NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM REPORT 45

DEVELOPMENT OF IMPROVED PAVEMENT MARKING MATERIALS

LABORATORY PHASE

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

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DEVELOPMENT OF IMPROVED PAVEMENT MARKING MATERIALS
LABORATORY PHASE

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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.

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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. This laboratory and field investigation presents an evaluation of pavement marking materials currently in use and a discussion of their shortcomings. Practical recommendations are made for the improved design of economical markings that would be more visible than conventional markings, both day and night. Special emphasis is given to the visibility of markings at night during periods of severe rainfall and a new, unique, low-cost, experimental marking has been developed and tested on a public highway. The newly conceived marker's ability to be visible at night when wet was judged excellent; furthermore, the low-profile marker is not likely to be damaged by snowplows. 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 the initial laboratory phase are presented herein. The results of the field testing phase will be presented in a future NCHRP report.

Present reflectorized highway paint markings lose their effectiveness to a marked degree during periods of darkness in adverse weather. However, during these periods the need for guidance is most critical and ease of driving and highway safety will be improved when the effectiveness of pavement delineation under adverse weather conditions approaches the effectiveness provided under normal conditions. With these thoughts in mind the research was initiated to seek ways of improving delineation of roadways under wet and dry conditions by improving techniques utilizing existing materials or by developing new materials and techniques.

Southwest Research Institute, in this thorough and well-documented effort, initiated a field study of the performance characteristics of conventional marking materials. Following this, their researchers conducted studies of the physical nature of reflective materials, with particular emphasis on performance characteristics under various types of water films. Based on the results of the laboratory and field tests a new pavement marking was designed and tested with very encouraging results. A systematic approach for the design of a pavement marking system has been developed wherein one qualifies the surface to be marked, determines the water film thickness to be encountered, and then selects one of the several marking systems that will perform under the imposed conditions.

The research points out that where pavement markings fail by mechanisms other than loss of their upper surface, a glass bead system having a uniform size gradation matched to the binder thickness should be used. Experiments have been conducted to determine the effectiveness of silicone-treated glass beads and the optimum depth of imbedment for glass beads to obtain maximum retroreflection. The feasibility of applying a surface coating of small beads to a carrier (pea-gravel) was investigated as a way to obtain a large-diameter reflecting material that would protrude through submerging water films.

After considering the factors that influence the performance of marking materials the researchers developed a new system of pavement markings that could be applied like paint but performs like raised reflectorized markers. In this system ¼-in. diameter glass beads are embedded in a pigmented epoxy binder.

The second phase of the research is under way to further develop and field test the new marking system that emerged from the initial laboratory research. The objective of the additional research is to optimize the application equipment, materials, and techniques necessary to demonstrate the practical feasibility of the new marking system.

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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 Allen C. Ludwig, Elgin O. Ott, and William T. Clayton.

The author is indebted to the Texas State Highway Department, the Los Angeles County Road Department, and J. E. Bauer Company, and gratefully acknowledges sample quantities of reflective materials contributed by the Cataphote Corporation; Corning Glass Works; Elastic Stop Nut Corporation; Ferro Corporation; Flex-O-Lite Manufacturing Corporation; Marbon Chemical Division of Borg-Warner Corporation; Minnesota Mining and Manufacturing Company; Potter Brothers Glass Company; Prismo Safety Corporation; Reflecting Roadstuds, Ltd.; Rupert Manufacturing Company; and Traffic Standard, Inc.

DEVELOPMENT OF IMPROVED PAVEMENT MARKING MATERIALS

LABORATORY PHASE

SUMMARY The information contained in this report will enable agencies responsible for highway pavement delineation to better understand the many variables that influence the performance of marking systems both in the day and night and particularly at night during periods of precipitation when many of the currently used marking systems become inoperative.

Beyond explaining how various marking systems work and their advantages and limitations, a systematic approach to decision making with regard to the marking of pavements has been developed, and a form is presented wherein engineers can select systems that will give day and night, dry and wet visibility at the lowest cost per mile per day of useful life. To do this, the engineer obtains a profile of the surface to be marked, qualifies the water-film thicknesses to be encountered during periods of precipitation, and then selects the marking system that will perform under the imposed conditions. Information in this report should be of use to engineers in designing new and improved systems. As an example, one such system is cited in this report and is documented through its initial field evaluations. The concept involves incorporating into one system the ability to be applied like paint and yet perform like raised, reflectorized markers as a means of combating the visibility problem of markings during periods of darkness and precipitation.

It is suggested that further research be conducted to investigate the development of heavier and more durable marking materials. Considerable attention should be directed to the study of raised markers in terms of their present and future use, both separately and in conjunction with surface-film markings and their relation to snow removal operations from the standpoint of determining if the marking system should be designed to accommodate the snow removal equipment or if the snow removal equipment should be designed to accommodate the marking system or if there is a compromise solution.

CHAPTER ONE

INTRODUCTION AND RESEARCH APPROACH

Commonly used pavement marking materials lose their effectiveness to a marked degree during periods of darkness in adverse weather. A driver's need for guidance is most critical during these periods, and driving ease and highway safety will be enhanced when the effectiveness of pavement delineation under adverse weather conditions approaches the effectiveness provided under normal conditions. The objective of this program was to study ways of improving delineation of roadways under wet and dry conditions by either improving techniques that use existing materials or developing new materials and techniques.

Pavement markings are but one facet of a complex set of interrelated factors that influence the visual problems of the motorist at night. Illumination, contrast, placement, size of object, shape, brightness, and time of exposure are but a few of these factors. If one could redesign the automobiles, changing the location of the driver and headlights, convert to a polarized light system, redesign the roadway and include self-illuminated markings plus various other changes, some rather dramatic visual improvements would result. However, such a long-range approach would do little to combat today's problems. In spite of certain limitations, the present system of marking roadways using surface markings that have been reflectorized has the advantage, under favorable conditions, of conveying a steady stream of uninterrupted visual information or warnings to the driver without diverting his attention from the roadway.

In the modern automobile the headlights, which may be only 26 in. above the road surface, provide the source of illumination. This illumination diminishes in intensity as the distance from the source increases, so that maximum safe operating speeds on low and high beams are considered to be approximately 30 and 55 mph, respectively, with perception distances for unmarked dark objects considered to be of the order of approximately 100 and 350 ft, respectively. Assuming a level pavement, a ray of light from a typical automobile strikes the pavement at an angle of 1 deg 14 min with the horizontal 100 ft in advance of the vehicle. This angle becomes progressively smaller and finally narrows to 0 deg 21 min at a distance of 350 ft. The light striking the surface of the road ahead of the vehicle is largely reflected forward or absorbed by the road surface itself. For the light striking the pavement marking to be directed back to the driver's eyes and present a clearly visible image, an optical focusing device is required. Most commonly used are small glass beads or spheres imbedded in the pavement marking material which focus and return the light to the vicinity of its source with varying efficiency, depending on a number of variables, including refractive index, true spherical shape, imperfections, and other variations in the beads themselves. Not all of the light striking a given bead will be reflected off its surface. That light which penetrates the bead and is refracted, focused, and redirected back to the driver suffers losses from absorption and scatter. Depending upon the road contour and during ideal dry weather conditions, pavement marking materials with glass beads properly applied can be very easily distinguished at night with high-beam headlights well beyond 350 ft, where there is no opposing traffic. The glare from the headlights of approaching vehicles and other light sources can very often be so intense as to limit a driver's ability to distinguish reflectorized markings for short periods to those directly in front of his vehicle.

During periods of adverse weather, the small glass beads often become submerged under a covering layer of water. Light from the drivers' headlights is largely reflected off the water surface and lost, and the small amount of light that penetrates the water suffers further losses to reflection, refraction, absorption, and scatter in its passage in and out through these various media. Thus, the retroreflective capabilities of currently used highway markings are generally lost during adverse weather, which greatly impairs the safety of the motorist during the period when his need for visual assistance is greatest.

RESEARCH APPROACH

The approach used to fulfill the study goals was to gather information with regard to how presently used marking systems perform in their environment and, within this framework, to determine techniques for improving present systems and, hopefully, to conceive other improved systems. It is pointed out that the emphasis in this program was placed on measurements and observations in the field under actual and simulated conditions rather than on the theoretical treatment of ideal systems.

Data Collection

In obtaining the information presented in this study, an extensive effort was made to get from manufacturers the best of currently available materials used for marking and reflectorizing highway pavements. Excellent response was received from the principal manufacturers as listed in the Acknowledgments. Their materials were placed in field road tests and evaluated, not from the standpoint of comparing one manufacturer's product with another but of observing the basic performance advantages and limitations of the different systems. Concurrent with the field evaluations of available marking systems, other field and laboratory studies were undertaken to more accurately define how glass beads function as retroreflective elements in highway marking materials and to qualify water-film thicknesses as encountered on roadways during periods of precipitation. This work is presented and discussed in Chapter Two.

Interpretation

The analysis of the work was undertaken by comparing data on water-film thicknesses obtained both in the laboratory and in the field with data pertaining to the performance characteristics of reflecting materials as determined in the laboratory and, finally, comparing all of these data with those pertaining to performance characteristics of present systems as observed in the field. It was then possible to make observations with regard to the basic advantages and limitations of present systems as well as to suggest methods of improving present systems. Results of this work are presented and discussed in Chapter Three.

Application

It was hopefully anticipated that during the course of this project some concept of a new and potentially improved system would evolve. Such a system did emerge, was taken into preliminary field evaluations, and appears to be an attractive concept within the limits that could be pursued in the final phase of this program. This work is presented and discussed in Chapter Four.

CHAPTER TWO

RESEARCH FINDINGS

This chapter is divided into three parts and contains the principal findings of the study. The first part covers field evaluations of conventional marking materials, describes how the field evaluations were conducted, and discusses the performance of conventional materials. The second part is devoted to the subject of precipitation and discusses its forms, characteristics, and the measurement of water-film depths on road surfaces. In the third part, the physical and retroreflective characteristics of glass beads are discussed.

FIELD EVALUATIONS OF CONVENTIONAL MARKING MATERIALS

Field evaluations of conventional materials were undertaken not to evaluate or rate the effectiveness of various manufacturers' products, but rather to examine the latest available commercial materials with regard to their general effectiveness and to help define in more specific terms the principal problem area of loss of visibility of marking materials during periods of precipitation.

Test Equipment

Paint stripes and reflective materials were applied with a Kelly-Creswell Model B–3–P, all-purpose striping machine. Special attention was given to handling the reflective materials. In addition to the use of a conventional gravity-feed, bead-dispensing apparatus, a chain-driven, proportioning-type bead dispenser was installed to provide precise control of bead application rates.

A water-spray device consisting of five nozzles was designed and fabricated to simulate rainfall over the entire length of a 15-ft painted segment of a broken line, commonly used as a standard for center and lane lines. The spray device combined the better features of similar devices used by General Motors Corporation and the U.S. Corps of Engineers, Fort Belvoir, Va., to simulate wet weather conditions. Nozzle Model Numbers 1/3GG2, 1/8GG3, 1/8GG3.5, 1/8G5, and 1/2G25 were purchased from the Spraying Systems Company, Bellwood, Ill. These nozzles are the full-cone type and provide a spray with an even distribution pattern. Flow rates were controlled by selection of nozzle size and water pressure. Rates of precipitation were further checked by placing conventional rain gauges at various points within the fall pattern.

In view of the dramatic difference between the wet and dry retroreflective capabilities of conventional marking materials and the lack of an industrially accepted measuring device, diversion of project funds to develop an optical instrument was not considered appropriate. After reviewing manufacturers' reports and car registration data, a 1965 Chevrolet was selected as the typical new car to be simulated. Thus, 1965 Chevrolet headlamps were installed on a plywood dummy, with careful attention given to dimensional locations on the dummy. A dimmer switch was installed for evaluations on both low and high beam, and an ammeter was installed in the circuit as a means of monitoring output. The power source was a 12-v battery which was kept fully charged by a portable d.c. generator. After installation, the headlamps were aligned with a Weaver photoscope headlight tester. Figure 1 is a photograph of these three pieces of equipment.

Materials Acquisition and Field Application

At the beginning of the project, letters were sent to manufacturers of reflective materials advising them of Southwest Research Institute's having been awarded the subject contract and of its interest in obtaining samples of their materials for study. Excellent and generous response was received from these inquiries, and a large number of samples were obtained representing, after elimination of duplicating products, some 9 different types of glass beads and some 18 different types of raised markers of both the reflectorized and unreflectorized type. These materials were taken to the test site and applied in accordance with the manufacturers' recommendations when received and otherwise by the best techniques available. The site selected for initial screening studies was on Southwest Research Institute grounds at a remote area with little traffic and free of foreign light sources at night. The pavement surface was a new, well-contoured, smooth asphaltic concrete, free of cracks, holes, and patches.

The paint was applied in stripes 4 in. wide and 15 ft long and set on 1-ft centers. The paint stripes were applied in groups of five, each group having a wet film thickness of 10, 15, 20, 25, and 30 mils, respectively. All groups received the same type of beads, which were dropped on at a rate of 6 lb per gal of paint, based on an assumed wet film thickness of 15 mils. One group of stripes was left unbeaded to serve as a control. The paint stripes and beads were applied with the striping machine. After application, the stripes were kept free of all traffic until they were completely dry. Four of each of the different types of raised markers were applied as a unit, equally spaced over a 15-ft length.

