal operations without severely damaging raised markers is the use of the rubber snowplow blade. One of these blades was purchased from the Goodyear Tire and Rubber Company and attached to a regular blade. During periods of precipitation, this unit was run repeatedly over conventional raised markers (Fig. 3) and over experimental markers (Fig. 4). Neither the conventional markers nor the experimental markers were damaged or dislodged by the action of this blade, and it was concluded that the rubber snowplow blade is one technique for plowing snow without destroying raised markers. For those states that have severe snow maintenance problems, the use of the rubber snowplow blade or the use of shoes on blades to raise them slightly above the pavement surface in conjunction with chemical treatment is seen as a method which would allow for use of different types of raised markers.

Testing on Research Agency Roads

During the week of September 18, 1967, those binder formulations shown in Appendix A plus a variety of other binder and reflective material combinations were placed in field tests on research agency roads. Figure 5 (taken on March 14, 1968) shows one of these locations after the markings had been at this site over the 6 winter months.

Figure 3. Rubber snowplow blade over conventional raised marker.

From these field tests, it was concluded that the following two binder formulations appeared to have the optimum set of physical properties:

FORMULA	FORMULATION (PARTS BY WT.)	MATERIAL
A	4	Shell Epon 828 Resin
	4	Titanox Pigment RCHT
	1	Shell Curing Agent U
B	100	Shell Epon 815 Resin
	30	Titanox Pigment RCHT
	3	M5 Cab-O-Sil
	50	Reichold 611 Curing Agent
	24	Reichold 610 Curing Agent

These formulations had a setup and ability-to-accept-traffic time of approximately 15 min. There was no observable difference in the field performance of these two formulations. The decision was made to proceed with Formula A in equipment design because it was simpler, and some of this material had been in service at another site for approximately 18 months with successful performance characteristics. Formula B was seen as an alternate for use if brittle failure was encountered. In addition to having these materials in field tests on agency grounds, where they experienced local environmental changes, specimens were prepared and temperature cycled in the laboratory, both dry and submerged in water, between 20°and 100° F with no observed deterioration.

In the field tests, in addition to extensive use of 0.25-in.-diameter glass beads as reflective elements, a variety of other reflective treatments were employed—such as bead-coated granules and small glass beads applied as a drop-on treatment to epoxy formulations which had been corrugated before the resin had set, such that the beads would be located on surfaces which protruded through submerging water films. Small glass beads were also dropped on large aggregate particles which had been sprayed down with an epoxy binder and presented a sufficiently elevated surface for the small beads to prevent their being submerged by water films. None of these other treatments was found to be as effective as the use of the 0.25-in.-diameter beads. The principal disadvantage to the use of the small beads was that their use in the surface of the markers accelerates dirt pickup, greatly impairing the daytime visibility of the markings.

Figure 6 shows the test site (Fig. 5) during a rainstorm on the night of April 27, 1968. The last row of markers to the rear of the test site (which is considerably brighter than the others) is of the same construction and had the same number of reflective elements per marker as the others, but contained The 3M Company's No. 722 coated beads.

Equipment Design and Operation

The philosophy that was followed in the design of the equipment was that the equipment should be a prototype unit, sufficiently large and sufficiently automated to prove the

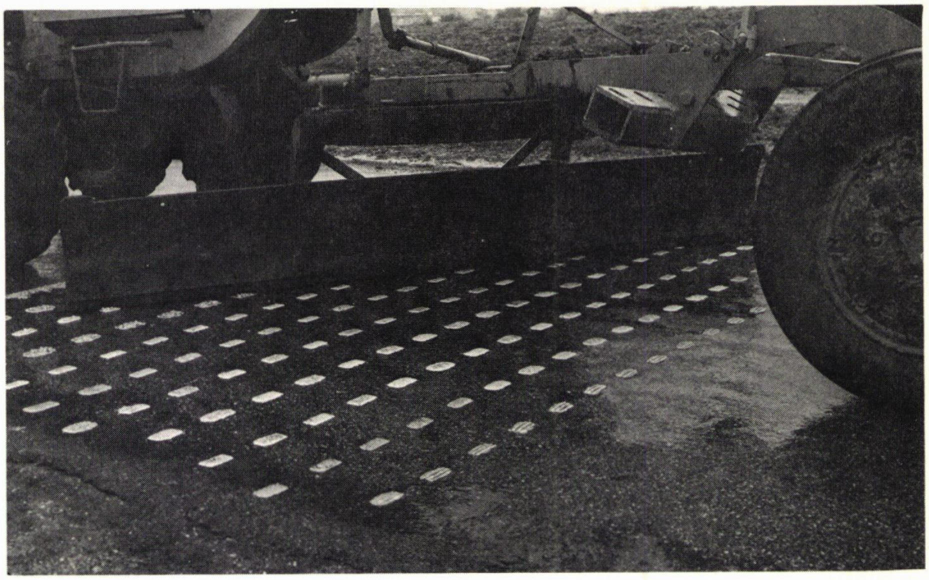

Figure 4. Rubber snowplow blade over experimental markers.

Figure 5. Field test site on research agency road.

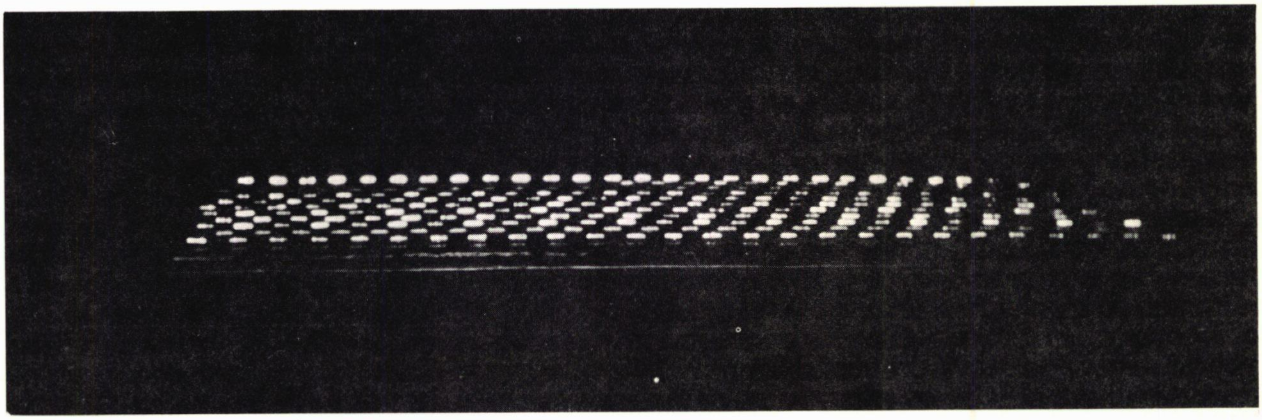

Figure 6. Field test site on research agency road at night during a rainstorm.

feasibility of the system, and yet (for reasons of project economy) not as large and automated as a commercial type unit.

The single feature which was considered to be mandatory in the machine was the automated handling and dispensing of the epoxy binder formulation. Epoxy dispensing equipment was studied, and equipment produced by the Gray Equipment Company was selected as meeting the requirements. Before this equipment was ordered, a sample quantity of the selected pigmented epoxy resin and curing agent was taken to Houston, Texas, where they were pumped, metered, mixed, and dispensed through a Gray Equipment Company unit in a demonstration of this equipment's ability to handle the formulation. Once the epoxy equipment was on order, design and assembly of the marking unit was undertaken.

A design with a centerline point of application was selected for several reasons. Stability problems were envisioned in placing the wire brushing surface preparation unit as an outrigger along with other application equipment on a relatively small unit such as the one considered. A second and very significant point is that a centerline point of application machine makes traffic control problems under certain circumstances much simpler. For example, in marking a two-lane opposing traffic roadway, the traffic in both directions must necessarily move out a short distance on the road shoulder to pass a centerline point of application marking machine, whereas a side application unit generally results in traffic being forced to pass over the marked line or divert to the deep shoulder, which is often unsatisfactory. For a two-lane artery with both lanes in the same direction, when the markings are being applied with a centerline point of application machine, the cars again have a tendency to stay in their lanes and divert to their respective shoulders, with only an occasional crossing of the marked line. Thus, such a design appeared logical for this application. Figure 7 shows the application equipment in an elevation view; Figure 8 shows the same unit in plan view. In Appendix B, drawings show the left elevation, right elevation, and plan view.

The main function of the No. 1 Operator (seated to the rear of the machine) is to drive the machine, guiding on a vertical sight bar on the front of the machine, select the points at which markers are to be applied, and clean the pavement surface at these points. Suspended in front of the machine is an engine-driven, 6-in.-wide by 8-in.-diameter circular wire brush assembly which is brought in contact with the road through a foot pedal operated by the No. 1 Operator. The rotation of the wire brush is opposite from the direction of rotation of the wheels of the machine; thus, dust and debris are thrown forward of the machine, avoiding possible surface contamination of a freshly made marker. The wire brush assembly is spring loaded in the UP position and automatically returns when the foot pedal is released.

The No. 1 Operator monitors a counting device directly under the steering wheel which is connected to a sensing element on the left rear wheel; this device advises him of the distance traveled, and allows for control of the spacing of the markings. At a specified number of counts for a given spacing, the No. 1 Operator activates the wire brush to clean the pavement surface. As the machine moves forward, the epoxy is dispensed onto the prepared surface and the beads are dispensed directly onto the epoxy. To the left of the No. 1 Operator is a 9-hp manual-start drive engine with gear reduction, clutch assembly, and a two-forward-and-one-reverse-gear transmission which is connected by chain and sprocket to the rear drive shaft. A foot-pedal-operated friction brake is employed to stop the machine. Hot exhaust gases from this engine pass through a bypass valve and can be directed to the atmosphere or through an annulus around the pigmented resin tank, for purposes of preheating the resin for viscosity control and acceleration of set time. The resin pigment premix is supplied to the unit in 5-gal buckets which easily slide in and out of the heating chamber. The resin pigment mixture is pumped by a low-pressure pump with follower plate. This unit can be easily lifted up and held in the extracted position while buckets of pigmented resin are changed.

Immediately forward of the resin tank is the curing agent tank, which is a fixed tank in a housing where the exhaust gases from the drive engine are also ducted. The lid for the curing agent tank is removed and the curing agent is added when needed. Both the curing agent and the pigmented epoxy resin are fed to the proportioning and high-pressure pump unit, which is located adjacent to the curing agent tank and toward the center of the machine. This pump and proportioning unit is also jacketed and heated by the engine exhaust gases. The pigmented epoxy resin and curing agent each proceed down separate high-pressure hoses to the mixing and dispensing head, which is located on the centerline of the machine. Forward of the curing agent tank is a warning cone storage area, and forward of this area is the air receiver tank, which serves as a reserve of high-pressure air to operate the epoxy dispensing equipment. On the right forward corner of the machine is the engine-air compressor assembly, which automatically maintains 120-psi air in the receiver tank. The No. 2 Operator is located immediately behind this unit.

The No. 2 Operator, through hand controls, operates the epoxy- and bead-dispensing equipment. This consists of an air motor which drives an impeller in the epoxy mixing head and a double-acting level arm which, when activated, opens both the pigmented epoxy resin and curing agent valves, allowing correctly proportioned amounts of both of these materials to enter the mixing head and be mixed and dispensed onto the road. Immediately behind the epoxy-dispensing equipment is the glass-bead dispenser, which rides in a track so that it can be slid forward or backward, as the situation demands, centering the bead dispenser over the dispensed epoxy. An air-operated trip mechanism which is activated by a lever in the No. 2 Operator's right hand, allows for the dispensing of a measured quantity of 0.25-in.-diameter coated glass beads. The bead dispenser is reloaded by a forward hand motion applied to the level connected to it. Actuated through lever arms by a foot pedal is a spring-loaded drip plate which is swung to one side when epoxy is being dispensed, and swung back in place when the unit is not dispensing. Although this is not an absolutely necessary feature, it eliminates any unsightly drips. Thus, the No. 2 Operator's sole function is to con-

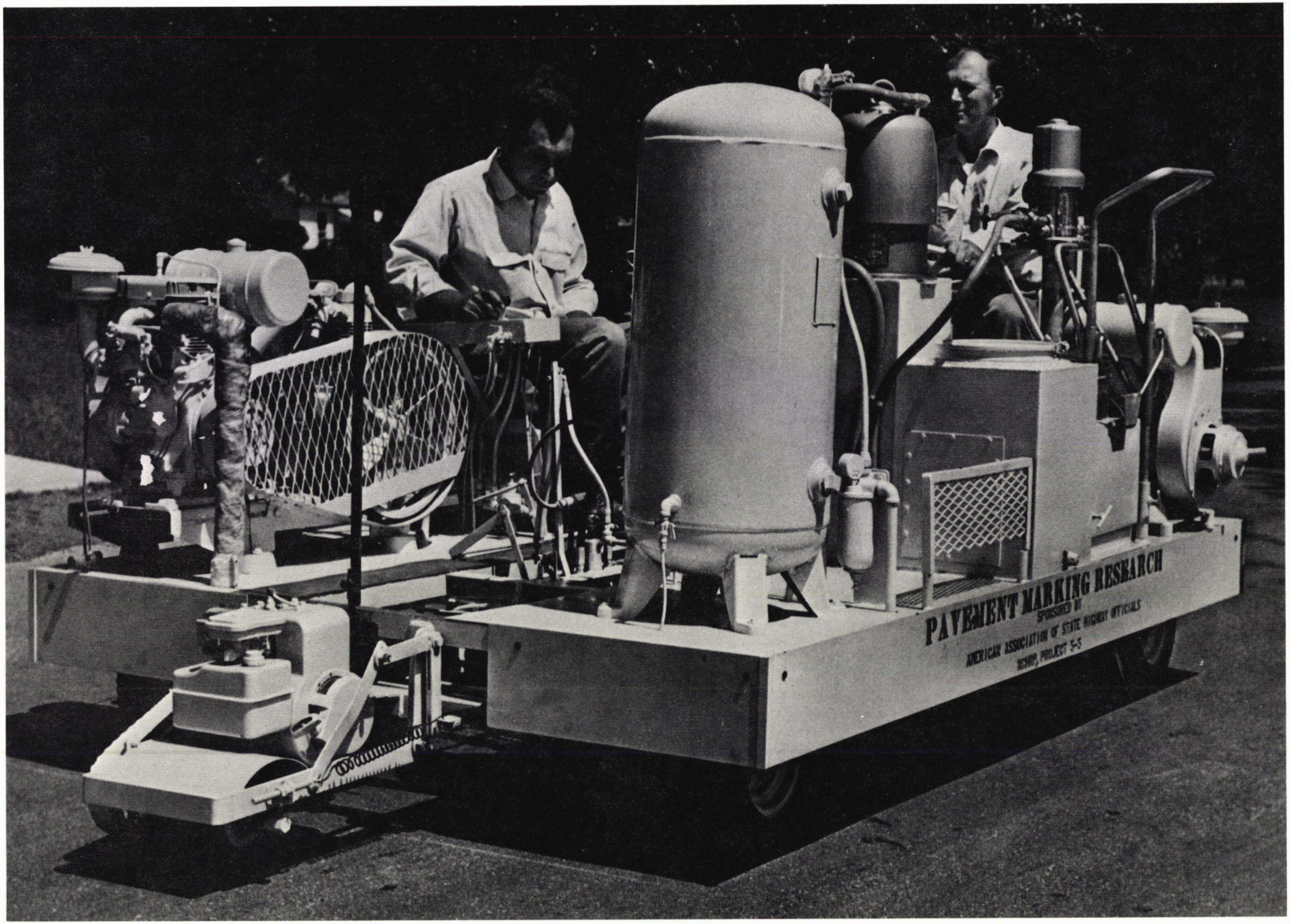

Figure 7. Left forward elevation of marking machine.

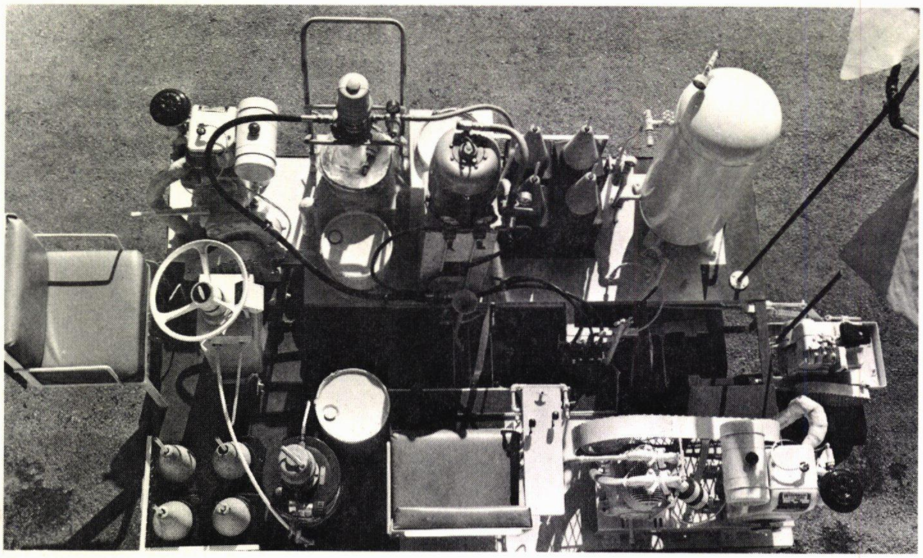

Figure 8. Plan view of marking machine.

trol the dispensing of the epoxy binder material and the reflective beads, and to monitor the quality of the markers being dispensed.

The quality of the marker is determined by relating the viscosity of the epoxy and the road temperature. A typical marker is produced by depositing approximately 63 grams of pigmented, catalyzed epoxy resin (Formula A) onto the road. At the instant of application, this material assumes a diameter of approximately 2.5 in. Approximately 19 to 20 0.25-in.-diameter glass beads are dropped as a concentrated load onto the center of the epoxy. Ideally, the epoxy will then flow out to a diameter of approximately 4 in. and the 0.25-in.-diameter beads will embed to just over their horizontal axes before the epoxy sets. Figure 9 shows an example of a well-formed marker. If the pavement surface is rough rather than smooth, a perfectly circular outer configuration is not always achieved.

The formulation is designed to be applied at an air temperature of 90°F at a road temperature of 90°F. If the epoxy does not flow out to the desired diameter and provide the proper bead embedment, heat is applied to the resin. At temperatures above those mentioned, it would be expected that the epoxy would flow out farther than desired; however, this is generally prevented by the fact that at the higher temperatures the formulation sets more rapidly and generally prevents excessive flow-out. In those special cases where excessive flow-out occurs, it can be controlled by increasing the pigment loading of the resin or by the use of a thixotropic agent such as Cab-O-Sil. In normal operation, the pigmented epoxy feed pump is set to operate at 40 psi, the proportioning pump at 40 psi, the mixer motor at 80 psi and solvent pump at 20 psi. Epoxy resin polymerization is not merely initiated by a curing agent but it reacts with the curing agent, necessitating complete and intimate mixing of the two. Therefore, the mixing motor must always be in operation before the resin and curing agent discharge valves are opened. Incomplete mixing is evidenced in markers by the presence of unreacted resin or curing agent that remains tacky or as stratified layers which are observable by breaking a marker in two and examining its cross section.

Located to the rear of the No. 2 Operator is the solvent storage tank and pump. Acetone is stored in this tank. After a series of markings have been completed or when it is desired to stop the machine for an extended period of time, the acetone is pumped through the epoxy mixing head and dispensing nozzle. At the end of a day's operation, the epoxy mixing head is removed by backing off a hand-threaded collar which holds the nozzle and mixing impeller to the mixing motor. With this chamber removed, the mixing impeller slips off the mixer drive shaft and both of these items are given a second thorough cleaning in acetone, and the "O" ring at the base of the mixer is also cleaned.

FIELD TESTING

Ten states were selected for placement of field tests. First preference in the selection of sites was given to those states that issued invitations to conduct test work. The remaining sites were selected to obtain the best possible coverage of the entire continental U.S. The field test work was initiated on June 9, 1968 and was completed on August 22, 1968, following the route shown in Figure 10. Two field tests were applied in Texas, creating a total of 11 field test sites in 10 different states.

At each of the test locations, the actual test site was selected by the given authority and an attempt was made to put down a mile or more of markings where conditions permitted. Exactly half of the installations were on asphaltic concrete pavements and the other half were on portland cement concrete pavements. The details concerning the location of the sites, the traffic density, quantity and type of markings applied, environmental conditions, performance, and other information are contained in the Field Notes in Appendix C. The sites are listed in Table 3.

The majority of the test sites were four-lane, median-separated expressways. The test markings generally were applied at a rate of one marker per marking module, with the markers being placed in the center of the skip or unmarked area along the lane lines. In most instances, this amounted to one marker every 40 ft. Variations to this practice were undertaken at several locations. Figure 11 shows Test Site No. 6 in Cheyenne, Wyoming, at the time of application on July 11, 1968, where six markers were evenly spaced between the beaded paint skip stripes. When this site was revisited in May 1969, the beaded paint stripe was gone and there was absolutely no trace of it (Fig. 12).