Evaluation Ratings of Marking Materials

ON SPRING APPLICATION

In the various model codes for evaluating highway marking materials, the three basic performance factors of appearance, reflectance, and durability are evaluated. In this initial phase of the study, attention was concerned

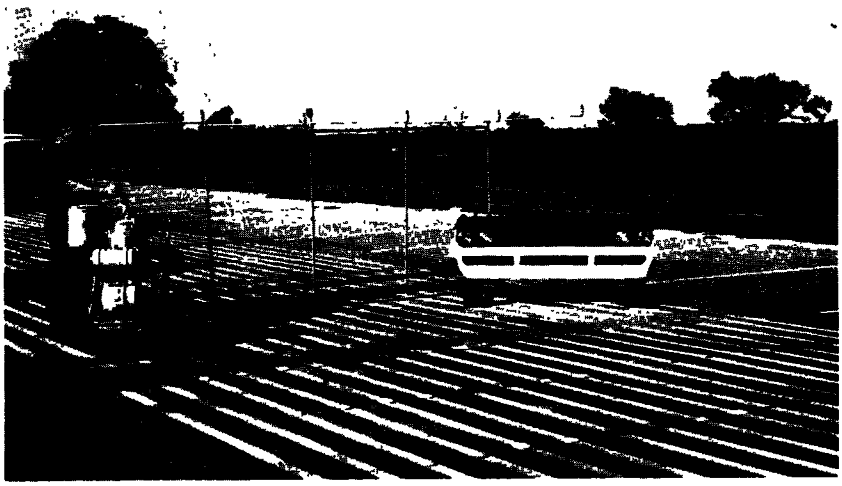


Figure 1. Equipment used in field evaluations of pavement marking materials.

primarily with reflectance, particularly during adverse weather. The materials were applied during the week beginning May 24, 1965, and evaluated in daylight and darkness under the wet and dry conditions. Night observations were made from a distance of 150 ft, with the lighting apparatus turned to either low or high with the beams focused longitudinally on the stripes, just as a driver would encounter a broken center or lane line. Selected observers rated reflectance visually with a rating scale from 0 to 10, with 0 indicating nonperformance and 10 indicating best performance.

Of the 65 paint stripes evaluated at night, all except 5 of the control stripes, which were unbeaded, and 3 stripes with special bead-coated granules were readily visible when dry. Visibility of the stripes dry improved as a direct function of the refractive index of the glass beads, those having a refractive index of 1.9 being considerably more reflective than those with a refractive index of 1.5. Under wet conditions at night, 60 of the 65 stripes were obliterated when subjected to a simulated rainfall of 4 in. per hr. Of the five stripes that reflected under simulated rainfall, two were of a tape-striping material and the other three had received an application of special bead-coated granules that showed poor reflectance when dry. The visibility of the silicone-treated and untreated beads was equally destroyed under the spray at high precipitation rates. When the surfaces of the two tape striping materials that performed well when wet were examined closely, it was noted that water beaded on their surfaces rather than flowed out over the stripe in a continuous film; therefore, many of their retroreflective elements were exposed and active. The three stripes that were coated with special bead-coated granules, which showed poor reflectance when dry but good reflectance when wet, did not reflect the color of the binder material but gave a gold-like color impression.

Under dry nighttime conditions, 10 of the 18 stripes employing raised markers were rated at 4 and above. The eight with ratings lower than 4 were unreflectorized markers. Under wet conditions, 8 of the 10 raised, reflectorized markers visible under dry conditions were rated at 4 and above. Thus, two of the raised, reflectorized marker types received a rating of 9 when dry and 9 when wet and were indeed as easily distinguishable when subjected to the water spray as when dry.

ON FALL INSPECTION

The test materials were allowed to weather over the summer, and, on September 27, 1965, after a 4-month exposure period, reevaluation of the markings was made. The 65 paint stripes in the dry condition had essentially the same ratings as they did in the spring. As pointed out previously, there was a minimum of traffic over the test site during the test period. In the wet condition, all of the stripes, except the two formed of tape-striping materials, were obliterated. Although these two stripes had lost their ability to bead water, their surfaces were sufficiently elevated so that many of their reflective elements were never submerged and remained active. Figure 2 is a photograph taken at night during the fall inspection of the test site in the dry condition. The brightest and most easily distinguishable stripes at the test site were a series of five located in the third row on the left side. On these stripes glass beads with a refractive index of 1.9 were used. Immediately behind these five stripes are five control stripes of paint, which had no bead treatment and thus were very difficult to distinguish. In Figure 3, the site is viewed with the water-spray rig mounted over these five brightest stripes; at a simulated rainfall rate of approximately 4 in. per hr, they can barely be distinguished. The raised markers had essentially the same ratings as they did in the spring. In Figure 4, the site is viewed with the water-spray rig mounted over a series of raised, reflectorized markers located to the extreme rear of the site; at a simulated rainfall rate of approximately 4 in. per

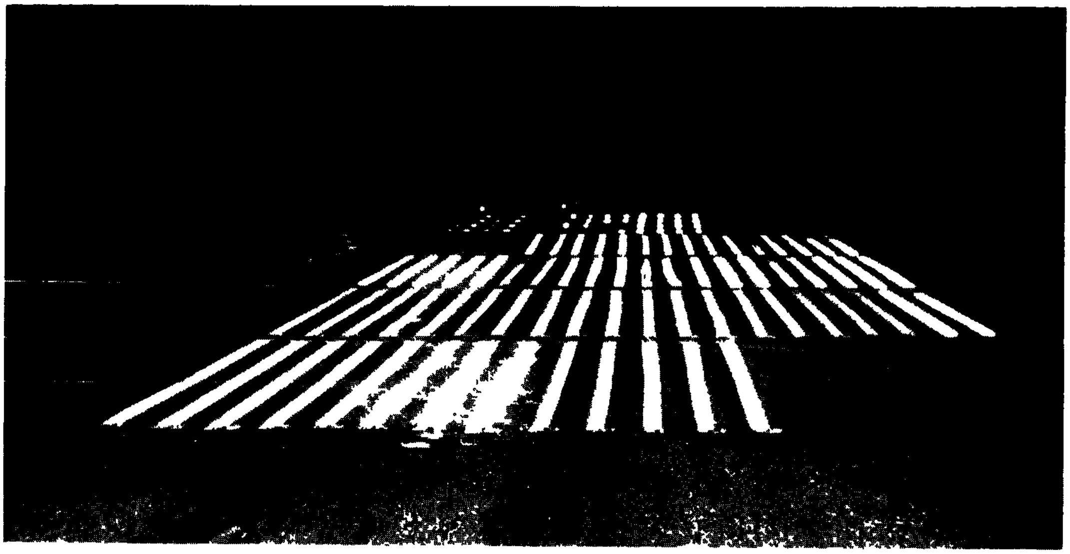


Figure 2. Test site at night, dry.

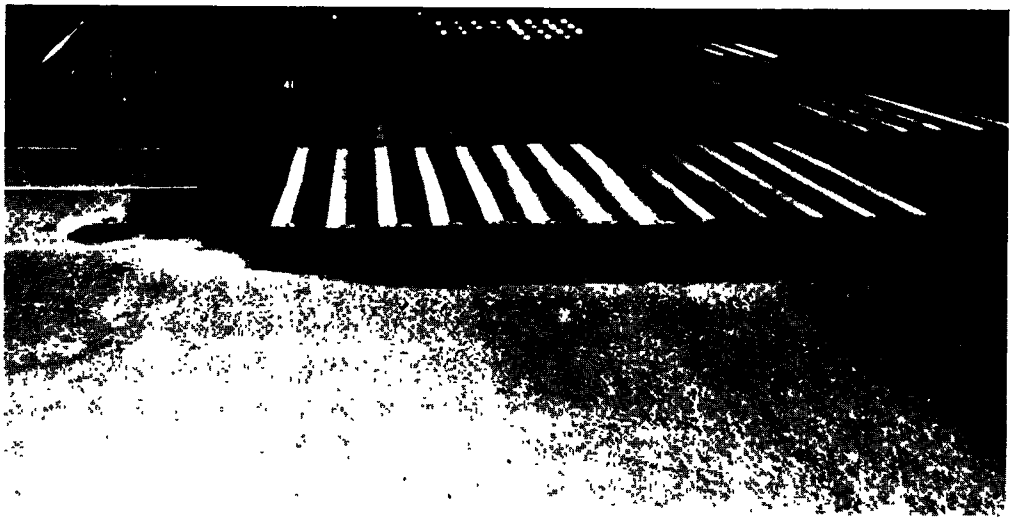


Figure 3. Water spray over brightest beaded stripes at test site.

hr, they are very distinguishable. It is interesting to note that the reflectorized paint stripes in the foreground, which are no longer being sprayed, are again becoming reflective.

PRECIPITATION—ITS FORMS AND CHARACTERISTICS

Precipitation may occur as rain, fog drip, dew, snow, hail, sleet, or freezing rain. Figure 5 shows the average annual precipitation in various areas of the United States. Most areas within the continental United States experience from 100 to 150 days annually on which precipitation of 0.01 in. and above occurs. Arid areas of the western states experience fewer such days, averaging 30 to 80 annually. Heavy fog occurs in areas of the country roughly from 10 to 35 days annually, with extremes along the coastal regions, particularly in the Pacific Northwest and in New England. Fog consists of water droplets so small that their velocities of fall are negligible. Fog particles which contact an object may adhere to it, coalesce with other droplets, and eventually form a drop large enough to fall producing what is referred to as fog drip. On clear nights, the loss of heat by radiation from the soil causes cooling of the ground surface and the air immediately above it. Condensation of the water vapor present in the air results in a deposit of dew. The solid forms of precipitation, when melted either naturally or more quickly by the use of various salts, also produce surface moisture.

Figure 4. Water spray over raised, reflectorized markers at test site.

Table 1 gives the limits adopted by the United States Weather Bureau, above which precipitation is considered to be excessive short-duration rainfall (*1*). Figure 6 shows 1-hr rainfalls to be expected in the United States once on the average in 25 yr. Figure 7 shows the average annual maximum rainfall for 30 min.

Selecting rainfall rates for design purposes can be approached from a number of viewpoints, some of which require study and analysis considerably beyond the scope of this program. One could design for the worst conditions because the driver then needs the greatest visual help. The intensity of rainfall can become so great during short periods that light from the vehicle headlights begins to be scattered by the individual raindrops to the extent that visual perception is greatly impaired. This condition is not readily measured and requires further study. For this study, a precipitation rate of 4 in. per hr was chosen. It is probable that using this precipitation rate results in overdesign for many regions or locations. For example, the States of Nevada and Florida experience precipitations that differ greatly in amounts, but are quite uniform on a statewide basis; whereas, in Texas, amounts vary greatly across the State, not to mention differences in rates. Thus, these factors should be taken into consideration when designing a marking system for a specific location.

TABLE 1

LIMITS ADOPTED BY U.S. WEATHER BUREAU ABOVE WHICH PRECIPITATION IS CONSIDERED SHORT-DURATION RAINFALL

DURATION (MIN.)	DEPTH OF PRECIPITATION (IN.)	RATE (IN./HR)
5	0.25	3.00
10	0.30	1.80
15	0.35	1.38
20	0.40	1.20
30	0.50	1.02
45	0.65	0.84
60	0.80	0.78
80	1.00	0.78
100	1.20	0.72
120	1.40	0.72
150	1.70	0.66
180	2.00	0.66

Theoretically, a completely impervious and flat surface should have a runoff coefficient approaching unity. Capillary water in small pores, hygroscopic water absorbed on the surface of materials, and puddles of water stored in surface depressions result in runoff coefficients of less than unity for most surfaces. In hygrographic analysis, a runoff coefficient of 0.85 for pavements of asphaltic concrete and portland cement concrete is accepted (*2*). However, such information does not answer this very important point: "In a given rain, how deep a film of water can one expect on the road surface?"

Test Apparatus for Measuring Water Film Thickness on Pavements

In order to determine precisely the true water-film thickness that one might expect to encounter, an apparatus was designed for measuring water films at various rates of simulated rainfall. Measurement of water film is complicated by the high surface tension and capillarity of water. So as to avoid these characteristics and the problems associated with immersion-measuring devices, an

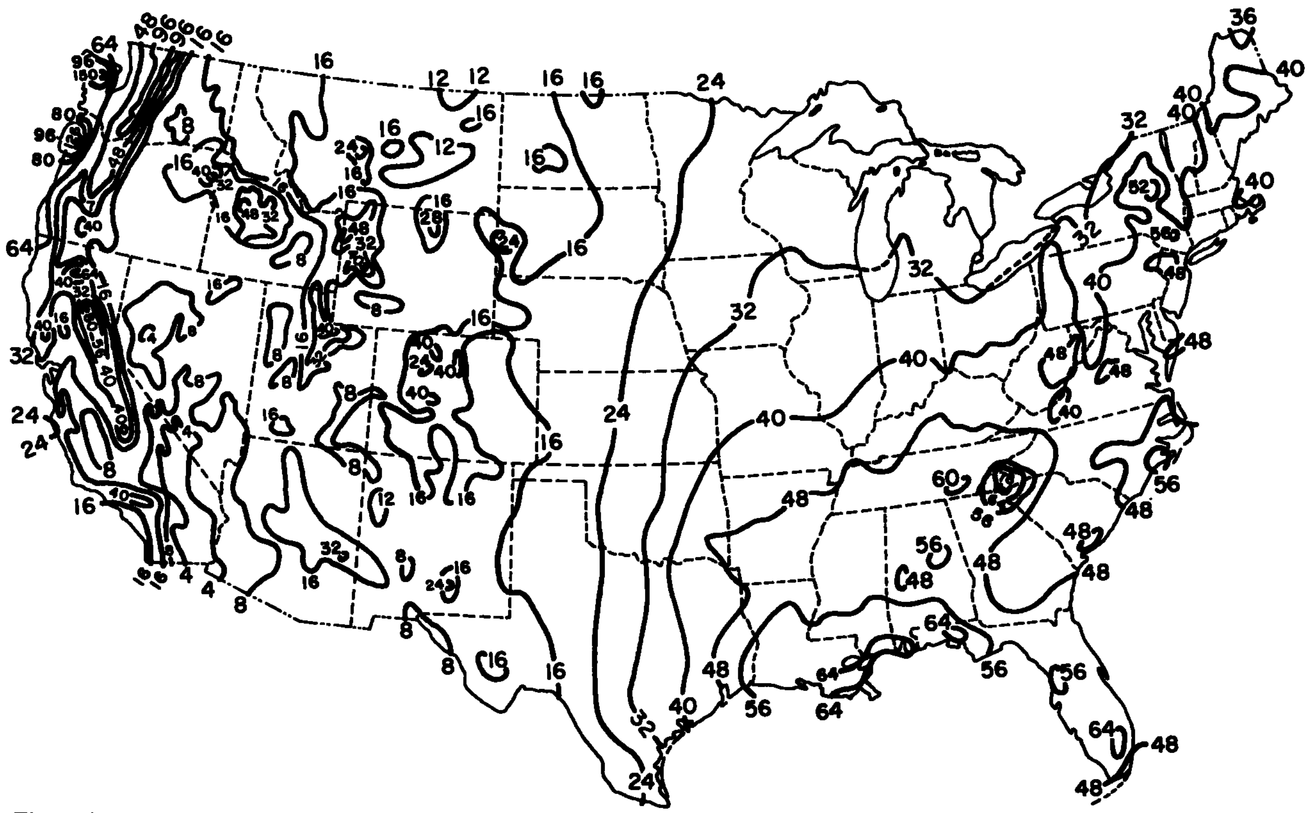


Figure 5. Average annual precipitation (in inches) in the United States (U.S. Weather Bureau).