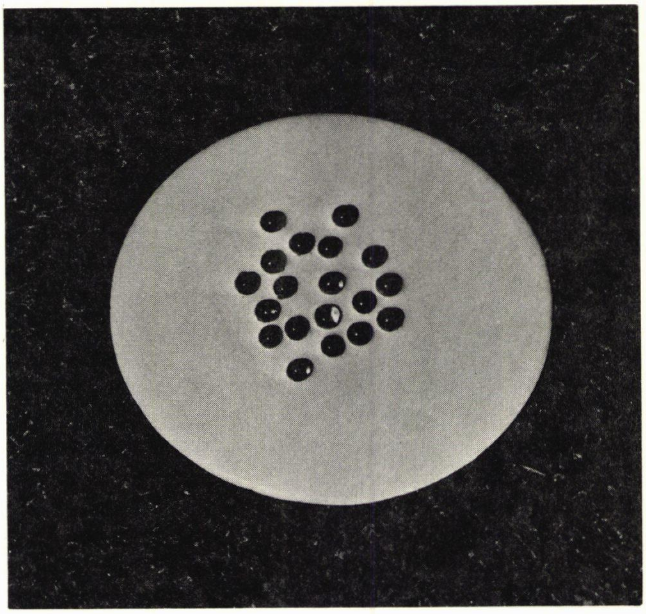

Figure 9. Typical 4-in.-diameter marker.

Performance of Markers at Field Test Sites

The performance at the various test sites has been compiled from the field notes and is summarized in Table 4. The most outstanding performance turned in on this project was that of the Formula A epoxy system which was the basis of the marker. It provided excellent service and adhesion to the road. Where failure of the epoxy occurred, it was due exclusively to steel snowplow blades, with the exception that in Missouri some marker loss was due to the markers placed knowingly over old paint and primer which lost their bond with the pavement. Whenever a marker was dislodged, it took with it the underlying pavement. The parting face was always within the pavement surface and not at the interface with the epoxy or within the epoxy.

Formula A showed excellent resistance to staining and marking by tires. The California test site was the only location where this subject was raised, but, on final inspection, the markers were completely clean. There had been rain the previous week which could account for their being clean. Figure 13, taken May 6, 1969, at the time of the final inspection of the California test site, shows a typical marker which had been in service for almost a year. Excluding snowplow damage, wear of the epoxy from abrasion, tire studs, and chains at all of the sites was imperceptible, and it would appear that the Formula A system should have a useful life equivalent to that of the pavement.

The performance at the two Texas test sites and the California test site was superior to that experienced at the

Figure 10. States selected and route followed in placing test sites.

TABLE 3

FIELD TEST SITES

TEST SITE NO.	AUTHORITY	TEST SITE LOCATION	DATE OF APPLICATION
1	City of San Antonio	Commerce Street West—San Antonio, Texas	June 13, 1968
2	Texas State Highway Dept.	Loop 410, West—San Antonio, Texas	June 20, 1968
3	California State Highway Dept.	Highway 80, South—Sacramento, Cal.	July 1, 1968
4	Oregon State Highway Dept.	Highway 22, East—Salem, Ore.	July 3, 1968
5	Washington State Highway Dept.	Highway 101, North—Olympia, Wash.	July 8, 1968
6	Wyoming State Highway Dept.	East Lincoln Way—Cheyenne, Wyo.	July 11, 1968
7	Missouri State Highway Dept.	Highway 71, South—Kansas City, Missouri	July 23, 1968
8	Connecticut State Highway Dept.	Highway 84, East—E. Hartford, Conn.	July 20, 1968
9	New Jersey State Highway Dept.	Route 1, South—Trenton, N.J.	August 1, 1968
10	North Carolina State Highway Dept.	Highway 50, North and South—Raleigh, N. C.	August 5, 1968
11	Florida State Highway Dept.	Highway 20, North—Tallahassee, Fla.	August 9, 1968

other test sites. Although part of this difference can be attributed to studded tires, chains, snowplowing, and other environmental-induced differences, one of the major reasons for excessive bead loss in some installations was improper bead embedment due to viscosity changes which was a result of accelerated settling of the pigment in the resin on traveling the required 300 to 600 miles between test sites. During all of the operations in and around the

Figure 11. Test Site No. 6, East Lincoln Way, Cheyenne, Wyoming, July 1968.

Figure 12. Test Site No. 6, East Lincoln Way, Cheyenne, Wyoming, May 1969.

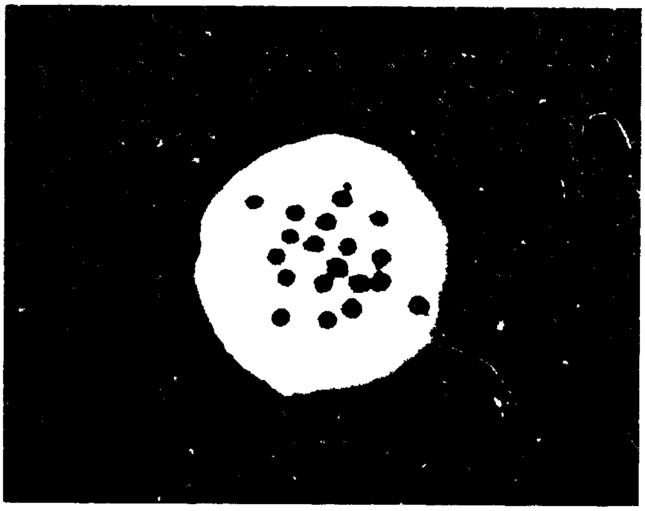

Figure 13. Typical marker at Test Site No. 3, California, on final inspection.

San Antonio area, the pigmented resin exhibited such excellent stability that settling was not recognized as a potential problem. The low-pressure pump which pumps the pigmented resin to the high-pressure proportioning pump, unlike most pumps, takes suction from the top of the vessel rather than the bottom of the vessel. This difference, until it was realized in conjunction with other observations, obscured the fact that difficulties of viscosity control and improper bead embedment at some of the field installations were indeed related to settling of the pigment. The use of manual rather than automatic control of heat supplied to the resin and curing agent also contributed to problems of viscosity control. Unfortunately, these points were discovered toward the end of the field test program. Improved field performance could have been achieved had they been recognized earlier in the program. Loss of beads in both the North Carolina and Florida test sites was definitely due to improper bead embedment caused by viscosity control problems with the epoxy, and was not related to the physical performance of the beads themselves.

The performance of the beads at the sites where no snowfall was encountered was excellent. At those locations where snowfall occurred, it was found that visibility of the markers declined rapidly beginning in November and could be directly related at each site to the use of steel-bladed snowplows and the use of studded tires and chains. The steel-bladed snowplow will generally ride over the epoxy portion of the formed-in-place marker, but not the beads. The beads will be sheared off level with the top of the epoxy. As an example of this, at Test Site No. 4 in Oregon, all of the epoxy portion of the formed-in-place markers was in place after the winter. Figure 14 shows this site at the time of the final inspection on May 8, 1969. Although all of the markers were in place, all of the beads had been destroyed. Figure 15 shows a typical marker with one good bead, four empty sockets, and the remaining sockets filled with shattered glass.

The extreme detrimental effects of studded tires and

TABLE 4

PERFORMANCE AT TEST SITES

TEST SITE NO. AND LOCATION	LOSS (%)		PAVEMENT TYPE [a]	TRAFFIC		AREA WHERE STUDDED TIRES AND CHAINS USED	NO. OF TIMES PLOWED WITH		SCRATCHING OR FROSTING OF BEADS	SHOULDER TYPE	WINTER SANDING AND CHEM. TREATMENT
	MARKER	BEAD		DENSITY (ADT)	SPEED (MPH)		RUBBER BLADE	STEEL BLADE			
1 Texas	0	1	AC	2,000	50	No	0	0	No	Grass	No
2 Texas	0	2	AC+PCC	16,000	70	No	0	0	No	Grass	No
3 California	0	4	PCC	20,000	65	No	0	0	No	Grass	No
4 Oregon	0	98	AC	2,500	70	Yes	3	7	—	Fine aggr.	Yes
5 Washington	35	100	AC	4,000	65	Yes	0	30	—	Grass	Yes
6 Wyoming	0	100	AC	17,000	45	Yes	0	1	—	Sand	Yes
7 Missouri	8	100	PCC	25,000	70	Yes	8	0	—	Grass	Yes
8 Connecticut	72	100	PCC	35,000	55	Yes	0	6	—	Grass	Yes
9 New Jersey	10	100	PCC	20,000	50	Yes	0	6	—	Grass	Yes
10 North Carolina	1	99	PCC	22,000	45	No	0	0	No	Sidewalk	No
11 Florida	0	18	AC	20,000	60	No	0	0	Yes	Fine aggr.	No

[a] AC—asphaltic concrete; PCC—portland cement concrete.

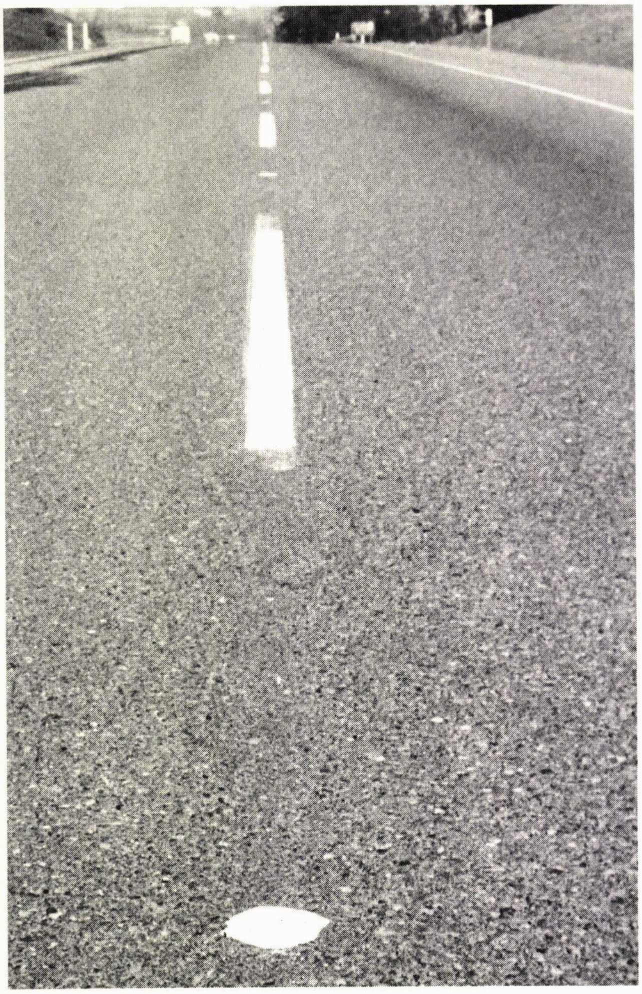

Figure 14. Test Site No. 4, Oregon, on final inspection, May 1969.