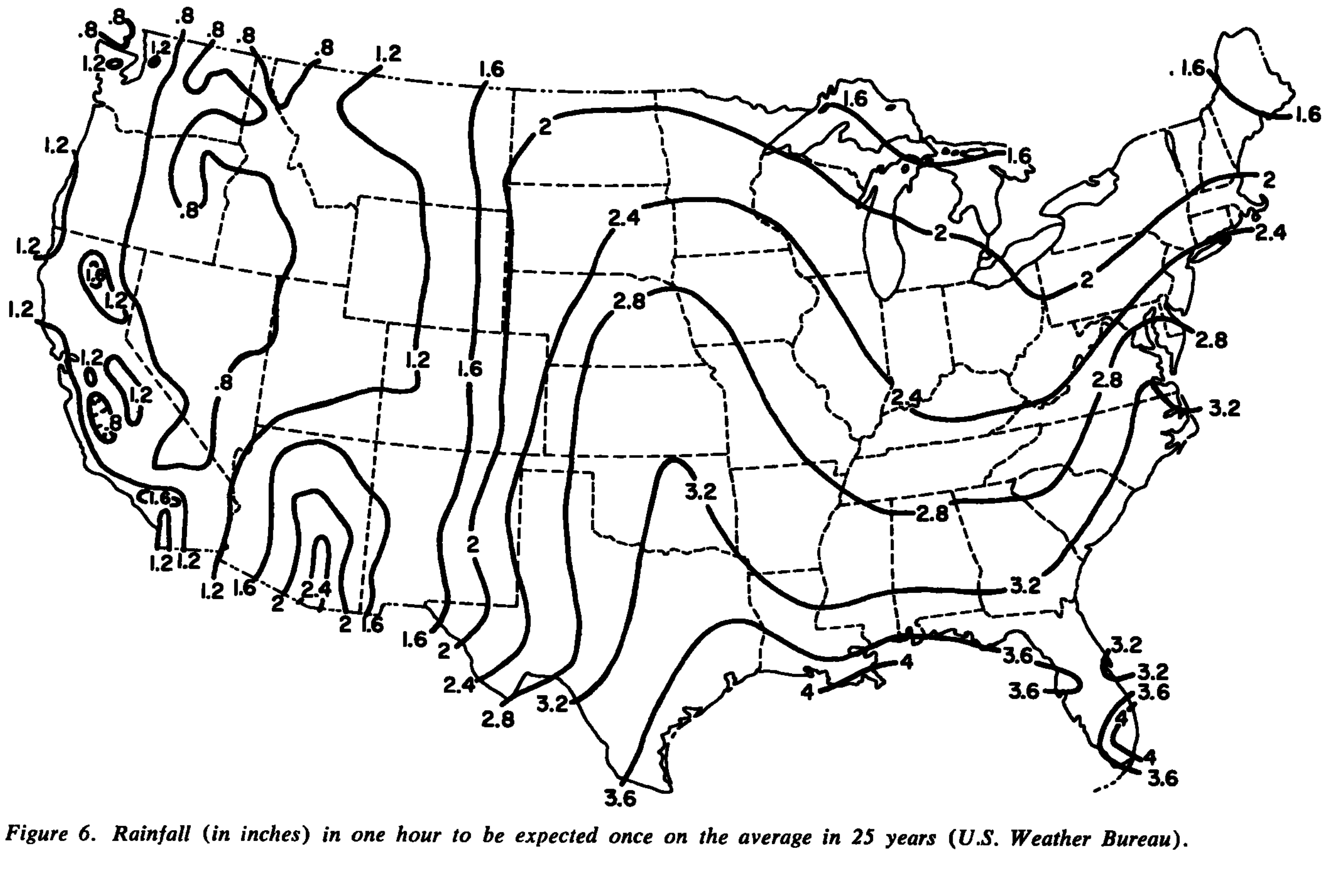


Figure 6. Rainfall (in inches) in one hour to be expected once on the average in 25 years (U.S. Weather Bureau).

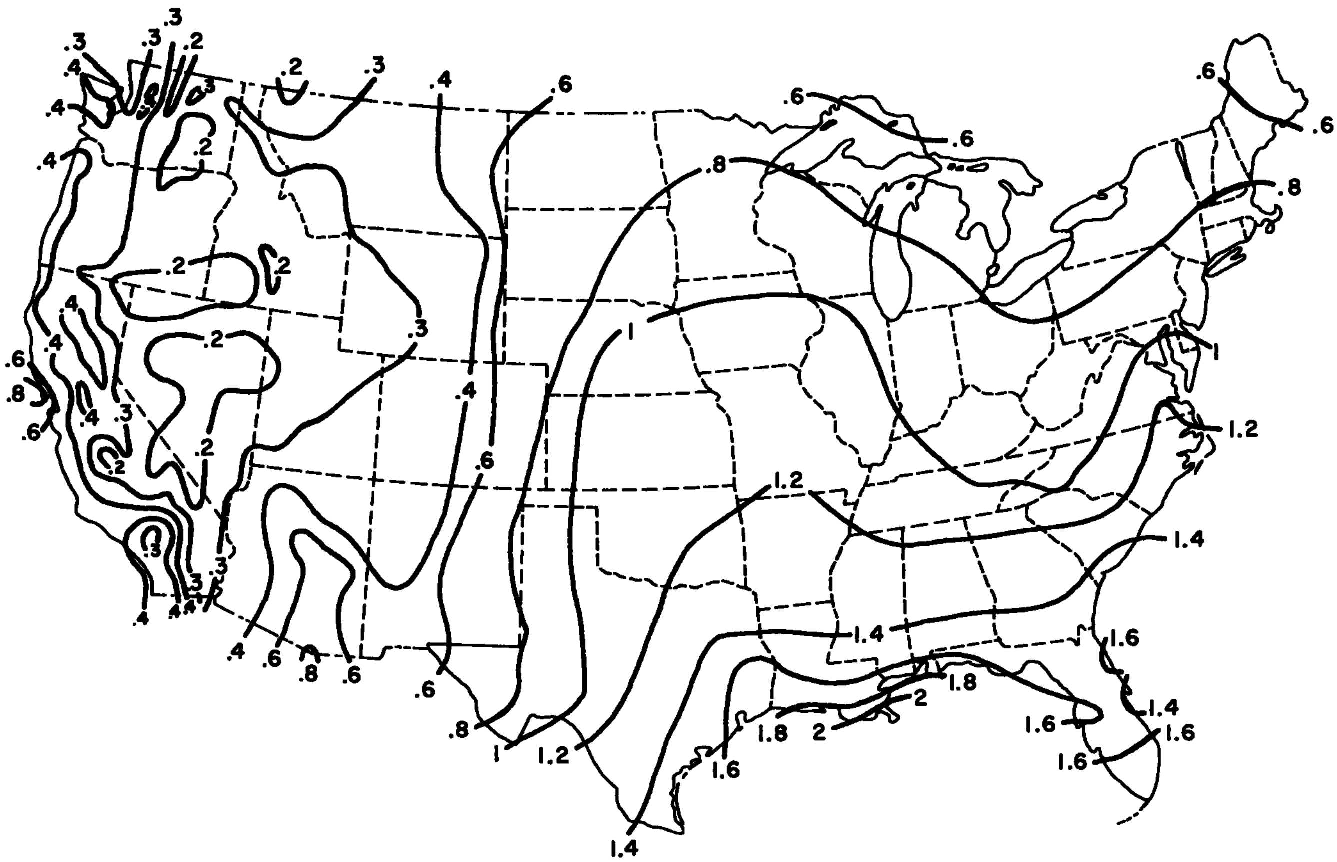


Figure 7. Average annual maximum rainfall (in inches) for 30 min (U.S. Weather Bureau).

apparatus consisting of a depth micrometer mounted on and protruding above a plate with supporting legs of rubber was designed. In this unit, shown in Figure 8, the micrometer was electrically insulated from the road. An insulated electrical conductor was attached to the micrometer and, hence, to a resistance meter. The other terminal of the resistance meter was connected to a heavy copper probe, which was laid in the water film on the road and in the vicinity of the micrometer. The micrometer was then turned downward until contact was made with the water film. Initial contact was sensed by watching the jump in the meter reading when the circuit was closed through the water film on the road. A reading of the micrometer was made at this point, and it was then turned downward until contact with the road was made—the difference between the two readings being the film thickness of the water. Figure 9 is a photograph of the water-film measuring apparatus and the spray rig being employed in the field. Because of the inherent unevenness of roadways, considerable areas of depression storage exist. It was therefore necessary to take a very large number of readings to arrive at representative figures. Studies of various water films on various characteristic pavements were made; these were further verified in studies of water films on a flat and very smooth surface especially fabricated for this purpose.

Runoff and Water Films on Pavements

Highway pavements may or may not be crowned. For those pavements that are crowned, the slope is generally 0.125 to 0.250 in. per ft. Shoulder slope is generally 0.750 to 1.500 in. per ft. The standard width of highways carrying large volumes of traffic is 24 ft.

The problem of a water film on a crowned two-lane rural highway is essentially one of the water falling on the marking material and flowing off in both directions so that there is little tendency for buildup from adjacent runoff. On a four-lane roadway carrying two lanes of traffic in opposite directions, with the road crowned in the center and marked there with double continuous yellow stripes and white skip lane lines, water falling in the center builds up a runoff pattern that crosses transversely the lane and edge lines. By selecting sites with the proper slope and contour, these conditions were simulated. By using the water spray apparatus at various locations where the pavement surface ranged from a very coarse to very smooth, as well as at one location having an extremely smooth surface of cement-asbestos, some 450 separate measurements of water-film thicknesses were made at a simulated rainfall rate of approximately 4 in. per hr. It was found that on the crown of the road the average of all readings was 0.030 + 0.005 in. At the same rainfall rate, a location 12 ft downslope from the crown of the road with a downslope rate of 0.25 in. per ft, had an average water-film depth of approximately 0.040 + 0.005 in. These readings were made by using the artificially produced rain from the spray apparatus, but when rain occurred naturally, the occasion was taken whenever possible to go into the field and measure water-film thicknesses occurring on local county and State roads. The sporadic character of natural rainfall introduces certain uncontrollable variables into an analysis of data pertaining to it. However, there was good correlation among the thicknesses of naturally occurring water films and those produced artificially and those observed in earlier work by Izzard (*3*).

Other factors can influence runoff from a pavement but resist general interpretation. For example, "rainfall-disturbance," caused by variations in the rainfall drop size and intensity, can retard runoff, as can the character of the vegetation growing on the road shoulder.

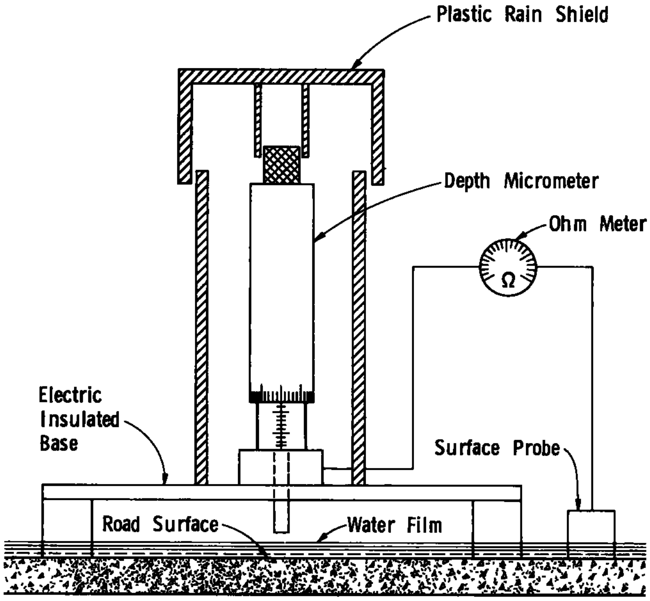


Figure 8. Schematic of device for measuring water-film thickness.

GLASS BEADS IN PAVEMENT MARKINGS

Physical Nature of Glass Beads

Reflective glass beads used in highway marking are largely produced from glass cullet or scrap, which is ground, heated sufficiently to allow surface tension to pull each individual particle into a spherical shape, cooled, sieved, and bagged for use. It should be noted that this manufacturing process lends itself to the production of beads of a mixed gradation of sizes rather than of uniform single size. Much of the glass used in making beads has a high silica content and a relatively low refractive index (1.5), whereas glasses of higher refractive index (1.9) generally have lower silica contents and lower chemical durability, but not necessarily lower serviceability (*4*). The glass from which beads are made is very hygroscopic. Thus, glass beads have a built-in affinity for water, which not only causes problems in their application but also makes them actively seek water in the highway environment. This result is exactly opposite of what is desired. Beads in a container opened on a day when the relative humidity is high will absorb moisture and lose their free-flowing characteristics. When an attempt is made to apply them as a reflective medium to a highway marking material, they will have a tendency to fall as groups of beads rather than as individual beads. It is not uncommon for the beads to clog the bead-dispensing apparatus so that these dispensers must be unclogged before striping can be continued.

The hygroscopic constituents on the surface of the glass beads are alkaline in nature. One of the earlier methods of producing a free-flowing glass bead was to inject sulfur dioxide into the process stream or into the containers holding the beads. Although this addition solved the problem, it presented several difficulties in practice and was largely discontinued. Afterward it was found that various absorbent powders added in very small amounts were efficient in making glass beads free-flowing.

Further development work resulted in the use of silicone products to make the beads free-flowing. Processes for applying the silicone treatment vary; the silicones may be introduced as a gas phase during manufacture of the beads or they may be applied after the beads are produced. The silicone treatment results in a bead that has water-repelling characteristics. For example, silicone-treated beads dropped into water will agglomerate and hold with them bubbles of air for an extended period of time. Further, immediately after silicone-treated beads are dropped onto a painted highway stripe, any water falling

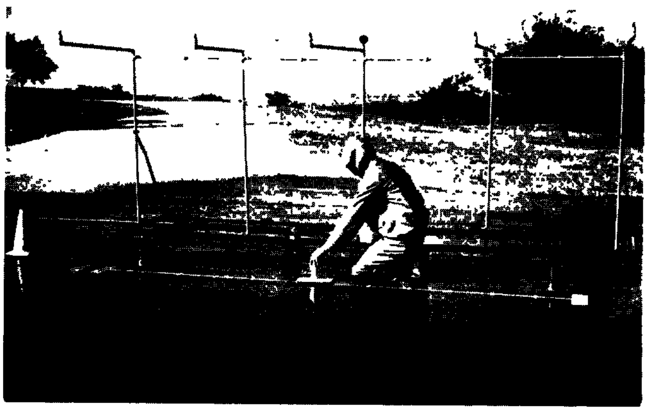


Figure 9. Measuring water films in the field.

on the stripe will, because of its surface tension and the repellency of the silicones, bead up into small individual pools. There is some indication that some of the silicone on the beads might actually migrate off the beads and onto the surface of the paint film. When the water does bead up, there are many areas which are free of a submerging film of water, and the retroreflective elements are active and are fully retroreflective.

Experiments were conducted to determine the duration of effectiveness of the silicone treatment in the actual roadway environment. A series of stripes was put down, and the silicone-treated beads applied to them. After this, the water-spray rig was set over these stripes and run intermittently during the daylight hours. After 3 days of this exposure, the water repellency of these stripes had diminished to the point where the water would no longer bead on the surface, and the retroreflective elements became submerged and no longer active. Although this treatment offers a significant and very useful function in terms of nighttime visibility, the shortness of its life greatly diminishes its significance. Because of its potential, some of the better known and most effective water-repellent silicone fluids were obtained and mixed with a paint binder in proportions of 1, 2, and 3 percent by weight. These binders were then applied and subjected to water spray, as were the stripes with silicone-treated beads. It was found that the treated binders beaded water nicely initially but, like the silicone-treated beads, after 3 to 5 days' exposure became ineffective and the stripes again became subject to continuous submerging water films.

GRADATIONS OF BEADS

State highway department specifications for drop-on-type glass beads for reflectorizing paint markings call for the typical gradations given in Table 2.

Specifications for drop-on-type glass beads for reflectorizing hot-extruded thermoplastic markings call for the typical gradation given in Table 3. Specifications for glass beads used as an admixture with paints and thermoplastics call for a mixed gradation of beads of a smaller size than are called for in the drop-on application.

THICKNESS OF BINDERS

More than one-half of the State highway departments apply their bead binder paints at a spreading rate of over 16.5 gal per mile of continuous 4-in. wide line. This amounts to a wet-film thickness of approximately 15 mils. One-fourth of the State highway departments apply their bead binder paints at a wet-film thickness of over 16.5 mils.*

The hot thermoplastic marking materials are generally applied at a film thickness of 125 mils.

APPLICATION RATES FOR GLASS BEADS

The standard application rate for glass beads is 6 lb of beads per gal of paint. In some instances, it is the practice to premix 4 lb of beads with the paint and apply this, dropping on 2 lb per gal during application on the basis that the 2 lb dropped on will give immediate reflectorization and later with abrasive wear the premixed materials will come into service. Figure 10 is a photomicrograph of a highway marking paint with a beads-on application.

Retroreflective Characteristics of Glass Beads, Dry

RETROREFLECTION AS A FUNCTION OF BEAD IMBEDMENT

So as to more clearly demonstrate how retroreflection takes place in a pavement marking material at a location where the vehicle light makes a very small angle with the pavement, a series of large glass beads with a low refractive index were coated to various depths in a standard highway-marking, bead-binder paint. In Figure 11(*a*), a series of these beads is viewed from the source of the incident beam and on the horizontal with the plane of imbedment. The bead on the left received no coating, the second bead from the left was coated to 50 percent of its vertical height, the third bead was coated to 60 percent, the fourth to 70 percent, and the final bead to 80 percent. The bead imbedded to 60 percent of its vertical height shows a high degree of reflectance and a large active area. As the depth of imbedment increases, the angle which the light makes with the surface of the bead decreases, and a growing percentage of the light is reflected off the surface rather than being refracted. Furthermore,

* Private communication, The Sulphur Institute (June 1964).

TABLE 2

TYPICAL GRADATIONS FOR DROP-ON-TYPE GLASS BEADS FOR REFLECTORIZED PAINT MARKINGS

U.S. STD. SIEVE NO.	SIEVE OPENING (IN.)	TYPICAL SPECIFICATIONS (% PASSING) EXAMPLE NO. 1	EXAMPLE NO. 2	EXAMPLE NO. 3	EXAMPLE NO. 4
20	0.0331	98–100	100	100	100
30	0.0232	60–90	75–95	95–100	75–90
50	0.0117	15–50	15–35	10–35	15–30
100	0.0059	0–10	0–5	0–5	0–5
200	0.0029	0–5	0–1	0	0–1

TABLE 3

SPECIFICATIONS FOR DROP-ON-TYPE BEADS FOR REFLECTORIZING HOT-EXTRUDED THERMOPLASTIC MARKINGS

U.S STD. SIEVE NO.	SIEVE OPENING (IN.)	PERCENT PASSING
20	0.0331	90–100
35	0.0197	0–10

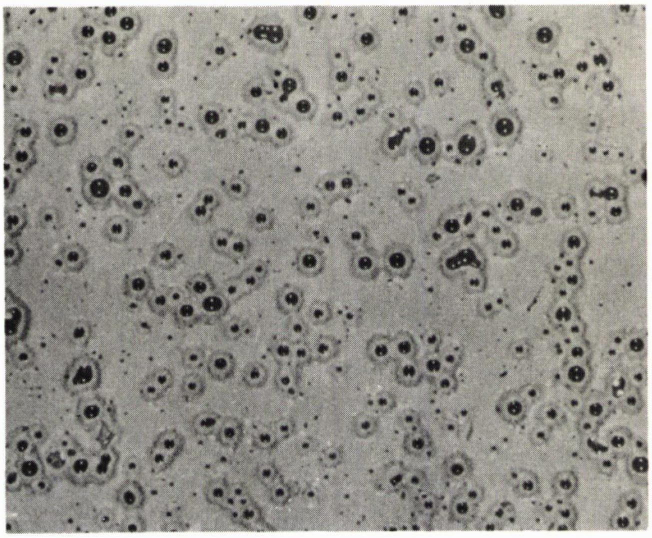


Figure 10. Photomicrograph of a paint stripe with beads applied by drop-on method.

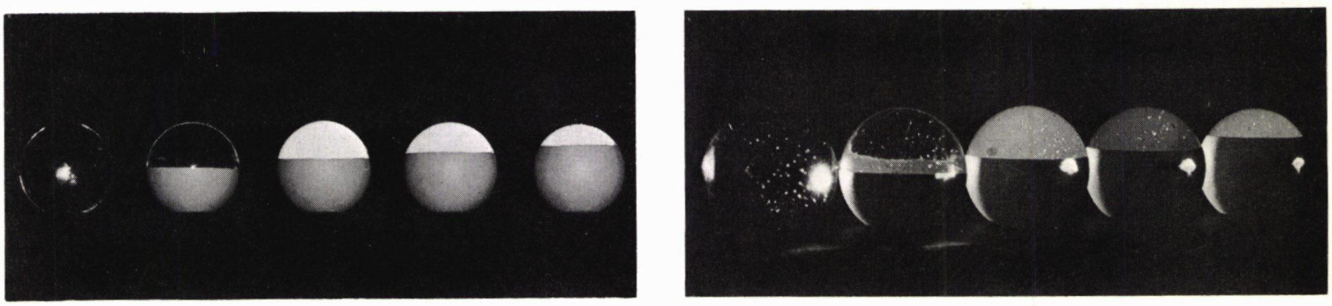
the total area of the bead available for retroreflection declines. Figure 11(*b*) is a photograph of the same beads as shown in Figure 11(*a*) under the same illumination and at an approximate angle of 135° with the incident beam. In this photograph, both the change in the active portion of the beads and the focal areas on the back of the beads can be seen quite clearly. Since the angle of light thrown by a vehicle headlight on the pavement diminishes rapidly as the distance in front of the vehicle increases, the possibility of focusing in the lower half of the bead declines accordingly. Any retroreflection that then takes place must occur in the upper hemispherical section of the bead; for this to occur, the binder must be above the horizontal axis of the bead. Thus, imbedment above the horizontal axis of the bead is not only important for good retention in the binder but also for good retroreflection at increased distances. The current practice of dropping a mixed gradation of beads into a binder of constant thickness results in efficient retroreflection in only a small percentage of the beads applied.

From these experiments, it was indicated that, as the angle the light makes with the pavement decreases, the lower half of the vertical height of the glass bead contributes little to the retroreflective capabilities of beads in the highway environment; it was desired to demonstrate this in a more complete manner. For this demonstration, two identical large glass beads were obtained, and one of these was cut in half. The whole bead was coated to 60 percent of its vertical height. The hemispheric portion of the other bead with its cut face down was coated to 10 percent of its vertical height, and the two were mounted so that the tops of the coatings were in the same horizontal plane as the light source.

In Figure 12(*a*), these two beads are viewed from the source of the incident beam and on the plane of imbedment. The half bead is on the left; as can be seen, it shows the same degree of retroreflectance as the full bead. In Figure 12(*b*), the same two beads under the same illumination are viewed at an approximate angle of 135° with the incident beam.

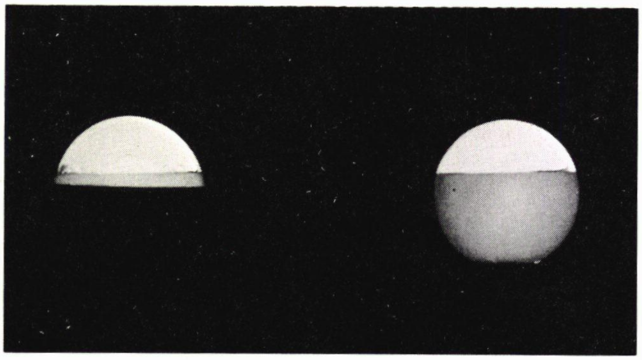
RETROREFLECTION AS A FUNCTION OF BINDER ORIENTATION WITH THE LIGHT SOURCE

Since the angle at which the automobile headlights impinge on a retroreflective highway-marking material is extremely small and subject to little alteration, an experiment was set up to determine the feasibility of altering the orientation of the binder on the bead with respect to the plane of the headlights. Figure 13(*a*) is a view, from the source

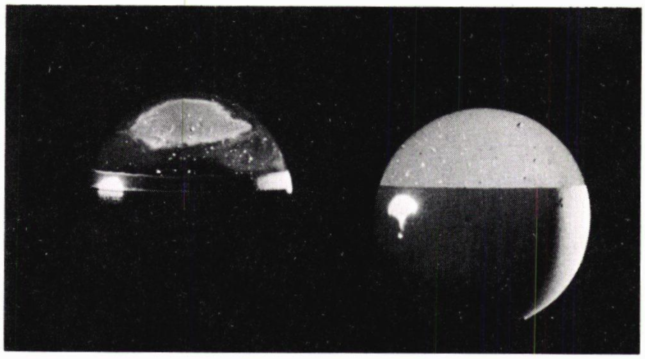


(a) (b)

Figure 11. Beads imbedded in binder to various depths.



(a)



(b)

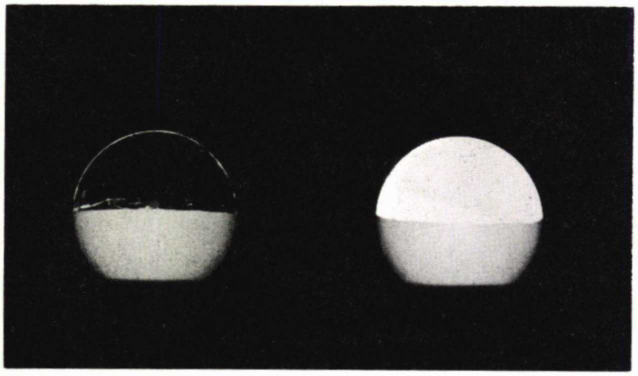
Figure 12. Retroreflectance of hemispherical sections of a half and a whole glass bead.

of the incident beam, of two identical large beads which have been imbedded to 50 percent of their height in a bead binder, with the bead on the left imbedded in the same plane as the light source. The bead on the right has been tilted forward approximately 3°, raising the binder on the back and lowering it on the front. This effect is quite dramatic. In Figure 13(*b*), the same two beads are viewed at an approximate angle of 135° with the incident beam.