Figure 15. Typical marker with most beads destroyed, at Test Site No. 4, Oregon, on final inspection, May 1969.

chains on the glass beads were not fully appreciated before the field tests were conducted. These forces were sufficient to completely destroy all of the beads in the Wyoming test site, where the steel snowplow blade was raised above the markers. They were also sufficient to completely destroy all of the beads in the Missouri test site, where rubber-tipped snowplow blades were used. At many of the other sites in the snowfall area of the U.S., all that remained of the glass beads were empty sockets or sockets filled with shattered glass. Because they were subject to steel blading and impact damage from studded tires and chains, it was difficult to assign damage between these two. At sites outside of snowfall areas, where bead loss was generally in the 1 to 4 percent range, this loss was thought to be attributable to rocks carried in tire treads. At no location was staining or tire marking evidenced on the glass beads. At the Florida site, there was evidence of scratching and frosting of the glass beads, which was attributed to the large amounts of sand and fine aggregate present on the road and shoulder of the test site.

Figure 16 shows a typical marker at Test Site No. 11 in Florida at the time of the final inspection after approximately 1 yr of service. This clearly shows the low vertical profile of the formed-in-place marker. No really significant differences could be attributed to differences of pavement type (i.e., asphaltic concrete and portland cement concrete) or traffic density. The detrimental effects of steel snowplow blades and studded tires and chains completely overshadowed these other relationships. An intent operator and a heavy-duty steel snowplow blade combined to make a very effective scraping system that will even remove irregularities in portland cement concrete pavements.

At the test sites, there was a natural tendency for authorities, in some cases, and manufacturers, in other cases, to seek to place various types of raised, reflectorized markers adjacent to or following the formed-in-place markers. Because these were placed by others and under circumstances unknown to the project personnel, no attempt was made to rate their performance or compare them with the formed-in-place markers. Their presence could not be completely ignored, when, in fact, their presence at one location must be acknowledged as unlocking a vital bit of information necessary to rounding out the formed-in-place marker concept. In analyzing the field test site data, it was found that severe glass bead damage occurred as soon as the testing moved into the snowfall areas of the U.S. There was no way to definitely establish if this damage was caused by steel snowplow blades or studded tires and chains or both, until the performance of Test Site No. 6 in Cheyenne, Wyoming, was analyzed. At this site, all of the markers, some 465 of them, survived the winter, but all of the glass beads were either badly damaged or missing. Despite the fact that 24.6 in. of snow fell over the winter, it fell in such small individual amounts and the traffic was so heavy that the test site was plowed only one time with a steel blade, which was purposely kept above the markers, thus establishing that studded snowtires and chains could indeed completely destroy all of the glass beads. Between the formed-in-place markers, some commercial acrylic lens raised reflectorized markers were placed by local authorities. The lenses of these markers survived the winter quite well, thereby suggesting the practicality of employing 0.25-in. spheres made of acrylic rather than glass in the snowfall areas of the country. These too could be given the reflective high-intensity coating.

The use of glass beads in non-snowfall areas and acrylic or plastic beads in snowfall areas provides each area with a material best suited for the environment. In non-snowfall areas, reflective elements of glass have been found to be superior to those of plastic because they do not pick up hot-weather-induced staining and tire marks, as do the plastic. On the other hand, plastics are more resistant to tire stud impact than glass, and should be well suited for the snowfall areas where hot-weather-induced staining and tire marking of plastics is not a particular problem.

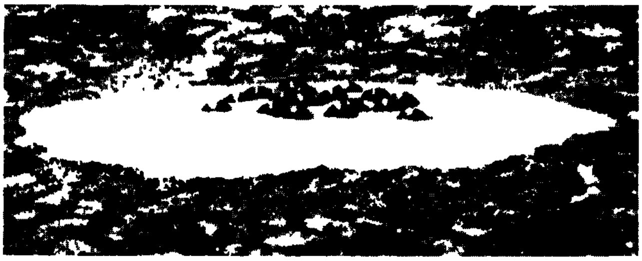

Figure 16. Test Site No. 11, Florida, on final inspection, May 1969, showing low profile of formed-in-place marker.

CHAPTER THREE

INTERPRETATION OF FINDINGS

ECONOMICS

Pavement markings are justified by virtue of the fact that they save lives. The merits of any particular system must be evaluated on the basis of its cost-performance characteristics in relation to other systems. These comparisons are necessarily complicated by the difference in performance characteristics of the different systems, not only from the standpoint of their useful life, but also their nighttime, wet-weather visibility. The Bureau of Public Roads has recently published a report on the performance and economy of conventional paint striping and hot extruded thermoplastic highway striping (*1*). That report indicates that the average cost—including materials, labor, expendable supplies, equipment depreciation, and other costs—of paint striping for open highways is approximately $0.022 per linear ft of 4-in.-wide striping. This figure is substantiated by other data (*2*). It further indicates the average useful life of paint striping to be primarily a function of the amount of traffic over it, as shown in Figure 17.

The average cost of 4-in.-wide longitudinal thermoplastic striping was found to be $0.327 per linear ft. It further indicates that the average useful life of thermoplastic striping is a function of the intensity of snowplow operations and relates to the mean annual snowfall, as shown in Figure 18.

The cost of installing commercial raised markers varies from location to location but is approximately as follows:

COST ITEM	COST OF COMMERCIAL MARKER ($) NON-REFLECTORIZED	REFLECTORIZED
Marker unit	0.25	0.85
Epoxy	0.15	0.15
Labor	0.15	0.15
Depreciation, fuel, etc.	0.10	0.10
Total	0.65	1.25

The State of California (*3*) has evaluated and adopted a system for delineating traffic lanes using four white non-reflective raised markers placed on 3-ft centers followed by a 15-ft skip. A raised, reflective marker is placed in the center of every other skip. The cost of placing the marker pattern described with a sandblasting preparation of the point of application of markers is approximately $700 per lane-mile or $0.71 per marker (average 8 non-reflectorized to 1 reflectorized), which is in rather close agreement with the previously tabulated $0.65 and $1.25 figures. The useful life of the non-reflectorized raised markers in the California installations on portland cement concrete pavements is estimated to be 10 yr, whereas the life of the reflectorized raised

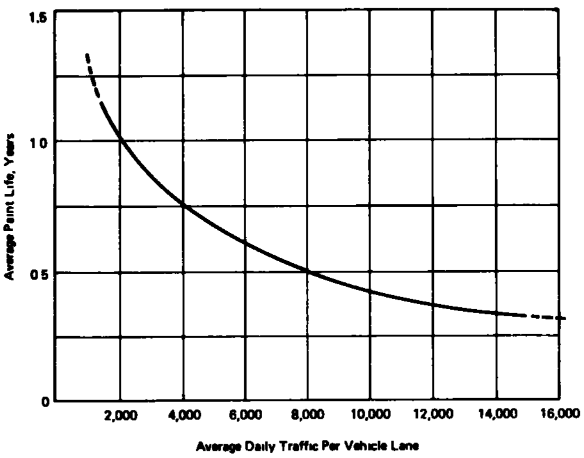

Figure 17. Average useful life of paint striping as affected by traffic density on both asphaltic and concrete pavement (1).

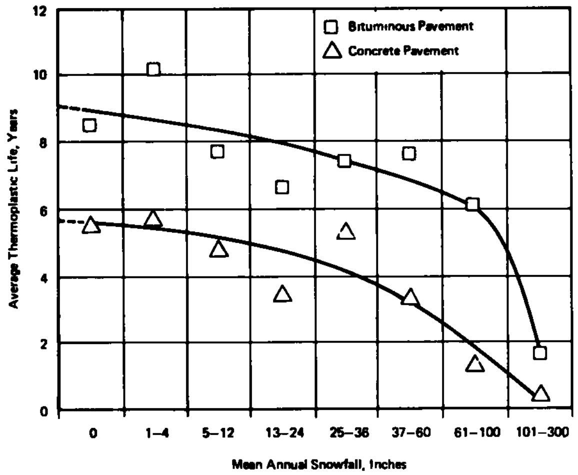

Figure 18. Relation between average thermoplastic life and annual snowfall (1).

markers is estimated to be approximately 4 yr. Both of these figures cover experience outside of snowfall areas. The life of a marking system is necessarily a function of the maintenance-free life of the road surface. Asphaltic concrete pavements have an average maintenance-free life of approximately 8 yr (*1*). This establishes maximum useful life of the markers.

The formed-in-place marker has a raw materials cost of approximately $0.11. A detailed breakdown of this cost is shown in Appendix D. Experience in the field with the prototype application machine, which required that the machine stop at each point of application, was that a 4-man crew could apply 1,000 markers in an 8-hr day for a maximum labor cost of approximately $0.10 per marker. Adding another $0.10 for depreciation, fuel, and other miscellaneous costs gives an approximate total cost of $0.31 per marker. This is approximately one-fourth that of conventional raised, reflectorized markers. This fact should be borne in mind, and comparisons should reflect this difference. Performance comparisons should relate one conventional marker with four of the formed-in-place markers, or, if they are compared one-to-one, then the cost differential should be definitely noted. Although it is difficult to estimate the useful life of the formed-in-place markers, there were three test sites that showed no marker loss and less than 4 percent bead loss over the first year, suggesting that where formed-in-place markers are not plowed with steel snowplow blades and studded tires are not used excessively, they might easily be expected to have a useful life of 4 yr.

Because beaded paint, non-reflectorized commercial raised markers, and thermoplastics have poor nighttime, wet-weather visibility, it is attractive to supplement these marking systems with some type of raised, reflectorized marker. The open-road cost for a bead paint marking system consisting of 15 ft of beaded paint per 40-ft module is approximately $44 per lane-mile. This system can be supplemented for night-wet visibility with either formed-in-place markers in the center of each skip (for approximately $41 per lane-mile) or commercial raised, reflectorized markers in the center of each skip (for approximately $165 per lane-mile). If the paint stripe is assigned a useful life of 1 yr, and the raised, reflectorized markers are assigned a useful life of 4 yr, the total cost at the end of 4 yr and the average cost per year are as given in Table 5.

Where conditions permit the use of the raised, reflectorized markers, the added investment is actually quite nominal in terms of the benefit derived by providing night, wet-weather visibility. Some states have found it practical to use raised, reflectorized markers every 80 ft instead of every 40 ft. This would reduce the average cost per year over the 4 yr for the beaded paint plus the formed-in-place

TABLE 5

COST PER LANE-MILE OF A BEADED PAINT SYSTEM COMPLEMENTED BY RAISED, REFLECTORIZED MARKERS

ITEM	COST PER YEAR ($)				TOTAL ($)	AVERAGE COST/YR ($)
	1	2	3	4		
Beaded paint	44	44	44	44	176	44
Beaded paint + formed-in-place	44	44	44	44	176	
markers	41	—	—	—	41	
					217	54
Beaded paint + commercial, raised,	44	44	44	44	176	
reflectorized markers	165	—	—	—	165	
					341	85

markers to $49 per lane-mile, and for the beaded paint plus commercial, raised, reflectorized markers to $65 per lane-mile. For those interested in converting to a completely raised marker system where six non-reflectorized markers are used to replace 15 ft of beaded paint and where conditions permit this, the economics must reflect the approximate 8-yr life of the raised non-reflectorized markers and the cost of complementing them with raised, reflectorized markers. This is given in Table 6.

The figures in Table 6 do not reflect the advantages of traffic channelization through the use of raised markers and the reduction of accidents through less frequent marking, nor do they reflect the fact that raised markers are often used where bead paint has a useful life of less than 1 yr. Also to be considered is the fact that the raised markers provide continued good delineation, whereas the delineation offered by beaded paint stripes varies from good at the time of application to poor just before repainting. Increasing the spacing of the raised, reflectorized markers to 80 ft would reduce the respective costs to $70 per lane-mile and $85 per lane-mile.

A similar comparison for using a 4-in.-wide by 15-ft length of thermoplastic per 40-ft module, complemented by one raised, reflectorized marker every 40 ft, must reflect an 8-yr approximate useful life of thermoplastic. These costs are given in Table 7.

Increasing the spacing of the raised, reflectorized markers to 80 ft would reduce the respective costs to $86 per lane-mile and $102 per lane-mile. This comparison reflects a rather high cost for thermoplastics as compared to beaded paint, which must be tempered by the fact they are made on the basis of open-road costs, whereas, in most instances, thermoplastics are used in areas of high traffic density and severe wear where the useful life of beaded paint is considerably less than 1 yr and the unit cost of applying paint because of traffic control problems is much higher. Under such conditions, thermoplastics can be less expensive than beaded paint. These comparisons show, among other things, the need to compare and select the marking system that provides the greatest return on the investment for a given location.

TABLE 6

COST PER LANE-MILE OF A RAISED, NON-REFLECTORIZED MARKER SYSTEM COMPLEMENTED BY RAISED, REFLECTORIZED MARKERS

ITEM	COST PER YEAR ($) 1	2	3	4	5	6	7	8	TOTAL ($)	AVERAGE COST/YR ($)
Non-reflectorized raised markers	515	—	—	—	—	—	—	—	515	64
Non-reflectorized raised markers +	515	—	—	—	—	—	—	—	515	
formed-in-place markers	41	—	—	—	41	—	—	—	82	
									597	74
Non-reflectorized raised markers +										
commercial, raised, reflectorized	515	—	—	—	—	—	—	—	515	
markers	165	—	—	—	165	—	—	—	330	
									845	106

TABLE 7

COST PER LANE-MILE OF A THERMOPLASTIC SYSTEM COMPLEMENTED BY RAISED, REFLECTORIZED MARKERS

ITEM	COST PER YEAR ($) 1	2	3	4	5	6	7	8	TOTAL ($)	AVERAGE COST/YR ($)
Thermoplastic	647	—	—	—	—	—	—	—	647	81
Thermoplastic +	647	—	—	—	—	—	—	—	647	
formed-in-place markers	41	—	—	—	41	—	—	—	82	
									729	91
Thermoplastic +										
commercial, raised	647	—	—	—	—	—	—	—	647	
reflectorized markers	165	—	—	—	165	—	—	—	330	
									977	122

Consideration should be given to the use of the formed-in-place markers in each and every installation. More consideration should be given to balancing the investment in lane lines, edge lines, and raised, reflectorized markers, to provide a more balanced performance under all environmental conditions. For example, on a rural highway marked with a broken center stripe on a 40-ft module consisting of 15 ft of beaded paint and 25 ft of skip and continuous beaded paint edge stripes on both sides, the broken 4-in.-wide center stripe of beaded paint will cost approximately $44 per lane-mile. Each 4-in.-wide edge line of beaded paint will cost approximately $116 per lane-mile, for a total marking cost per road-mile of approximately $275. Although this marking practice has many advantages, it is rendered ineffective and of little use at night in a light rain. A more balanced system from the performance standpoint might be achieved by reducing the width of the edgelines from 4 in. to 3.3 in. and taking the resulting $41 per road-mile savings and investing it in the placement of formed-in-place raised markers in the midpoint of the skip on the centerline. At night and during rain, the motorist would then have the formed-in-place markers to delineate the center of the road, rather than riding along blindly.

CHAPTER FOUR

APPLICATION OF FINDINGS

Pavement markings are used because they ease the driving burden and reduce the amount of loss in human life and property. They are a positive approach to eliminating accidents, whereas seat belts, guardrails, crash barriers, and the like are but attempts to respond to a large variety of possible results stemming from an accident. Approximately 35 percent of all motor vehicle fatalities and approximately 65 percent of all freeway fatalities are single-vehicle, running-off-the-road type of accidents. The use of pavement marking systems which lose their effectiveness at night in adverse weather conditions where they are needed the most can hardly be tolerated, particularly when raised, reflectorized markers systems are available that perform under these conditions. They are tolerated largely because of economic considerations. The developed system of formed-in-place markers has been shown to have acceptable performance characteristics, but, more importantly, it is a very low-cost system. Furthermore, this cost is subject to further reduction through the development by the highway departments and other potential users of commercial-sized, high-speed, automated application equipment and the use of fillers, extenders, and dilutents in the resin formulations.

The longer than desired set or cure time for the epoxy as encountered at different test sites was determined to be primarily related to low pavement temperatures. More rapidly setting resin-curing agent systems and higher preheat temperatures on the resins and curing agent offer advantages, but the basic problem of the mass relationships between the epoxy and the pavement is such that the pavement acts as a very large heat sink, which adversely affects the epoxy reaction which is both mass- and temperature-sensitive. After considering various methods to supply external heat to speed the setup time of the formed-in-place markers, microwave energy was singled out as having potential for this application. Initial experimentation was conducted with a microwave unit at the research agency, and later experiments were conducted in the Technical Service Laboratory of Varian Associates in Palo Alto, California. Although epoxy, portland cement concrete, and asphaltic concrete are all well suited for heating by microwave energy, it is difficult to couple the right amount of energy into both the epoxy and the pavement surface at the same time.

In view of these findings, this approach was set aside in favor of applying the microwave energy to the pavement before the epoxy was applied. It was found that 40 kilowatt-sec was sufficient to heat both portland cement concrete and asphaltic concrete from 70° to 197°F to a depth in excess of 2 in. For a 5-kilowatt unit at 2,450 megacycles, this would call for an exposure of 8 sec. Formed-in-place markers of Formula A composition applied to both types of pavements heated in such a way had a cure time of approximately 3 min. Furthermore, when the epoxy first encounters the hot pavement, it absorbs heat and loses viscosity on its bottom surface, greatly improving penetration and bonding to the pavement. The mass of the pavement being much greater than the epoxy, it continues to supply heat to the epoxy, accelerating the curing reaction fairly independently of the air temperature, thus providing a method for extending the temperature range at which the markers might be applied.

For commercial application, it is envisioned that an infrared detector would be used to sense the pavement temperature and control the amount of microwave energy to be directed to the spot where a formed-in-place marker will be applied. The cost of this energy in a truck-mounted unit is estimated to be between $0.001 and $0.002 per marker. Preheating of the pavement surface with microwave energy, the use of faster curing agents, plus preheating of the resin and catalyst, should further enhance the curing reaction. It should be possible to alter the State of California's new rapid set type epoxy adhesive (California State Specification 68-F-44) for use in preparation of formed-in-place markers. This formulation, like many of the faster-set resins, uses a polymercaptan curing agent rather than an amine-type curing agent. Because of variations in climatic conditions around the U.S., it is probable that curing agents specific to the different areas will ultimately be adopted.

The developed system can be looked on as one that complements the existing system of paint and beads. As such, consideration has been given to how best to integrate its equipment requirements with those of paint and beads. A typical paint striping machine has a large amount of equipment that is either identical or has very much in common with that required for applying the formed-in-place markers. Namely, it has the guiding mechanism, primemover, skip mechanism, air compressor, heating elements, and cone-laying capacity, thus suggesting direct integration of the formed-in-place marker dispensing equipment. This would offer substantial savings in capital costs as well as operational costs. The epoxy dispensing equipment is compact by nature and, on some of the more modern paint striping machines, there would appear to be sufficient room on the truck bed to mount the necessary equipment. On other paint striping units, it might be necessary to mount the formed-in-place marker dispensing equipment on a trailing sulky.

For those interested in converting from paint and beads to a system of non-reflectorized and reflectorized raised markers, the prototype machine developed on this project could be scaled up in size and speed so that it could automatically dispense, in sequence with the formed-in-place markers, any desired number of conventional, raised, non-reflectorized markers. If it is desired to construct a commercial machine to dispense only the formed-in-place markers, consideration should be given to several design changes. One engine should serve to drive the wire brush assembly, and the air compressor, and to propel the machine. Capacity of the epoxy-dispensing unit should be increased and automated in such a way that the machine would not be required to stop at each point of application. The wheels on the machine should be increased in size so that the machine can be driven or towed rather than trailered to location, as considerable work time is lost in unloading and loading a trailer-mounted machine. Location of the epoxy- and bead-dispensing equipment is an optional matter and these units can be side-mounted if desired.

In the field operation of the machine, the epoxy is discharged onto the pavement, the reflective materials are dropped into the epoxy, and the machine moves on to the next location. By the time the epoxy has assumed its final configuration, the beads have imbedded themselves, and the epoxy has set, the machine is several thousand feet down the road. Thus, it is to be expected that field crews will have to learn by experience to control the variables of temperature, viscosity, and pressure required to produce consistently well-formed markers.

Although the prototype application machine was designed and fabricated specifically for the purpose of applying the formed-in-place markers, many of the traffic engineers and other personnel, observing its use for the first time, often suggested the possibility of using the machine, with minor modifications, for applying commercially available raised markers which are largely hand-applied. They were particularly interested in the automated equipment for dispensing the epoxy, and related on numerous occasions the problems they were having with dermatitis on their crews who were working by hand with the epoxy. Others noted that they felt that many of their marker failures could be traced to improper hand mixing of the epoxy adhesive. Experience on this project would bear this out in that the machine-mixed epoxy was in every instance superior in uniformity and physical properties to that which was mixed by hand.