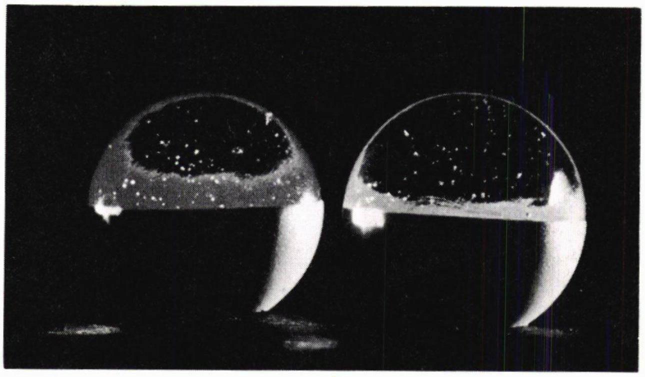
When a glass bead is dropped into a marking material, such as paint, surface tension causes the paint to climb up the side of the bead. This capillary rise is influenced by a number of variables, including the contact angle, the surface tension and viscosity of the marking material, and the wettability or surface treatment which the bead may have received. Both surface tension and viscosity may vary with temperature. The capillary attraction of liquid to glass beads manifests itself in an interesting manner in that experiments in the laboratory indicate that if one lays a marking material in a horizontal position and begins to apply beads under pressure in a vertical direction and then alters the direction of application from vertical to a very shallow angle, the encapsulation of the beads is for all practical purposes the same. In another experiment, the painted surface was positioned at various angles from the horizontal, and beads were again applied by pressure at various angles. Again the beads were found to be encapsulated in the same manner; that is, the paint had risen to the same height around the bead with respect to the plane of the painted surface. Thus, these experiments indicated that orientation of the beads to give maximum retroreflection in one direction occurs more readily on an inclined surface which faces the light source.

RETROREFLECTION AS A FUNCTION OF MIXED BEAD SIZES IN A CONSTANT-THICKNESS BINDER

Since beads are commonly applied as a gradation of a variety of sizes in a paint-film binder of constant thickness, it was desired to ascertain the influence of the various size beads upon one another (*4*). To do this, two large beads of the same diameter were coated to 60 percent of their height and placed side by side. Three smaller beads, each with a diameter approximately 75 percent that of the larger bead, were coated to a height equiva-

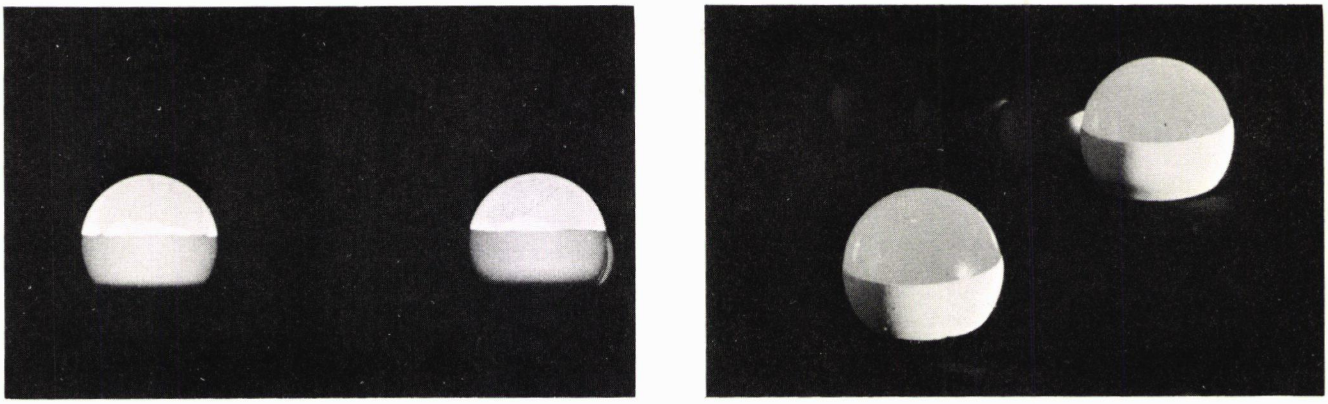


(a)



(b)

Figure 13. Retroreflection as a function of binder orientation.



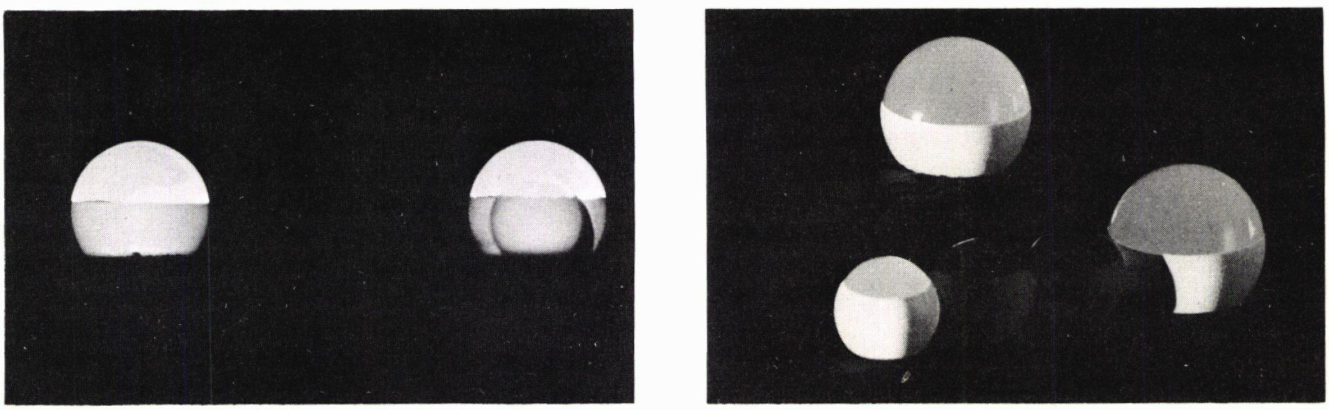
(a) (b)

Figure 14. Small beads behind large beads.

lent to the coating height of the larger beads (as they might be if dropped into a binder of a uniform film thickness) and then placed behind one of the large beads. In Figure 14(*a*), the two large beads are viewed from near the source of the incident beam with the three smaller beads located directly behind the large bead on the right. The smaller beads do not contribute to retroreflection. Figure 14(*b*) is a view of the same beads shown in Figure 14(*a*), but at an approximate angle of 135°. It shows the smaller beads lying in the shadow of the larger bead in front of them. In Figure 15(*a*), the two large beads are viewed from near the source of the incident beam; but, in this instance, the three smaller beads are placed in front of the large bead on the right. Figure 15(*b*) is a view of the beads in Figure 15(*a*), but at an approximate angle of 135°; note how the first little bead, which is too deeply imbedded to present anything but its least effective area to the light source, blocks out the remaining two smaller beads and also the most effective area of the large bead.

RETROREFLECTION AS A FUNCTION OF REFRACTIVE INDEX, SHAPE, AND IMPERFECTIONS

As the refractive index of the glass is increased from 1.5 to 1.9, the focal point of the refracted light progresses from outside and to the rear of the bead toward the back inside surface of the bead. Thus, as the refractive index is increased, a great deal less scattering occurs and retroreflective efficiency improves directly. The shape of the beads is also an important variable in that any deviation from the true spherical shape destroys the in-line focusing ability of the bead. Imperfections in the glass may be caused by striae (which are streaks or veins due to the composition differing slightly from the average), or bubbles (that were trapped in the melt and could not escape), or stones (small fragments of undissolved material), or crystallized bodies (which precipitated out during cooling), or cloudiness (from turbidity in the melt), or other irregularities. All are undesirable and have an adverse effect on the retroreflective capabilities of the glass.



(a) (b)

Figure 15. Small beads in front of large beads.

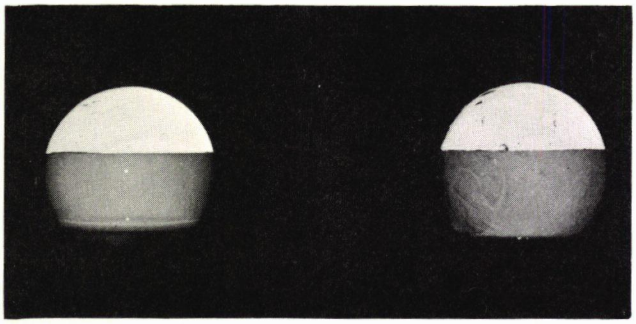


Figure 16. Thin coating films of water on beads.

Retroreflective Characteristics of Glass Beads, Wet

THIN COVERING FILMS OF WATER

In demonstrating the influence of thin covering films of water, two large beads were coated with a paint binder to 60 percent of their vertical height and mounted side by side. A water source was mounted over one of the beads, and a continuous stream of water droplets was allowed to fall on the bead, covering it with a thin film of water at all times. Figure 16 is a view of these two beads from near the incident beam source, with the water-coated bead on the left. A water meniscus can be seen around the base of this bead. The bead on the right is dry except for several small splash droplets on the side facing the bead being wetted. The significant point to be drawn from this demonstration is the fact that a thin film of water covering the bead has a relatively minor influence on its retroreflective capabilities.

THICK SUBMERGING FILMS OF WATER

In another experiment large glass beads were coated to various heights with conventional paint binders and placed in a submerging film of water so that their upper surfaces did not protrude when viewed from near the light source. Their presence beneath the water surface was imperceptible. As their height was increased to the point where they rose above the surface of the water, though they were still covered with a thin film of water, they again became retroreflective, poorly at first but showing improvement as they were raised progressively higher.

WATER FILM CHARACTERISTICS AS A FUNCTION OF BEAD APPLICATION DENSITY

Water has a strong tendency to rise up on the sides of materials, like glass, that have an affinity for it. Where the surface density of glass beads in a binder is very high, the wetting characteristics of water help to bridge the gaps between beads. Furthermore, a high-density application of the beads leaves fewer channels for the water to flow away from the beads; thus, submerging films are more easily achieved in high-density applications of beads than in moderate applications. In demonstrating this, a series a stripes was prepared in which the density of beads was continuously increased until the surface became completely saturated with beads. When the series was subjected to simulated rainfall, the stripe saturated with beads was the first to lose its retroreflective capabilities.

CHAPTER THREE

INTERPRETATION OF FINDINGS

MARKING PRACTICES AND DAY AND NIGHT VISIBILITY

Because reflective materials are only a part of the marking material system, their effectiveness and the length of their service are direct functions of the life of the marking material itself, since it is acknowledged that the reflective materials often contribute to this life. In looking at the use of marking materials in 50 different States, each of which may have climatic conditions that vary widely within it, and each of which has different specifications for paving materials with varying traffic densities and road surfaces, it may be seen that failure of paint and marking materials can be manifested in a variety of ways. Interestingly, all of the States have adopted bead-gradation specifications that are essentially the same. However, one must consider the mechanism of paint failure before selecting an optimum bead system and gradation.

If the paint fails by abrasion and erosion or a combination of both, as described in American Society for Testing and Materials (ASTM) publication D821–47, then the smaller size beads become exposed and active and the larger beads become dislodged. If, however, the paint fails by developing cracks or chipping off, as described in ASTM Traffic Paint Test D913–51, then the smaller beads never have the opportunity to become active. Concrete pavements, being porous, allow water to rise up through them; this action plus the highly alkaline environment contribute to the often observed more rapid failure of paints on concrete through loss of adhesion. Thus, paint failure of this character would not allow the larger percentage of the glass currently being used to become effective. At other locations, such as on rural roadways where traffic directly over the stripes is at a minimum and where road surfaces are generally much coarser in character, marking paints often fade or after a while become dirty. It is necessary to repaint them annually, even though physically they are still largely intact, except possibly on the surfaces of the uppermost pieces of aggregate, where they may have worn away. Again, a large percentage of the glass may never become active. Another type of paint failure is that caused by erosion. Wind, sand, and other environmental conditions allow a slow and steady erosion of the marking material, particularly those having built-in chalking characteristics. Very often, the road surface itself is covered by film that is not readily apparent; but by wetting a finger and rubbing the road, one can appreciate the extent of these films. Preconditioning the road surfaces to be marked is practiced infrequently; therefore, paint is often applied over road film, adhesion is poor, and the paint fails by breaking away.

In the summer months, marking materials can fail when the bituminuous materials feed up from the substrate or when road film deposited by vehicle tires completely covers up the markings. Marking materials that have received a dropped-on application of beads exhibit a far greater tendency to pick up road film than do unbeaded materials. It is not uncommon to find stripes in some of the warmer areas of the country where road film from tires has made the markings completely indistinguishable in the daytime. Paradoxically, these same markings at night can be very attractive because they retroreflect the binder color on the inside backs of the glass beads. Physically, these markings can be 100 percent intact; yet they have failed in terms of delineation of the roadway in the daytime, and only a small percentage of the incorporated beads has been utilized for retroreflective purposes at night.

Thus, for a marking material of limited thickness that loses its upper surface with time, a bead system of varying gradation is most desirable. On the other hand, where markings fail by mechanisms other than loss of their upper surfaces, a bead system with the bead gradation approaching a single size matched to the binder thickness would be more desirable. It should be remembered that improvements in matching wearing characteristics with film thicknesses and bead gradations that range from 0.005 to 0.040 in. in diameter, as currently used, cannot be expected to provide good visibility at night during periods of precipitation.

Day and Night Visibility, Dry

Unreflectorized surface markings such as paint may be characterized as being a highly effective means of delineating roadways that command driver attention and response during daylight hours but an ineffective means of delineating roadways at night under vehicle headlight illumination. The surface-marking system is one lending itself to high-speed application of markings that conform to existing surface contours as a film and thus do not present themselves so prominently for damage by snow removal and other maintenance equipment.

In dry weather, the use of reflective glass beads is an effective means of providing visibility to surface markings at night under vehicle headlight illumination. Glass beads also lend themselves to high-speed application that can be performed in conjunction with the application of the surface markings. Glass beads applied to surface markings detract from the daytime visibility and appearance because they cause surface reflections and result in an uneven surface texture that allows dirt and road film to be picked up and held. The glass beads focus sunlight and produce heat that can cause bleeding of the substrate into the marking material.

Just as light impinges on a water film and is reflected forward and lost, there are a number of phenomena that can aid or hinder the driver in distinguishing the roadway. Both early in the morning and late in the evening, when the sun is just above the horizon and the motorist is driving into the sun, glare or reflections glancing off the roadway and into the driver's eyes make it very difficult for him to perceive surface markings. During these same periods, when the driver is driving with the sun over his shoulder, it is not uncommon for the sunlight to be focused in the reflective materials on the roadway and directed back to the driver, thus improving the daylight visibility of the markings.