Epoxy resins are rapidly becoming a household item. For field personnel who are unfamiliar with these resins, it is good practice to have them work with a limited number of laboratory samples to become familiar with the general handling properties of the resin system; i.e., to experience the exotherm phenomena, the pot-like characteristics, the effect of temperature on viscosities, and to assess the other variables influencing the handling characteristics of the system. Many liquid epoxy resins and, more particularly, the curing agents used in industrial formulations, are primary skin irritants (*4*). For this reason, direct contact with the skin must be avoided by the use of vinyl plastic gloves, and one should avoid breathing of the vapors. Should contact occur, the contaminated areas should be washed immediately and thoroughly with soap and water or alcohol, but never with a solvent. One of the attractive features of the epoxy-dispensing equipment used on the prototype machine is the elimination of the need for physical contact with the resin, because all the functions are handled automatically. Once the resin is cured, it is no longer a skin irritant.

More than any other one thing, the formed-in-place marker concept is flexible. It may be used in conjunction with beaded paint, raised, non-reflectorized markers, and thermoplastics, or it may be used alone. The form of the markers need not be round and contain 19 beads, but may be adapted to the situation. How the concept can best be used will ultimately be determined by these who decide to try it and adapt it to their needs.

CHAPTER FIVE

CONCLUSIONS

It is concluded that:

1. The basic hardware, equipment, and procedures for applying formed-in-place, wet, reflective markers were successfully developed and field-tested.
2. Formed-in-place markers consisting of a pigmented epoxy base with 0.25-in.-diameter glass bead reflective elements were field-tested and found to perform exceptionally well in snow-free areas of the country.
3. In snowfall areas of the country, the 0.25-in.-diameter glass bead reflective elements in the formed-in-place markers were severely damaged by steel snowplow blades, studded tires, and chains.
4. The damage to the formed-in-place markers and other raised markers by snowplowing with steel blades can be overcome by the use of rubber-tipped snowplow blades.
5. The damage to the 0.25-in.-diameter glass bead reflective elements in the formed-in-place markers by studded tires and chains should be markedly reduced by the use of plastic beads.
6. The formed-in-place marker concept is a means of obtaining night-wet visibility on highways; this concept may be used alone or in conjunction with beaded paint, non-reflectorized, raised markers, and thermoplastic markings.
7. More consideration should be given by authorities to balancing their investment in pavement markings to provide day and night, dry and wet visibility.
8. The low cost of the formed-in-place, wet, reflective markers is such that their use should be considered at every location.
9. The formed-in-place, wet, reflective marker concept is in its infant stage and subject to further development that should improve performance and reduce costs.

CHAPTER SIX

SUGGESTED RESEARCH

It is recommended that future attention be given to the following points:

1. The development of equipment and procedures for rating the retroreflective characteristics of all types of raised, reflectorized markers.
2. The development of epoxy resin systems that cure more rapidly and at lower temperatures.
3. The optimization of the use of fillers, extenders, and diluents in the epoxy resin system used in the formed-in-place markers.
4. The development of 0.25-in.-diameter acrylic beads for use in the formed-in-place markers.
5. The development of reflective elements other than 0.25-in. glass beads for use in the formed-in-place raised markers.
6. The development of economic comparisons between marking materials on the basis of cost per mile per day of useful life per unit of viewing motorist. New marking materials and systems, unlike older systems, no longer have useful lives that relate directly to the traffic density.
7. The development of a field application unit for applying microwave energy to the pavement surface where formed-in-place markers as well as other types of raised markers are to be applied.

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1. CHAIKEN, BERNARD, "Comparison of Performance and Economy of Hot-Extruded Thermoplastic Highway Striping Materials and Conventional Paint Striping." *Pub. Roads,* 35 (Feb. 6, 1969).
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3. ROONEY, H. A., and SHELLY, T. L., "Development and Evaluation of Raised Traffic Lane Markers 1953-1968." *Res. Report M&R No. 635152,* California Division of Highways (June 1968).
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APPENDIX A

BINDER FORMULATIONS EXAMINED IN FIELD TESTS ON RESEARCH AGENCY ROADS

FORMULATION NO.	FORMULATION (PARTS BY WT.)	MATERIAL
1	100	Shell Epon 828 Resin
	100	TiO_2
	25	Shell Curing Agent U
2	100	Shell Epon 828 Resin
	65	TiO_2
	25	Shell Curing Agent 2000
3	100	Shell Epon 826 Resin
	50	TiO_2
	12	Thixtrol ST
	5	DMP 30 Rohm & Haas
	54	Curing Agent V-25
4	100	Shell Epon 826 Resin
	25	TiO_2
	33	Talc
	5	DMP 30 Rohm & Haas
	35	Curing Agent V-40
5	100	Shell Epon 826 Resin
	50	TiO_2
	20	Thixtrol ST
	3	DMP 30 Rohm & Haas
	4	Pennsalt S1
	45	Curing Agent V-25
6	100	Cel Chemical A
	10	Hardener B
	1	M5 Cab-O-Sil
7	100	Shell Epon 815 Resin
	30	TiO_2
	3	M5 Cab-O-Sil
	50	Reichold 611 Curing Agent
	24	Reichold 610 Curing Agent

APPENDIX B

RESEARCH AGENCY MACHINE DRAWINGS OF PAVEMENT MARKER APPLICATION UNIT

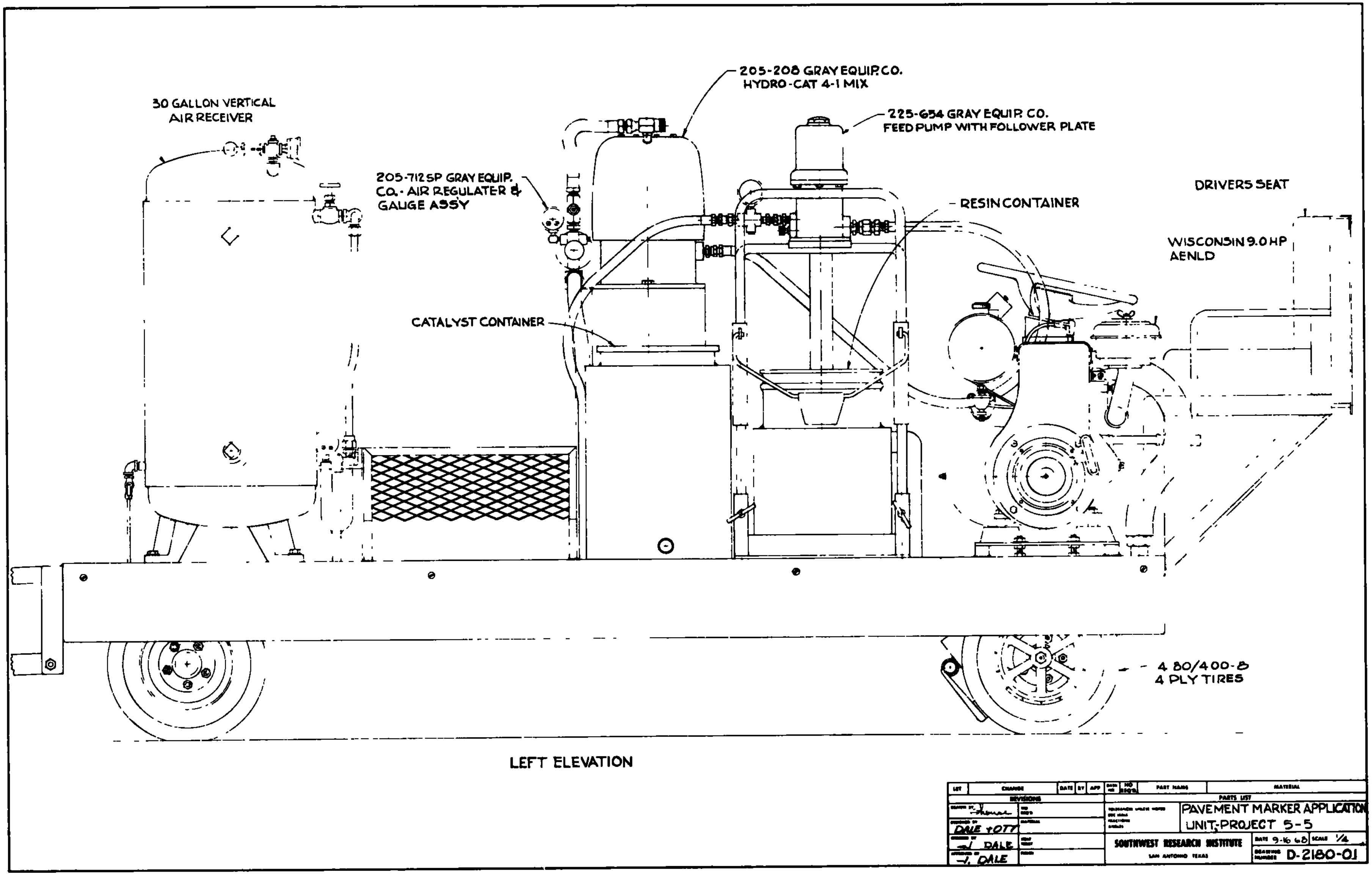
205-208 GRAY EQUIP. CO.
HYDRO-CAT 4-1 MIX
30 GALLON VERTICAL
AIR RECEIVER
225-654 GRAY EQUIP. CO.
FEED PUMP WITH FOLLOWER PLATE
205-712SP GRAY EQUIP.
CO.- AIR REGULATER &
GAUGE ASSY
RESIN CONTAINER
DRIVERS SEAT
WISCONSIN 9.0 HP
AENLD
CATALYST CONTAINER
4 80/400-8
4 PLY TIRES
LEFT ELEVATION
PAVEMENT MARKER APPLICATION
UNIT, PROJECT 5-5
SOUTHWEST RESEARCH INSTITUTE
SAN ANTONIO TEXAS
DATE 9-16-68
SCALE 1/4
D-2180-01
DALE + OTT
DALE
DALE

Figure B-1.