Raised, unreflectorized markers, such as buttons, may be characterized as an effective means of delineating roadways that command driver attention and response during daylight hours, but are ineffective at night. The reflectorized types are very effective at night; but high-speed techniques for their placement have not been fully developed. Markings that rise above the surface contour of the road are subect to damage by snow-removal equipment. A recent approach to this general problem is a raised marker mounted in a suspension system that is buried in the pavement; in operation the portion of the marker rising above the surface contour of the road deflects down and out of the way when subjected to an external force and then returns to its raised position. The unit is self-cleaning of ice and snow. Another approach to this problem is the use of snowplows with flexible blade attachments and other devices to protect the markers. Raised markers must generally be removed before resurfacing operations can be conducted. Raised markers are also subject to damage by tire chain and winter tires equipped with studs. Nearly 5 million of the 16 million new snow and ice tires sold during the 1966–67 winter were equipped wih studs (*5*). The nature and extent of this damage to all types of markings have not been ascertained.

Unbeaded Stripes

The current practice of dropping glass beads on highway marking materials is a recognized compromise to gain night visibility at a detriment to the appearance of markings during the day. A variety of practices has been employed to strike a balance between the daytime attractiveness of the unbeaded stripe and the need for retroreflectance at night. The application of beads to one-half of the length of a 15-ft center or lane line has been employed; this gives a reflective stripe at night, yet leaves a portion of the stripe unbeaded and attractive in appearance during the daylight hours. Others have employed the practice of dropping on reflective materials over the entire length of the stripe but only over one-half of the stripe's width. Some municipalities, in striping downtown areas, reason that the majority of the people are downtown during the daylight hours; therefore, they seek to have their markings in their most attractive state at that time and, therefore, do not bead the stripes. The need for retroreflectance of markings at night is paramount to driving safety; thus, compromising appearance to gain retroreflectance is well justified. The deterioration of the appearance of the paint marking materials with the application of glass beads has been observed and documented throughout the entire field test program. The development of a retroreflecting system that would not detract from the daylight visibility of the marking material would be advantageous.

Intermittent Black Contrast Lines

Often a condition arises wherein there is a very poor degree of contrast between a white beaded paint stripe that has picked up road film and deteriorated in color, and the pavement itself. This condition is very evident on many concrete pavements. It does not manifest itself quite so rapidly on asphaltic pavements; but, given time, it can be observed as the asphalt recedes to expose more and more of the aggregate. This condition is more evident where limestone and similarly light-colored aggregates are employed. So as to improve the contrast of white center lines and lane lines, it has been the practice in certain areas to lay a black stripe of paint or bituminous material in the interval between the white paint stripes; sometimes this stripe is overcoated with a drop-on application of a black aggregate, such as basaltic rock. This black line, particularly on concrete pavements, greatly improves the contrast and often is far more visible in the daytime than a white stripe, particularly one that has lost its initial brilliance.

Depth of Bead Imbedment

As discussed in the previous chapter, there is an optimum depth of imbedment that allows glass beads to furnish the maximum retroreflection and area of retroreflection. This depth was found to range from 55 to 60 percent of the vertical height of the bead. Beads imbedded to less than half of their vertical height in ordinary binders have insufficient mechanical imbedment to prevent them from being dislodged under traffic. The available area and intensity of retroreflection are greatly reduced if the beads are too deeply imbedded. Bead size, paint film thickness, and capillary action largely control depth of imbedment in the conventional systems. Another possible approach to imbedment depth is to surface treat the beads so that surface forces between the bead and the binder will prevent the bead from being completely submerged in the binder.

Direction of Application

It was shown in the previous chapter that if a bead is imbedded in the binder so that the binder is low on the side of the bead facing the incident light and elevated on the side away from light, improved retroreflectance will be observed. Experimental work has shown that glass beads orient themselves in a binder in essentially the same manner irrespective of whether the binder is in a horizontal or vertical position or whether the beads have been applied directionally. This orientation is due largely to the capillary action of the paint on the beads. Thus, for smooth horizontal surfaces, directional application offers few, if any, advantages. If the surface to be marked is irregular rather than smooth, much of the surface will be inclined toward the light; glass beads on this surface will be favorably oriented with respect to retroreflection. In the field, it was noted that vertical application of beads by a machine moving over an irregular surface resulted in a painted stripe with greater reflectance when viewed from the same direction the striping machine followed than when viewed from the opposite direction. Following this, an experiment was conducted in which beads were dropped vertically onto a line from a striping machine on a seal-coated surface by a hot oil-asphalt application, followed by dropping on a crushed aggregate ranging in gradation from 0.250 to 0.125 in. Close inspection of this stripe revealed that vertical application of beads from a moving machine onto an irregular surface resulted in a large percentage of the beads being dropped on the forward or front side of the aggregate, as viewed from the direction which the striping machine followed. For center and lane lines of one-directional traffic, this feature could be employed to advantage. For multiple-direction arteries, angling the bead dispenser to the rear away from the machine and pressure application of beads so that their fall velocity is as close to vertical as possible offer a technique to more evenly distribute the glass on both sides of the aggregate particles and thus provide a line with more equal reflectance in both directions.

Bead Gradation

Gradation of beads, as discussed in the previous chapter, indicates that most of the glass being used in the country today is material that passes a No. 30 sieve and holds on a No. 50 sieve, giving it an average diameter of approximately 17 mils. Current paint application film thicknesses range from 16 to 20 mils. Because of the optical characteristics of glass beads, there is really only one optimum bead size, for a given paint film thickness, to give maximum retroreflection. Thus, today's bead gradations are designed for use in markings that usually fail by abrasion or wearing away. Because there are many other mechanisms of paint failure, there is considerable justification to question the current practice.

Refractive Index

The use of glass of a high refractive index shows a progressive improvement in terms of retroreflection as the refractive index increases from 1.5 to 1.9. The difference is principally one of degree, which can be measured. Where comparative stripes having glass beads of high and low refractive indexes are laid, the improvement is most distinguishable and easily recorded photographically. Without comparative stripes, only the more trained eye is apt to be able to distinguish the differences in refractive index of the glass in a painted line. As the refractive index of the glass increases, the focal point progresses from the back and outside of the bead to the inside. Therefore, color and character of the binder have a diminishing influence on retroreflectance.

Day and Night Visibility, Wet

During daylight hours, precipitation very often improves delineation of the roadway by improving the contrast between the road surface (which is generally darker when wet than the marking materials) and the markings. During darkness in urban areas, overhead lighting is very often reflected off the road surface toward the driver, and markings are less distinguishable than in a rural environment with few or no foreign light sources.

Conditions of moisture in the nighttime environment produce effects which are almost entirely detrimental. In addition to wetting and submerging the marking materials and their reflective elements, the light from approaching automobiles is reflected off the water on the pavement surface and forward to the approaching vehicle; which greatly magnifies the headlight glare problem and makes surface-marking materials more difficult to perceive. The marking materials on expressways and major thoroughfares, which have very smooth surfaces when new and become even smoother with age, are subject to frequent restriping and are the first markings to lose their effectiveness when wet. On the other hand rural roads that have been given a seal coat with large aggregate, followed by the application of reflectorized paint markings, can be almost as effective when wet as when dry because much of the reflective material is elevated on the large pieces of aggregate; thus, only under extreme rainfall conditions does this material become submerged.

Raised, reflectorized markers offer an effective means of providing visibility at night under dry and wet conditions. Not all raised, reflectorized markers perform well when wet, but those that do are effective up to the point when the precipitation becomes so intense that it begins to scatter the light as does fog.

Regular Elevation of Area to Be Marked

It was desired to determine if simple elevation of the area to be marked would improve the retroreflection of the marking materials at night in the wet condition. To determine this, a series of stripes was laid wherein a smooth base coat of a modified, molten, elemental sulfur was applied to the road in thicknesses ranging from 30 to 90 mils, thus providing an elevation completely above the 30 to 40 mils of water film that one encounters during periods of precipitation. These stripes were then painted with a dropped-on beads application using the standard bead gradation and viewed under simulated rainfall. It was found that the reflective elements in the beaded stripes became submerged and ineffective. It was further found that, on discontinuance of the rain, these stripes recovered their ability to retroreflect far more rapidly than adjacent stripes that were unelevated. This might have been expected, since the elevated stripe did not prevent submergence of the reflective elements but did allow the submerging film of water to flow off the stripe in an easy path, therefore exposing the retroreflective elements again. Regular elevation of the stripe did not provide a solution to having a visible stripe during periods of precipitation.

Irregular Elevation of Area to Be Marked

A second means tried for elevating the retroreflective media out of the submerging water film was that of applying a coarse-aggregate precoat to the area to be marked. This was done by seal-coating with asphalt and various rock gradations up to materials passing a 0.500-in. sieve. Conventional beaded paint stripes were then applied over these areas. It was found that these stripes were reflective either wet or dry. This suggests the precoating of areas to be marked with a seal coat of aggregate of sufficient size to protrude up through the water films before conventional markings are applied.

Use of Large Beads

Since water films on roadways have certain definable thicknesses, it therefore becomes practical to consider the use of beads of sufficient size to extend up through these submerging films and thus be retroreflective when wet. As the size of the beads is increased, the area of retroreflection per unit weight of glass decreases, since in a sphere the area increases by the square of the diameter and volume increases by the cube of the diameter. If one is to employ beads of the larger size in paint, it is necessary that the film thickness of wet paint be correspondingly increased. In general application, highway-marking paint binders tend to form a surface film and have an extended drying time when applied in increased thickness. The physical and mechanical forces imposed on the binder become correspondingly greater as the size of the beads increases.

Since the thermoplastic marking materials are currently being applied at a thickness of approximately 125 mils, the opportunity to go to larger size beads that will project up through the submerging films of water is a simple, straightforward solution. Currently, the practice is to use essentially the same bead gradation in the thermoplastic materials as is being used on paint; therefore, this solution is apparent and begging for application. Many of the thermoplastic marking materials are filled with fine aggregate and have mechanical properties considerably in excess of those of paint binders.

Use of Small Beads on a Carrier

Since for a given weight of glass the area available for retroreflection is much larger for small beads than it is for larger beads, there are considerable advantages in using small beads. However, the use of smaller beads would require much thinner paint films at a detriment to the hiding power and the life of the paint; they would also be more easily submerged by rain than materials currently being used. This suggests the application of small beads as a continuous and covering coating to some carrier, the size of the carrier and the size of the coating beads being selected for the specific application. By selecting a carrier that does not necessarily have to be perfectly spherical in shape and coating its surface with a covering of small beads, one can obtain an equivalent area of retroreflection using as little as one-tenth the volume of glass of a single sphere of equivalent size.

Several experiments were conducted on methods for applying a coating of small beads to the surface of a carrier. The carrier can be one of a variety of materials so long as it has good structural integrity and preferably a specific gravity greater than that of the glass. In this work, a pea-gravel aggregate passing a 0.250-in. mesh and holding on a 0.125-in. mesh was used. This material was washed and dried and then charged to a rotating drum mixer equipped with internal flights; the axis of the drum was inclined to approximately 25 deg from the horizontal and rotated at a speed of approximately 36 rpm. Conventional highway marking paint was added to the aggregate until it was wetted but not flooded. As soon as the aggregate was throughly wetted, conventional highway marking beads passing a No. 50 sieve were then introduced into the rotating mixer in excess. The mixer was allowed to rotate for approximately 2 min, during which time the small beads completely coated the aggregate. At this point, rotation of the mixer was discontinued, and the materials were poured onto a drying screen through which the excess beads not attaching themselves to the aggregate fell and were recovered for later use. It is envisioned that this process, which is really very simple, could be converted to a continuous process with a minimum of difficulty. Microscopic examination of the coated particles revealed that the beads were encapsulated to just above their center axis and bonded to the aggregate in a very satisfactory manner. The coated aggregate was then allowed to dry for approximately 1 hr and then placed in a bead dispenser. It was found to be free flowing and was then used in preparing test panels. Retroreflection of these coated particles is excellent, and the use of highly refractive glass contributes further to retroreflection.

By using small beads applied to a carrier, there is an opportunity to obtain more area of retroreflectance per dollar invested in glass. Further, using glass of higher refractive index is suggested. The use of a bead-coated carrier or granules is a direct way to obtain reflecting materials of a larger diameter that will protrude up through submerging water films. Since the granules will reflect the color of the binder attaching the beads to the carrier, the color of the binder in which they are imbedded on the pavement will no longer be a controlling factor. Thus, the retroreflecting media could be removed from the white center and lane lines, thereby improving their daytime appearance. Further, there would be the opportunity to place the reflective granules in some of the black, low-cost bituminous thermoplastics used to provide contrast stripes and that have physical properties better suited for holding materials of a larger diameter than have conventional paints. Thus, in performance, as darkness approached, the unbeaded white paint stripes would become progressively less visible, but the black contrast stripes would become white because the retroreflected light would be light focusing in the white binder holding the beads to the carrier.

Another method of reflectorizing the black contrast stripes would be to drop on large glass beads of a uniform diameter, a small portion of which have been coated with a water-soluble pigmented binder that would immediately wash off the top of the bead making it retroreflective and a large portion of which have been coated with a water-insoluble pigmented binder which would, with time and abrasion, wear away and become retroreflective.

Reflectors Mounted on Posts

Reflective objects mounted vertically on posts along the roadway are very visible either dry or wet; they find excellent application around curves and when used to mark obstacles. However, they do not offer the advantages of a pavement marking in that, if they are located too close to the edge of the road, they quickly become covered by a surface film. Thus, unless they are periodically cleaned, they become a hazard, with vehicles striking them. They can be used to advantage along a straightaway to give delineation to the general road pattern; however, the guide they provide during periods of precipitation is considerably less efficient than a pavement marking.

DESIGNING THE MARKING SYSTEM FOR ALL-WEATHER VISIBILITY

Using a paint binder of a single thickness with a gradation of bead sizes for general application, irrespective of road surface conditions, fails to give proper return for one's investment in marking materials. Consideration should be given to the texture or profile of the road surface as it relates to retroreflection under wet and dry conditions. Water films on roadways have been determined to be within certain limits. Thus, if a road surface has a profile that is sufficiently smooth to permit applied retroreflective materials to be submerged during periods of precipitation, then such markings cannot be expected to be retroreflective when wet. By the same token, surfaces with sufficient irregularities to raise the retroreflecting materials above the submerging water films can be efficient. Thus, to obtain a system that will give maximum retroreflectance under varying environmental conditions, one should first determine the surface profile of the roadway to be marked. Once this profile has been determined, the marking system yielding the greatest efficiency should then be selected for use.

Pavement Surface Profile

It was concluded that a profile recorder for field use should be a simple, portable, mechanical device that could be handled by one man and record enough length of road to be representative of the area to be marked. Further, it should magnify the vertical displacements of the road surface by a factor of at least 4. Figure 17 is a photograph of an instrument designed and built for obtaining such measurements. In the field, this instrument is placed on the pavement surface to be marked, and the spring-loaded ballpoint stylus is released so that it encounters the paper strip chart. The feeler and stylus carriage is then moved down the frame, thereby recording a magnified profile of the pavement surface. The paper strip chart is then removed, identified, and returned to the office for interpretation. Some typical recordings encountered are shown in Figure 18.

Interpretation of the chart is handled in the following manner. A median line bisecting the recorded curve is drawn so that the area under the curve and above the bisecting line is equal to the area below the bisecting line and the curve. The bisecting line is considered to be the mean surface of the road above which precipitation can find passage to flow away. The area below the bisecting line is considered to provide surface depression storage. Since water films have been measured and found to range from 30 to 40 mils, this height can then be scaled in above the bisecting line, thus indicating the number of protrusions in the surface that will be expected to be exposed and retroreflective during periods of precipitation. If, in a length of 2 ft, there are fewer than 16 protrusions rising 0.015 in. above the scaled-in water depth, then the texture is considered to be smooth. If there are more than 16 protrusions rising 0.015 in. above the scaled-in water depth, the texture is considered to be rough.

It is imperative that one record the surface profile of the areas to be marked because the transverse surface profile of a pavement can vary widely. Wheel track areas are often very different from the general surface. Repeated applications of marking materials to a given area can result in a profile also quite different from that of the general surface.

Selection of the Marking System

On a rough surface conventional markings can be employed to give good reflectance in both dry and wet conditions. One exception to the use of conventional markings on a rough surface is the use of beads of a single size matched to the binder thickness to give maximum efficiency. The

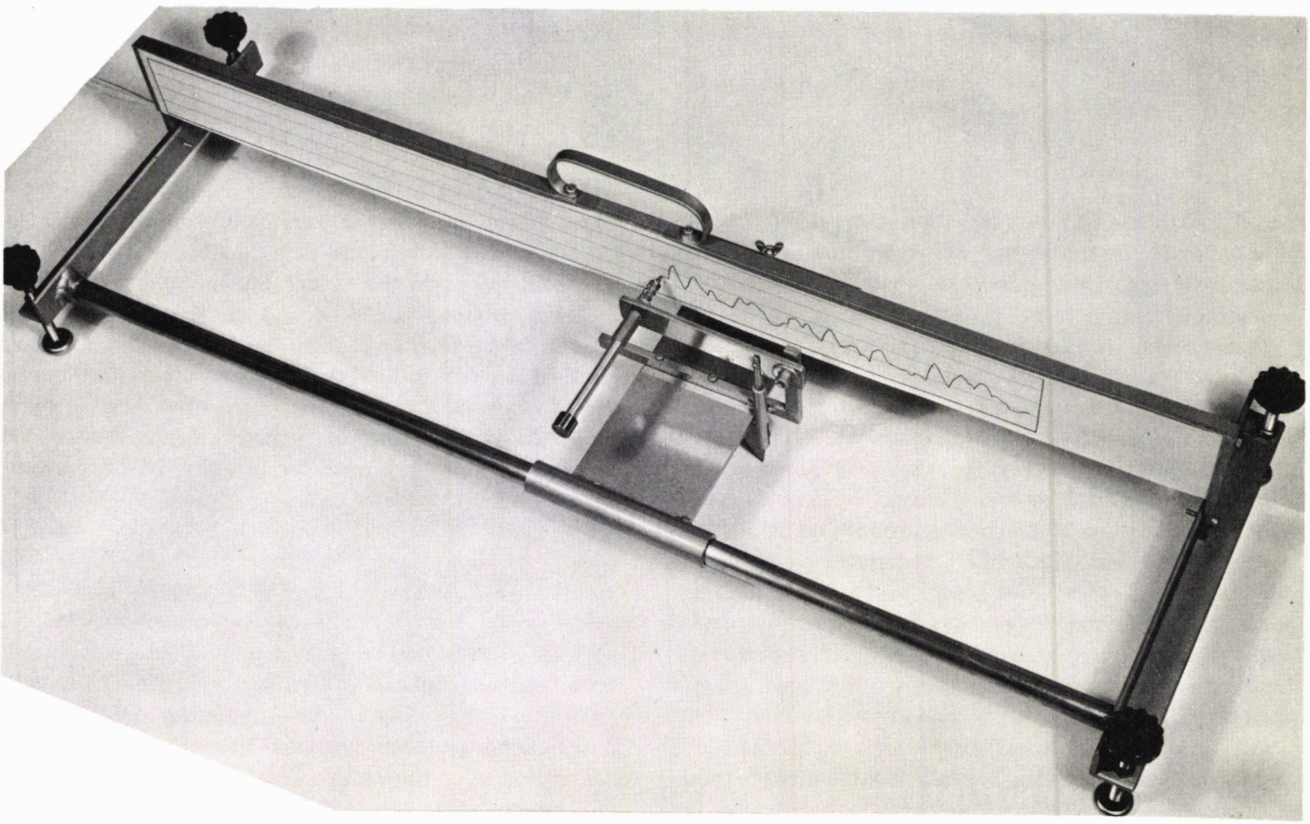


Figure 17. Pavement surface profile recorder.

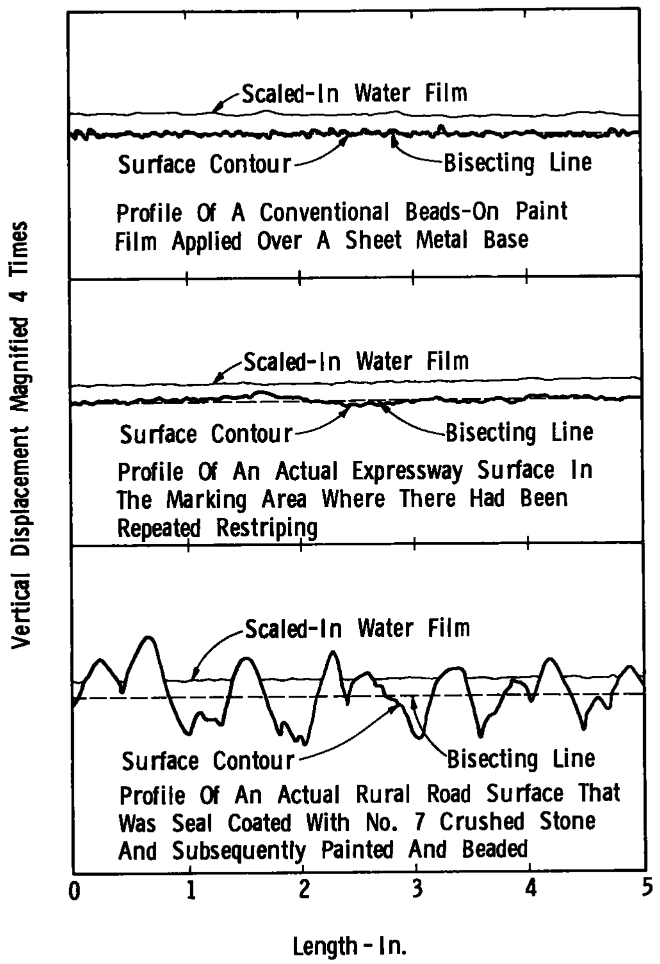


Figure 18. Typical pavement surface profiles.

use of a gradation of beads of various sizes is unattractive, since wearing characteristics are such that the smaller beads have little chance to exhibit their retroreflective capabilities.

When a road surface is either naturally rough or the area to be marked has been given a pretreatment so that it can be classified as having a rough surface, another system with potential would involve the use of a two-coat application procedure: an initial heavy hiding coat of paint is applied and allowed to dry; a second thin binder coat is then applied with a simultaneous dropped-on application of small glass beads of a single size matched to the second coat thickness so as to give optimum reflection efficiency. The advantage of such a procedure would be the use of beads of a smaller diameter with their greater area of reflectance per unit weight of glass. It would have the disadvantage of involving the cost of a second application.

The film thicknesses of marking materials currently applied will sufficiently hide a black bituminous surface. In re-marking operations, where the surface is rough yet light colored (as with some concretes), a thinner binder coat with the smaller beads of single size could, in many instances, be sufficient and offer a savings over the present practice of using one system for all situations. Transverse markings and center, lane, and edge lines are each subject to different and less severe service, respectively, and therefore could be marked accordingly with appropriate savings. The use of raised, reflectorized markings; raised, reflectorized markers in combination with raised, unreflectorized markers; and thin film markings with or without glass beads in combination with raised, reflectorized markers are three systems that can perform effectively on both rough and smooth surfaces.

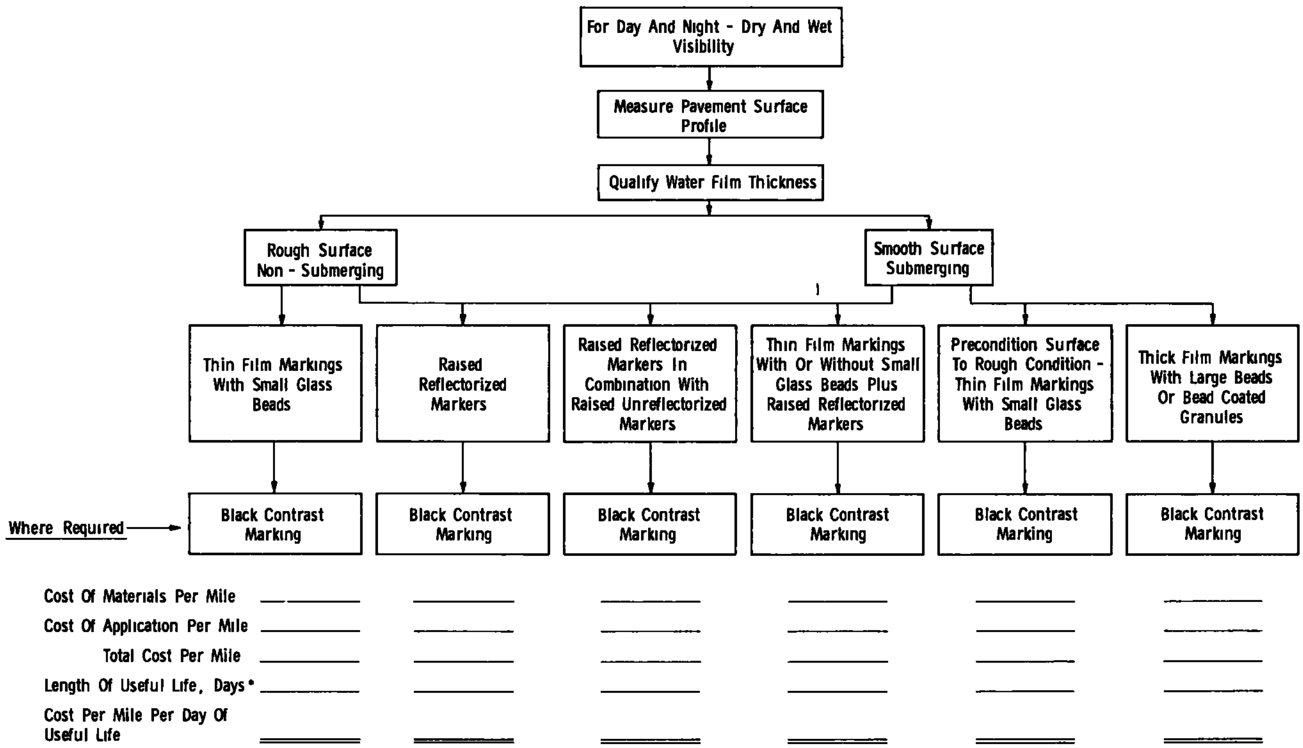
Where a smooth surface is encountered, it is to be expected that the application of conventional paint with beads of standard gradation dropped on will be ineffective during periods of precipitation.

Another method of approaching the smooth surface condition involves preconditioning the area to be marked with an aggregate and then applying a conventional paint with dropped-on beads of a single size matched to the binder thickness to give optimum efficiency. Large beads of a single gradation in a thick binder may also be used in this situation. Since conventional paints do not lend themselves to heavier applications and do not have the power to hold the large beads, which suffer dislodgement under traffic more readily than the small beads, one must look to the thermoplastic and other binder materials being developed. Employing large beads of a single size insures their protrusion through the water films, even under conditions of abrasive wear when the binder is slowly being lost. The use of small beads or a gradation of beads results in the smaller beads being buried in the binder upon application; even after abrasion of the binder, they have insufficient height to protrude above the water films before they are dislodged.

Another solution is to use reflective granules. These are particles of some material, such as an aggregate, that have been coated with an appropriately colored binder and further coated with beads of a single size and small diameter matched to the binder thickness. These granules are then dropped into a second binder, which has been applied to the road and which has sufficient thickness and physical strength to hold them under traffic. Furthermore, use of beads as a coating on granules provides an opportunity to utilize those of a small diameter with their greater retroreflecting area per unit weight of glass than beads of a large diameter.

Comparing Systems

Selecting a system for a given application resolves itself into an effectiveness analysis and must be geared to the conditions encountered in the field. Figure 19 is an example of a flow diagram for comparing systems. It indicates, among other things, that the proper selection of a delineation system involves several variables, each of which must be evaluated and related to one another if maximum benefit is to be derived from the marking materials.