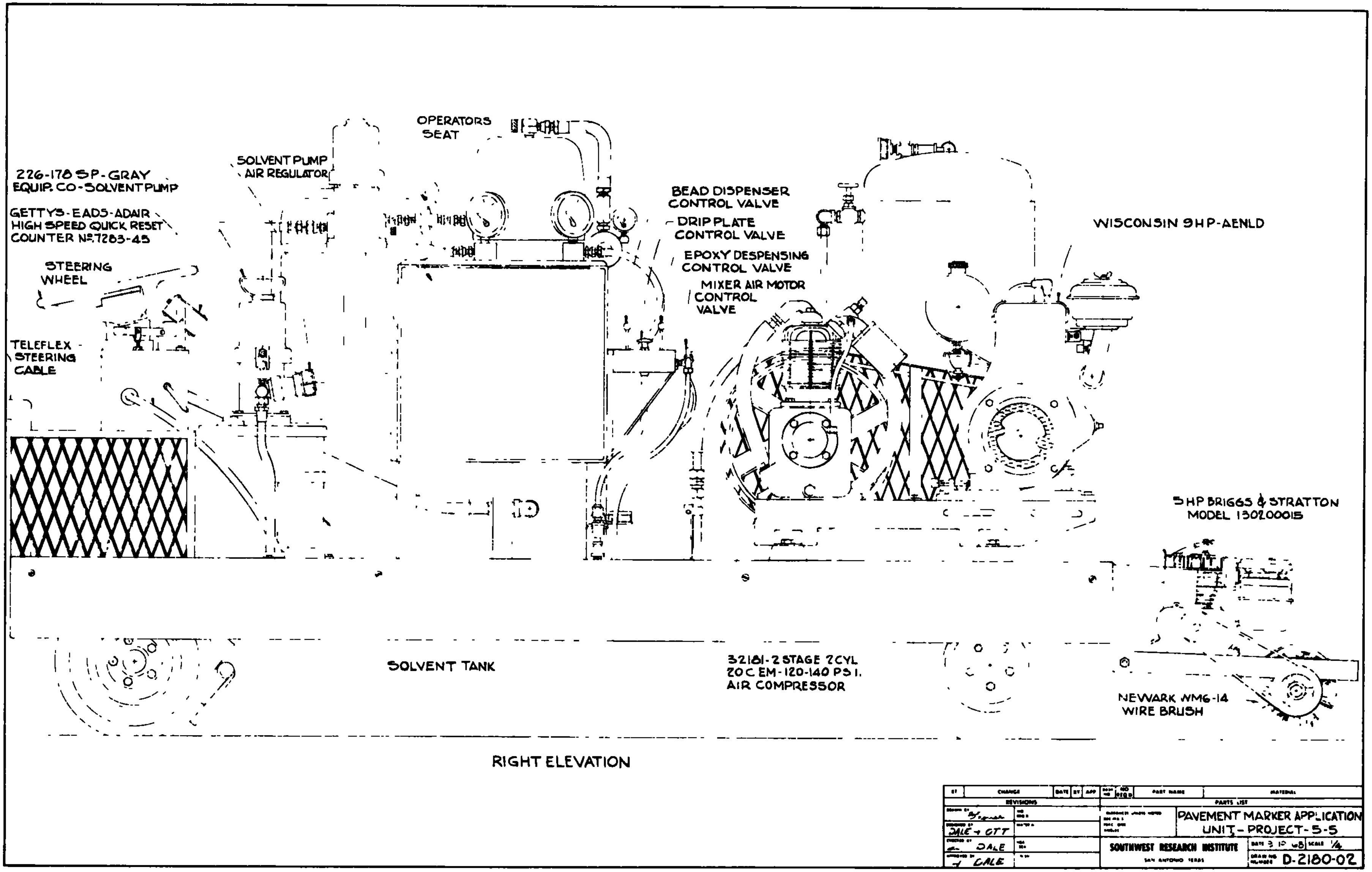
OPERATORS SEAT
SOLVENT PUMP AIR REGULATOR
226-178 SP-GRAY EQUIP. CO-SOLVENT PUMP
GETTYS-EADS-ADAIR HIGH SPEED QUICK RESET COUNTER Nº 7283-45
STEERING WHEEL
TELEFLEX STEERING CABLE
BEAD DISPENSER CONTROL VALVE
DRIP PLATE CONTROL VALVE
EPOXY DESPENSING CONTROL VALVE
MIXER AIR MOTOR CONTROL VALVE
WISCONSIN 9HP-AENLD
5HP BRIGGS & STRATTON MODEL 130200015
SOLVENT TANK
32181-2 STAGE 2CYL 20C EM-120-140 PSI. AIR COMPRESSOR
NEWARK WM6-14 WIRE BRUSH
RIGHT ELEVATION
PARTS LIST
PAVEMENT MARKER APPLICATION UNIT - PROJECT-5-5
SOUTHWEST RESEARCH INSTITUTE
SAN ANTONIO TEXAS
DALE + OTT
DALE
DALE
DATE 3 10 68
SCALE 1/4
D-2180-02

Figure B-2.

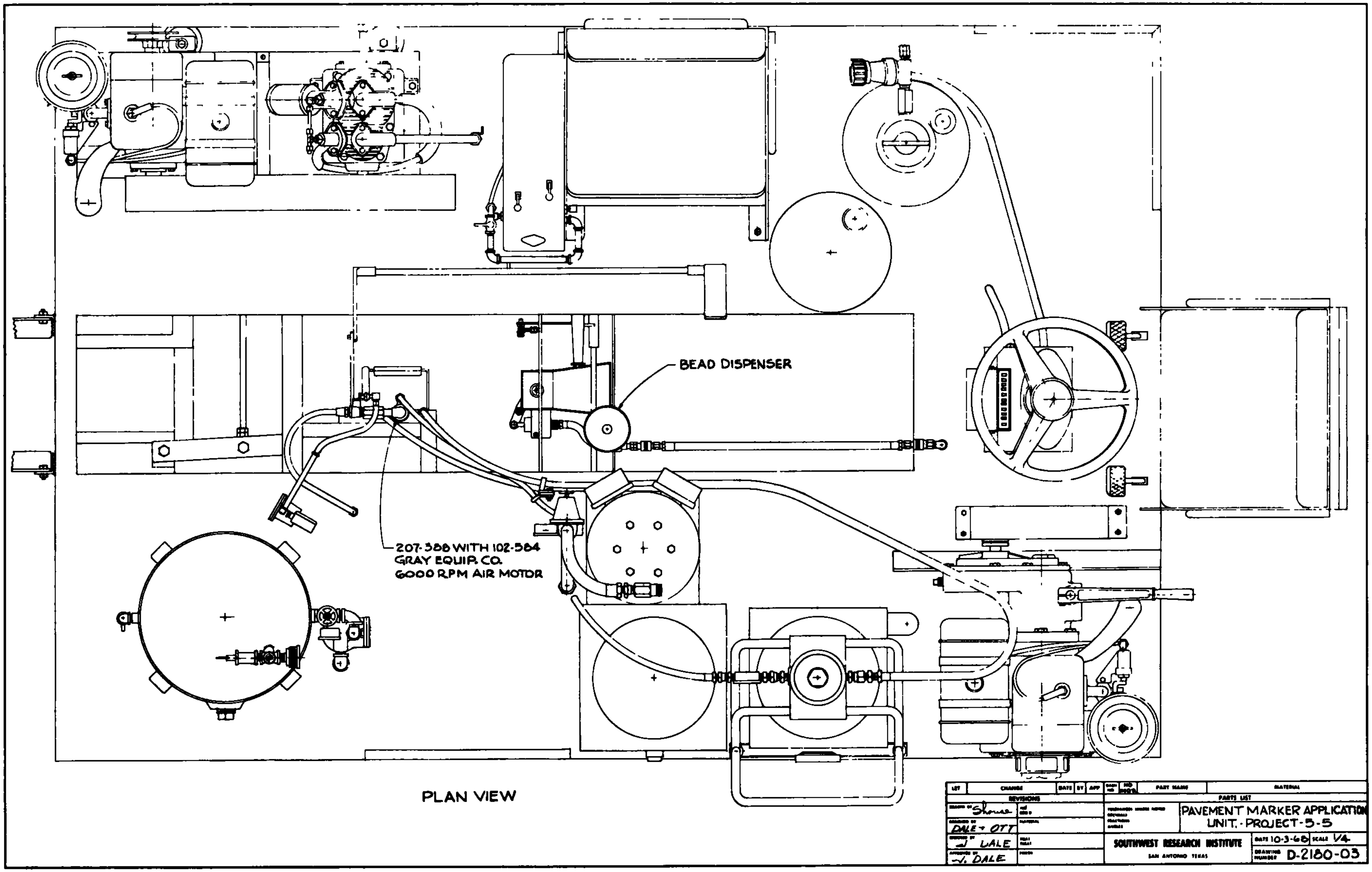
BEAD DISPENSER
207-388 WITH 102-584
GRAY EQUIP. CO.
6000 RPM AIR MOTOR
PLAN VIEW
CHANGE
DATE
BY
APP
PART NAME
MATERIAL
REVISIONS
PARTS LIST
Shouse
DALE + OTT
DALE
DALE
PAVEMENT MARKER APPLICATION
UNIT. - PROJECT - 5 - 5
SOUTHWEST RESEARCH INSTITUTE
SAN ANTONIO TEXAS
DATE 10-3-68
SCALE 1/4
DRAWING NUMBER D-2180-03

Figure B-3.

APPENDIX C

FIELD NOTES ON TEST SITES

The following field notes on the test sites have been condensed. The key to their presentation is as follows:

Authority/Location of test site/Date of application/Local authority personnel in attendance/Type of traffic/Direction of traffic/Traffic density/Pavement surface/Traffic speed/Temperature/Relative humidity/Wind speed/Setup time for epoxy/Footage marked/Marking pattern/Epoxy formula/Type of beads/Amount of snowplowing/Exposure to studded tires and chains/Monitored by.

TEST SITE NO. 1

City of San Antonio, Texas/West Commerce between Southwest Research Institute entrance and Pinn Road/June 13, 1968/Pat Carroll and John Miller, City of San Antonio/Rural/Bidirectional/2,000 ADT/Asphaltic concrete/50 mph/95°F/30%/8 mph/15 min/4,320 ft/1 marker every 40 ft in center of skip/Formula A/3M-No. 700 Coating/No snowplowing/No studded tires or chains/W. J. Lindsay, BPR.

Comments on Application

Application conditions ideal. Placed warning cones directly over markers.

Performance Over Year

There was no loss of markers and less than 1% lost or shattered beads. In November 1968, a portion of the markers was inadvertently painted over by a striping crew with an alkyd-base traffic marking paint. This paint quickly wore off the exposed portion of the glass beads and the markers again became reflective.

Final Comments

The high-intensity, 3M-No. 722 coated beads were not available at the time this test was applied. Their use would have enhanced the visual performance of this site.

TEST SITE NO. 2

Texas State Highway Dept./Interstate 410, Northbound Lane between intersection of West Commerce and Culebra Road, San Antonio, Texas/June 20, 1968/L. E. Youngblood, Dist. 15 Maint. Engr.; Tim Mercer, Safety Eng., TSHD; H. L. Hawkins, Maint. Div., Austin; all of TSHD/Urban/Unidirectional/16,000 ADT/Asphaltic concrete and portland cement concrete/70 mph/80°F/90%/Variable/40 min/2,800 ft/1 marker every 40 ft in center of skip/Formula A/3M-No. 709 Coating/No snowplowing/No studded tires or chains/W. J. Lindsay, BPR.