*Institute Of Traffic Engineers Technical Report No. 4 - ASTM Designation D - 713, D - 821, D - 913, D - 1011

Figure 19. Flow diagram for comparing highway marking systems.

CHAPTER FOUR

APPLICATION OF FINDINGS

DEVELOPMENT AND FIELD TESTING OF AN ADVANCED DAY-AND-NIGHT, DRY-AND-WET MARKER

By considering the various principles that influence the performance of marking materials, it is possible to select one of several methods of improving the delineation of roadways or of employing these principles, and to design additional and improved marking systems. The design of one such additional system was undertaken. In reviewing the previous sections of this report, one finds continued reference to the use of large beads of a single size, stronger binders, and high-speed application techniques. Furthermore, in designing marking systems for all-weather visibility, the use of raised, reflectorized markers finds application on pavements having both smooth and rough surfaces. Thus, developing a system incorporating the combined features of the ability to be applied like a paint but perform like raised, reflectorized markers was undertaken. To do this, it was necessary to select a reflectorizing medium and a binder and then to field test the combination.

For a reflectorizing medium, glass beads were chosen because of their simplicity and low cost. From a mechanical standpoint and for random application a material having a spherical shape as opposed to an irregular shape is ideal for transmitting an imposed load. A glass bead should rise at least 60 mils above any water film encountered during periods of precipitation. Based on a 40-mil water film and a 20-mil imbedment of a bead over its equator for binding and proper retroreflectance, a bead radius of 120 mils results; thus, a glass bead having a diameter of 240 mils or approximately 0.25 in. is needed. A commercially available source of glass beads of this size proved to be limited to one company. It was found that manufacturers of glass beads for highway marking produced a mixed gradation ranging from 10 to 200 mesh, and that commercial manufacturers of marbles produced these at a diameter down to 0.375 in.

The only glass beads of 0.25-in. diameter that could be located were from the Industrial Components Department of Corning Glass Works. Unfortunately, these beads were made of glass with a low refractive index, whereas glass beads with a high refractive index would have been preferable. However, it was desired to proceed with the development work using the glass beads with a diameter of 0.25 in. and a low refractive index and at the same time to initiate contacts with several manufacturers for the production of some beads of this size with a high refractive index. Bead-coated granules could have been used effectively had they been available or had there been time to prepare them. The use of beads of single size with a large diameter has the potential of providing a reflective medium that would have better self-cleaning characteristics under precipitation and the action of vehicle tires than gradations of small beads or bead-coated granules.

As a high-strength, thick-film binder for beads of a large diameter, conventional paint materials have the major limitations of less strength, longer drying time, and less adhesion compared with the plastic or resin materials of both the thermosetting and thermoplastic types. Outstanding among the resin materials for durability, curing time, and adhesion are the epoxy materials. They are widely used as an adhesive for applying factory-made raised, reflectorized markers. Although they were selected for use in this effort, some of the other resin types could have been used and deserve more attention because of their generally lower cost. To give the epoxy color as well as body so that it would not be too fluid to hold a thick film, a filler and a pigment were required. Titanium calcium was used as both a filler and a pigment. Other less expensive and physically stronger fillers are readily available.

So as to gain acceptance and lower the cost of raised, reflectorized markers, it is desirable that they be applied at speeds approaching those at which conventional marking paints are applied. The practice of making a raised, reflectorized marker in a plant at one site and applying it by hand at another site appeared less desirable than the concept of physically making and applying a raised, reflectorized marker in one operation at the same site at speeds approaching those employed for applying paint. The expense of machinery of sufficient capability to perform this function was beyond the budgetary limits of the program at that stage.

TABLE 4

COMPOSITION AND COST OF RAW MATERIALS USED IN REFLECTORIZED MARKERS ON ROADS AT SOUTHWEST RESEARCH INSTITUTE, 1966

WEIGHT PER UNIT (G)	MATERIAL	APPROXIMATE COST, ($/UNIT)
16	Shell Epon 828 epoxy resin	0.0432
16	Ti-Cal pigment	0.0035
4	Shell epoxy curing agent U	0.0124
7	19 glass beads, 0.25-in. diameter 1.5 RI	0.0100
	Total cost	0.0691

Initial experimentation was conducted by making and placing a number of markers on Southwest Research Institute roads. On June 16, 1966, a half-mile section of Culebra Road, which is a county-owned, asphaltic concrete road bordering Southwest Research Institute, was selected for marking by the developed technique. Reflectorized markers made from a pigmented epoxy and glass beads with a diameter of 0.25 in. and a low refractive index were applied at 40-ft intervals at the center point of the unpainted space between the existing 15-ft painted skip stripes. As the raised, reflectorized markers were being

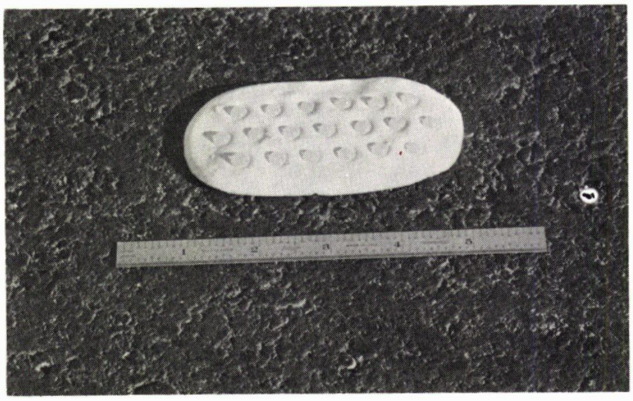


Figure 20. Experimental highway marker.

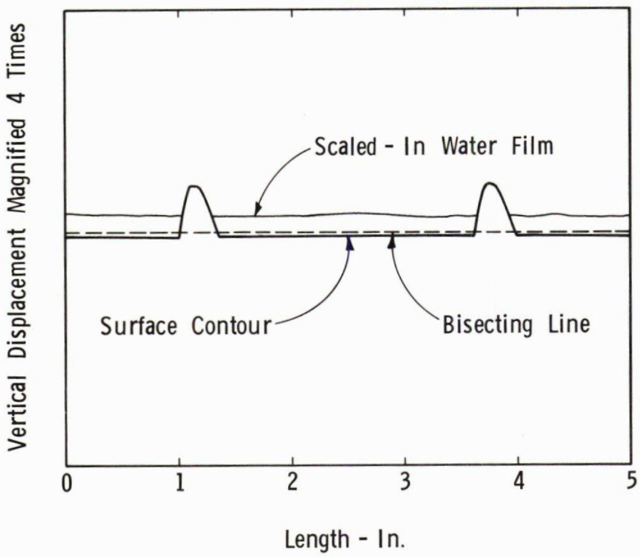


Figure 21. Surface profile of experimental highway marker.

applied, the white center skip stripes were repainted. Table 4 gives the composition and approximate cost of raw materials for the raised, reflectorized markers.

Physical placement of the markers involved premixing the pigment and the resin with a hand-drill mixer. The curing agent was then added and mixed with the resin. The mixture was then poured onto the road surface in a configuration approximately 4 × 2 × 0.145 in. A small perforated plate holding 19 glass beads 0.25-in. in diameter in a desired pattern was then placed over the freshly applied resin material and by a tripping mechanism made to fall into the resin; the beads then sank by gravity to the point where they were imbedded to approximately 60 percent of their vertical height. Figure 20 is a photograph of one of the experimental markers. The curing time for the resin system was approximately 15 min, after which the markers were released to accept traffic. This installation was observed closely over the summer and through the fall, in the wet and dry conditions, which occurred both naturally and were created artificially, down through the end of the project; the final inspection occurred on December 15, 1966.

The physical performance of the raised, reflectorized markers was better than anticipated. A surface profile of one of these markers is shown in Figure 21. Protrusion of the reflective elements of the glass beads 0.25 in. in diameter is shown to be sufficient to resist submergence by anticipated water films. The markers' ability to be retroreflective when subjected to natural and artificial precipitation was excellent; however, it was unfortunate that glass beads of a high refractive index could not have been located since their use would have materially improved the brightness of the individual markers. Physical damage to the large diameter glass beads was almost nonexistent except that several of the markers lost one or two beads where the resin began to react and set and became too viscous to allow the bead to settle and imbed itself over its horizontal axis. The only major physical damage to the markers occurred in two places where someone employed a blunt instrument, drove it into the pavement, and broke out sections of two markers for souvenirs. The paint stripes at this location had deteriorated to such an extent that, on December 1, they were repainted.

Because of the low vertical height of the developed markers, they should be less subject to snowplow damage and not require physical removal before resurfacing operations.

CHAPTER FIVE

CONCLUSIONS

So as to improve center, lane, and edge lines as well as the many other pavement markings used in delineation of roadways in the wet and dry condition, the following conclusions are made:

1. A systematic approach to marking pavements is needed wherein one obtains a pavement surface profile of the surface to be marked, qualifies the water film thicknesses to be encountered, and then selects one of several marking systems that will perform under the imposed conditions and provide the lowest cost per mile per day of useful life.
2. Only under very unusual circumstances, such as when a road surface is extremely rough or when the area to be marked has been pretreated to present a very rough surface, can conventional paint binders, reflectorized with the current bead gradations, be expected to perform when wet.
3. Retroreflective materials can perform satisfactorily, even when wet, so long as they are not covered by a layer of water. Raised, reflectorized markers perform in this manner and are very effective. The use of glass beads of a larger diameter or bead-coated granules in thicker binders or improved binders, such as some of the thermoplastic or thermosetting resins that have sufficient mechanical properties to hold these materials under traffic, is another attractive approach to this problem.
4. Incorporation or placement of retroreflective materials other than in or on surface film markings such as paint improves the daytime visibility and appearance of surface film markings.
5. Great benefits are seen from the use of beads that are essentially the same diameter, the diameter selected being the one that will result in the beads being imbedded in the binder to 55 to 65 percent of their vertical height.
6. The idea of producing waterproofed or water repellent glass beads is an excellent concept. Unfortunately, the silicone and other available treatments appear to be so short-lived in the field that they are of little practical significance.
7. The use of glass beads of a high refractive index and the use of larger quantities of glass per unit of stripe offer improvements in the field; however, it

would appear that, in the immediate future, greater dividends would accrue from the better utilization of glass beads having a low refractive index and costing less through improved bead-gradation specifications and application techniques.

8. Marking authorities should consider adding equipment, either separate or complementary, to their present marking machines that will allow raised, reflectorized markers to be made at high speed in one operation at the point of application along the lines of the system developed in this program and described in this report.

CHAPTER SIX

SUGGESTED RESEARCH

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

1. An analysis of the precipitation by areas as it relates to water films on various types of pavement surfaces and slopes to establish detailed design criteria for water film depths.
2. A qualification of rainfall intensity wherein the light scattering effect is sufficient to influence the ability of retroreflective materials to receive and return light.
3. The development of an inexpensive night visibility meter that can be used to evaluate pavement markings in both the dry and wet condition.
4. The development of a system for qualifying the point at which the contrast of a pavement-marking material and the road surface is insufficient and a contrast stripe is needed.
5. The development of thicker film and more durable and less expensive marking materials.
6. A study of raised markers in terms of their present and future use both separately and in conjunction with surface-film markings and their relation to snow removal operations from the standpoint of determining if the marking system should be designed to accommodate the snow removal equipment or if the snow removal equipment should be designed to accommodate the marking system.
7. The further development of the concept of both making and applying on site raised, reflectorized markers.

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44	Traffic Attraction of Rural Outdoor Recreational Areas (Proj. 7-2), 28 p., $1.40
45	Development of Improved Pavement Marking Materials—Laboratory Phase (Proj. 5-5), 24 p., $1.40

* Highway Research Board Special Report 80.

THE NATIONAL ACADEMY OF SCIENCES is a private, honorary organization of more than 700 scientists and engineers elected on the basis of outstanding contributions to knowledge. Established by a Congressional Act of Incorporation signed by President Abraham Lincoln on March 3, 1863, and supported by private and public funds, the Academy works to further science and its use for the general welfare by bringing together the most qualified individuals to deal with scientific and technological problems of broad significance.

Under the terms of its Congressional charter, the Academy is also called upon to act as an official—yet independent—adviser to the Federal Government in any matter of science and technology. This provision accounts for the close ties that have always existed between the Academy and the Government, although the Academy is not a governmental agency and its activities are not limited to those on behalf of the Government.

THE NATIONAL ACADEMY OF ENGINEERING was established on December 5, 1964. On that date the Council of the National Academy of Sciences, under the authority of its Act of Incorporation, adopted Articles of Organization bringing the National Academy of Engineering into being, independent and autonomous in its organization and the election of its members, and closely coordinated with the National Academy of Sciences in its advisory activities. The two Academies join in the furtherance of science and engineering and share the responsibility of advising the Federal Government, upon request, on any subject of science or technology.

THE NATIONAL RESEARCH COUNCIL was organized as an agency of the National Academy of Sciences in 1916, at the request of President Wilson, to enable the broad community of U. S. scientists and engineers to associate their efforts with the limited membership of the Academy in service to science and the nation. Its members, who receive their appointments from the President of the National Academy of Sciences, are drawn from academic, industrial and government organizations throughout the country. The National Research Council serves both Academies in the discharge of their responsibilities.

Supported by private and public contributions, grants, and contracts, and voluntary contributions of time and effort by several thousand of the nation's leading scientists and engineers, the Academies and their Research Council thus work to serve the national interest, to foster the sound development of science and engineering, and to promote their effective application for the benefit of society.

THE DIVISION OF ENGINEERING is one of the eight major Divisions into which the National Research Council is organized for the conduct of its work. Its membership includes representatives of the nation's leading technical societies as well as a number of members-at-large. Its Chairman is appointed by the Council of the Academy of Sciences upon nomination by the Council of the Academy of Engineering.

THE HIGHWAY RESEARCH BOARD, organized November 11, 1920, as an agency of the Division of Engineering, is a cooperative organization of the highway technologists of America operating under the auspices of the National Research Council and with the support of the several highway departments, the Bureau of Public Roads, and many other organizations interested in the development of highway transportation. The purposes of the Board are to encourage research and to provide a national clearinghouse and correlation service for research activities and information on highway administration and technology.