Comments on Application

Had to delay application from morning to afternoon because of wet pavement. Had to discontinue application after 2,800 ft because of approaching thunderstorm.

Performance Over Year

One marker was lost on the portland cement concrete pavement due to a structural failure in the concrete. One-half of one marker on the asphaltic concrete had been removed as a souvenir. The remaining markers were all in good physical condition, with only 2.4% lost or damaged beads.

Final Comments

The high-intensity, 3M-No. 722 coated beads were not available at the time this test was applied. Their use would have enhanced the visual performance of this site.

TEST SITE NO. 3

California Division of Highways/Highway 80, Pavement Marking Test Site, Sacramento, Cal./July 1, 1968/Frank Norris, Thomas Shelly, and John Beaton, all of CDH/Urban/Unidirectional/20,000 ADT/Portland cement concrete/65 mph/92°F/25%/5 mph/60 min/2,208 ft/1 marker every 24 ft/Formula A/3M-No. 709 Coating/No snowplowing/No studded tires/BPR.

Comments on Application

Protective truck destroyed three markers by running over them while wet.

Performance Over Year

There was no loss of markers and 3.9% lost or shattered beads. One marker was purposely removed for laboratory inspection.

Final Comments

The high-intensity, 3M-No. 722 coated beads were not available at the time this test was applied. Their use would have enhanced the visual performance of this site.

TEST SITE NO. 4

Oregon State Highway Dept./Highway 22 East, Salem, Oregon/July 3, 1968/Roger Trygstad, and Raymond Asburry, both of OSHD/Rural/Unidirectional/2,500 ADT/Asphaltic concrete/70 mph/84°F/40%/2 mph/60 min/

3,160 ft/1 marker every 40 ft/Formula A/3M-No. 709 Coating/Heavy snowplowing, rubber blade/Studded tires and chains/J. J. Hegmann, BPR.

Comments on Application

Road surface rough-textured and test site on steep grade.

Performance Over Year

Performance was good up to first snowfall. The first three plowing operations were conducted with a rubber snowplow blade, but due to unusual heavy snowfall, extra equipment had to be called in and resulted in site being plowed 7 times with steel snowplow blade. All markers intact. Five markers partially damaged. 98% of the beads destroyed. Several other types of commercial raised reflective markers applied in same area experienced severe damage, all of them being sheared off at their bases.

Final Comments

The high-intensity, 3M-No. 722 coated beads were not available at the time this test was applied. Their use would have enhanced the visual performance of this site. The daytime visibility of these markers was excellent in that there was excellent contrast between the marker and the dark-aggregate asphaltic concrete.

TEST SITE NO. 5

Washington State Highway Dept./Highway 101 North, Black Lake Interchange at Percival Creek/July 8, 1968/ Draker, Kerslake, Gallagher, and Deaver, all of WSHD/ Rural/Unidirectional/4,000 ADT/Asphaltic concrete/65 mph/83°F/40%/3 mph/60 min/1,800 ft/1 marker every 40 ft/Formula A/3M-No. 709 Coating/Snowplowing/ Studded tires and chains/BPR.

Comments on Application

Placed markers down over old paint.

Performance Over Year

Mr. Draker drove the test site daily to his home and reported that the markers were performing well, until snowplowing with steel blades began. Heavy snow fell over the winter at the test site and the location was plowed with steel blades more than 30 times. Nine markers were completely removed, 24 markers were partially (30%) removed. In the remaining markers, all of the glass beads had been destroyed.

Final Comments

The high-intensity, 3M-No. 722 coated beads were not available at the time this test was applied. Their use would have enhanced the visual performance of this site, until snowplowing with steel blades was begun. The test site was adjacent to Interstate 5, which runs from Portland to Seattle, and in an area where steel blades were used exclusively. Yet, Interstate 5 is completely marked with raised, nonflectorized markers complemented by raised reflectorized markers which were plowed with rubber blades and survived the winter in excellent condition, clearly demonstrating the practical aspects of using rubber plow blades with raised markers. Placing raised markers down over old paint is a bad practice and should be avoided where possible.

TEST SITE NO. 6

Wyoming State Highway Dept./East Lincoln Way/July 11, 1968/George Dale, WSHD/Urban/Bidirectional/17,000 ADT/Asphaltic concrete/45 mph/80°F/50%/5 mph/80 min/3,120 ft/78 groups of 6 markers—total 465 markers/ Formula A/3M-No. 709 Coating/Snowplowing/Studded tires and chains/BPR.

Comments on Application

Severe thunderstorm occurred at completion of test. Mr. Dale tested strength of markers with ball peen hammer. Because of rain, markers were reflective the night they were applied.

Performance Over Year

Between October and May, Cheyenne received 24.6 in. of snow, but it fell in increments of 2 in. or less. Mr. Dale reported that, beginning in November, visibility of the markers began to decline rapidly. On final inspection, all of the markers were intact, but 100% of the beads had been shattered or lost. The test site was plowed with a steel blade only once, but it was kept above the markers. Bead loss at this site was strictly a result of studded tires and chains.

Final Comments

The high-intensity, 3M-No. 722 coated beads were not available at the time this test was applied. Their use would have enhanced the visual performance of this site. During the period of this test, some commercial, raised markers with acrylic lenses were located adjacent to the formed-in-place markers and survived the winter with the acrylic lenses only moderately scratched but still performing well. The conclusion is inescapable—the beads should be acrylic rather than glass for a location like this.

TEST SITE NO. 7

Missouri State Highway Dept./Highway No. 71 North between 95th Street and Interstate 435, Kansas City, Mo./ July 23, 1968/R. N. Hunter, Roy Rucker, Lionel Murray, and George Satterlee, all of MSHD/Urban/Unidirectional/ 25,000 ADT/Portland cement concrete/70 mph/85°F/ 95%/Variable/120 min/2,500 ft/1 marker every 40 ft in center of skip/Formula A/3M-No. 722 Coating/Snowplowing with rubber blade/Studded tires and chains/ J. A. Thompson, BPR.

Comments on Application

Rain prior to application—surface visibly dry when applied. Light drizzle began 10 min after application completed. Some markers applied over old paint. Some markers applied over primer.

Performance Over Year

8% of markers lost; with the exception of two markers, all those markers that were lost were either applied over old paint or pavement primer. 100% of the beads were lost or shattered. Site snowplowed 8 times with rubber blade.

Final Comments

This site was plowed with rubber blade, and the 100% bead loss is thereby attributed to the use of traction devices such as studded tires and chains.

TEST SITE NO. 8

Connecticut Highway Dept./Highway 84 East, E. Hartford, Conn./July 30, 1968/J. P. Catalano, CSHD/Urban/Unidirectional/35,000 ADT/Portland cement concrete/55 mph/84°F/46%/Variable/80 min/5,400 ft/1 marker every 120 ft on straightaway and 80 ft on curve/Formula A/3M-722 coating/Snowplowing/Studded tires and chains/BPR.

Comments on Application

Application discontinued because of extreme heavy traffic. Traffic density at this site so heavy that counters do not record properly.

Performance Over Year

It was found that 72% of the markers were lost and 100% of the beads were lost or shattered. Site plowed 6 times with steel blade.

Final Comments

More severe traffic conditions encountered here than at any of the other test sites.

TEST SITE NO. 9

New Jersey State Highway Dept./U.S. Route 1, South Trenton, N.J./August 1, 1968/Goulding, Watson, Dill, and Cunningham, all of NJSHD/Urban/Unidirectional/20,000 ADT/Portland cement concrete/50 mph/85°F/85%/10-20 mph/60 min/10,800 ft/1 marker every 40 ft/Formula A/3M-No. 722 Coating/Snowplowing/Studded tires and chains/D. W. Gwynn, BPR.

Comments on Application

Epoxy too thin—beads were not properly embedded.

Performance Over Year

10% of the markers were lost over the year and 100% of the beads were lost or shattered. Site was plowed with a steel blade 6 times.

Final Comments

Other than traffic, the environmental conditions here and in Connecticut were much the same, except that many more markers were placed at this site than in Connecticut.

TEST SITE NO. 10

North Carolina State Highway Dept./U.S. 70-41-1 Business, between Wade Ave. and Peace Street, Raleigh, N.C./August 5, 1968/W. Warrick, Jr./Urban/Unidirectional/22,000 ADT/Portland cement concrete/45 mph/85°F/60 min/3,280 ft/1 marker every 40 ft/Formula A/3M-No. 722 Coating/Snowplowing/Studded tires and chains/Harold Rhudy, R. L. Walden.

Comments on Application

Epoxy got too hot. Epoxy flowed out excessively and proper bead embedment was not achieved.

Performance Over Year

There was less than 1% loss of markers over the year, but 99% of the beads were lost or shattered. The bulk of the bead loss was due to improper bead embedment on application.

Final Comments

The loss of beads at this site is attributed to operation error and lack of experience in handling an upset condition that occurred with the application machine at the time of application.

TEST SITE NO. 11

Florida State Highway Dept./Highway 27 North, Section 55010, Tallahassee, Fla./August 9 1968/Hunter and Mickler, both of FSHD/Urban/Bidirectional/20,000 ADT/Asphaltic concrete/70 mph/85°F/60%/Variable/60 min/3440 ft/1 marker every 40 ft/Formula A/3M-No. 722 Coating/No snowplowing/No studded tires or chains/Mickler, FSHD.

Comments on Application

Placed 6 markers down over old paint. Viscosity of epoxy too low at time of application.

Performance Over Year

Of the 6 markers applied over old paint, half of one marker was missing. All other markers at test site were in good physical condition, with the exception that 18% of the beads were shattered or missing. There was a slight frosting on the surface of some of the remaining beads.

Final Comments

The bead loss of 18% at this site can largely be attributed to the low viscosity of the epoxy at the time of application which did not embed all beads properly above their horizontal axes.

APPENDIX D

COMPOSITION AND RAW MATERIAL COST OF FORMED-IN-PLACE MARKERS

WT./ MARKER (GRAM)	MATERIAL	SUPPLIER	RAW MATERIAL COST ($/LB)	APPROXIMATE COST ($/MARKER) WITH UNCOATED BEADS	COATED BEADS
28.0	Epon 828 Resin	Shell Chemical	0.49	0.0302	0.0302
28.0	RCHT Pigment	Titanium Pigment Corp.	0.09	0.0055	0.0055
7.0	Curing Agent U	Shell Chemical	0.80	0.0123	0.0123
7.0	19 0.25-in. beads	Corning Glass	1.25	0.0193	—
	19 0.25-in. coated beads	The 3M Co.	3.75[a]	—	0.0580
70.0				0.0673	0.1060

[a] Experimental product by The 3M Co. Commercial cost not available from The 3M Co.; estimated by the research agency.

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