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GEORGIA INSTITUTE OF TECHNOLOGY

OFFICE OF CONTRACT ADMINISTRATION

RESEARCH PROJECT INITIATION

Date: September 29, 1975

Project Title: Open-Graded Asphalt Friction Course Lane Marking System

Project No: E-20-676 (Sub-project under A-1753/EES)

Principal Investigator Dr. James S. Lai - Dr. Quentin L. Robnett

Sponsor: U. S. Dept. of Transportation

Agreement Period: From June 18, 1975 Until December 19, 1977

Type Agreement: Contract DOT-FH-11-8782

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SPONSORED PROJECT TERMINATION

Date: 3/2/78

Project Title: Open-Graded Asphalt Friction Course Lane Marking System

Project No: E-20-676 (Sub-project under A-1753/EES)

Project Director: Q. L. Robnett

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Report No. FHWA–RD–77–164

DEVELOPMENT OF A POROUS LANE MARKING SYSTEM

Q. L. Robnett and W. H. Burrows

December 1977

Final Report

This document is available to the public through the National Technical Information Service, Springfield, Virginia 22151

Prepared for

FEDERAL HIGHWAY ADMINISTRATION
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16. Abstract

Good wet-night visibility is a major objective of highway delineation. The primary objective of the research project described in this report was to develop a lane marking system that has good visibility, has porosity and texture characteristics similar to open graded asphalt friction courses, and has good resistance to traffic and snowplow activity. The porous marking systems developed are composed of narrowly graded aggregate, binder, pigment, glass beads, and void space.

The scope of the study included binder compound selection, mixture formulation, laboratory evaluation of various systems, and a two-stage field evaluation of promising porous marking systems. Field evaluation of the porous marking systems was conducted on an expressway entrance ramp in Georgia and on a four-lane highway in Virginia. Delineator installation procedures and serviceability examination techniques are described. Wet-night visibility of the porous marking systems was evaluated using an automobile-mounted telephotometer.

Based upon the results of the study, it is concluded that the combination of an open-graded asphalt friction course and a special porous delineator centerline stripes provide superior wet-night delineation compared to conventional beaded paint stripes on a dense asphalt surface.

The project results do not establish the life expectancy or overall economy of "optimumly designed and installed" porous delineation systems. Additional field testing must be conducted to establish service life and overall economics.

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PREFACE

The study reported on here was conducted jointly by the School of Civil Engineering and the Engineering Experiment Station, Georgia Institute of Technology. This report describes the development and evaluation of a special porous marking system which was developed to improve wet-night visibility of highways surfaced with open-graded asphalt friction courses.

The authors wish to thank Mr. Lloyd Carver of the Georgia Department of Transportation and Mr. William Maupin of the Virginia Highway and Transportation Research Council for their cooperation and support during the field testing phases of the study.

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INTRODUCTION

1.1 THE PROBLEM

Provision and maintenance of lane guidance on highways is a primary goal of the highway engineer. Under wet weather conditions, provision of an adequate level of this important surface property is often difficult. The presence of water on the pavement surface contributes to a general loss in visibility of lane marking stripes and an increased glare under day and nighttime conditions. The lack of adequate lane guidance at night under wet conditions is in particular a critical highway safety problem. This is evidenced by the fact that the Congress singled out the problem for special efforts in the 1973 Highway Act [1], authorizing a significant appropriation "to develop new traffic control materials, devices, and related delineators to assist the traveling public during adverse weather and nighttime driving conditions". In southern states the problem of wet-night lane marking has been solved to a great extent by supplementing conventional painted stripes with raised reflective markers. In northern states, however, such markers are incompatible with snowplows and other solutions are needed.

The development of Open-Graded Asphalt Friction Courses (OGAFC), although developed primarily for other reasons, has reduced the wet-night lane delineator visibility problem. The OGAFC which was developed primarily to minimize the hydroplaning potential and to improve wet weather skid resistance, is a thin surface layer possessing a high porosity and permeability and a rough surface texture. The open-graded, high porosity characteristic of the material is obtained by using narrowly graded coarse aggregate having no appreciable fines content. The porous characteristic minimizes the potential for hydroplaning by allowing numerous escape channels for water beneath a moving tire. Additionally, the porous structure minimizes or eliminates the time during which the pavement surface and thus the delineator stripe is inundated and thereby ineffective as a reflective material. Minimizing or eliminating surface inundation should also help combat the loss of delineator visibility caused by headlight glare. It is also believed that as a result of the rough texture of the OGAFC, the angle of incidence of a vehicles' headlights on the reflective material will be improved thereby providing better reflection and night visibility.

The use of OGAFC is also believed to have other advantages [2] such as:

1. minimization of splash and spray during wet weather,
2. lower highway noise levels, and
3. retardation of ice formation on the surface.

The use of conventional paints and hot applied thermoplastic lane striping materials and raised pavement markers (RPM) with the OGAFC has certain limitations and undesirable features including:

1. Initially, greater quantities of paint or hot applied thermoplastic striping material are required because of the porous substrate.
2. Partial or complete restriction of lateral water flow at the lane striping location due to the filling of voids with low viscosity striping materials. This can cause local stoppage of outflow of water from the OGAFC thereby inundating delineator stripes.
3. More rapid loss of RPM from the OGAFC surfaces compared to other conventional pavement surfaces. Additionally, most RPM do not provide a delineation system which is snowplowable.

Based on the foregoing, it is apparent that conventional delineation systems have certain limitations and undesirable features when used with OGAFC. It has been proposed that a better delineation system for the OGAFC would be one which uses the same open texture principle.

1.2 PURPOSE OF RESEARCH

A research project was initiated to develop a snowplow resistant lane delineation system that has porosity and texture characteristics similar to open-graded asphalt friction courses and that provides adequate lane stripe visibility at night under rainy conditions. Additionally, the delineation system developed should have strength and thermal properties which are compatible with those of the OGAFC and should lend itself to placement simultaneously with or after the OGAFC.

1.3 SCOPE OF RESEARCH

1. Develop formulations of delineation materials and binders that have porosity and texture characteristics similar to that of the open-graded asphalt friction course. They shall lend themselves to placement at the time of construction of the roadway wearing course on new construction, and for installation after construction on older existing OGAFC pavements. These mixtures shall be compatible with OGAFC mixtures in physical properties.

2. Evaluate the formulated materials under laboratory but simulated real-life environmental conditions.

3. Place pilot test sections in an area where they will be subjected to deicing salts, sand, rain, snowplow action, and an adequate traffic volume to evaluate their serviceability.

4. Place field test sections under real-life conditions for at least one full winter's exposure in an area where there is moderate snowplow activity and high traffic density.

5. Prepare guidelines, specification requirements, and recommended laboratory test methods for evaluating suitable open-graded delineation material systems.

1.4 WORK PROGRAM

In order to fulfill the objectives of the research program, specific phases of activities were designated. These are:

Phase I - Mixture Development
Phase II - Pilot Field Test Sections
Phase III - Full-Scale Field Evaluation
Phase IV - Preparation of Guidelines, Specifications, and Laboratory Test Methods

A comprehensive flow diagram indicating the order of various activities of the research program is depicted in Figure 1.1.

1.5 PURPOSE AND ORGANIZATION OF REPORT

The purpose of this report is twofold. First, project activities pursued during Phase I, II, and III are described in detail. Results from these phases are discussed. A second purpose of this report is to present material requirements and guidelines for proper application of special porous delineation systems.

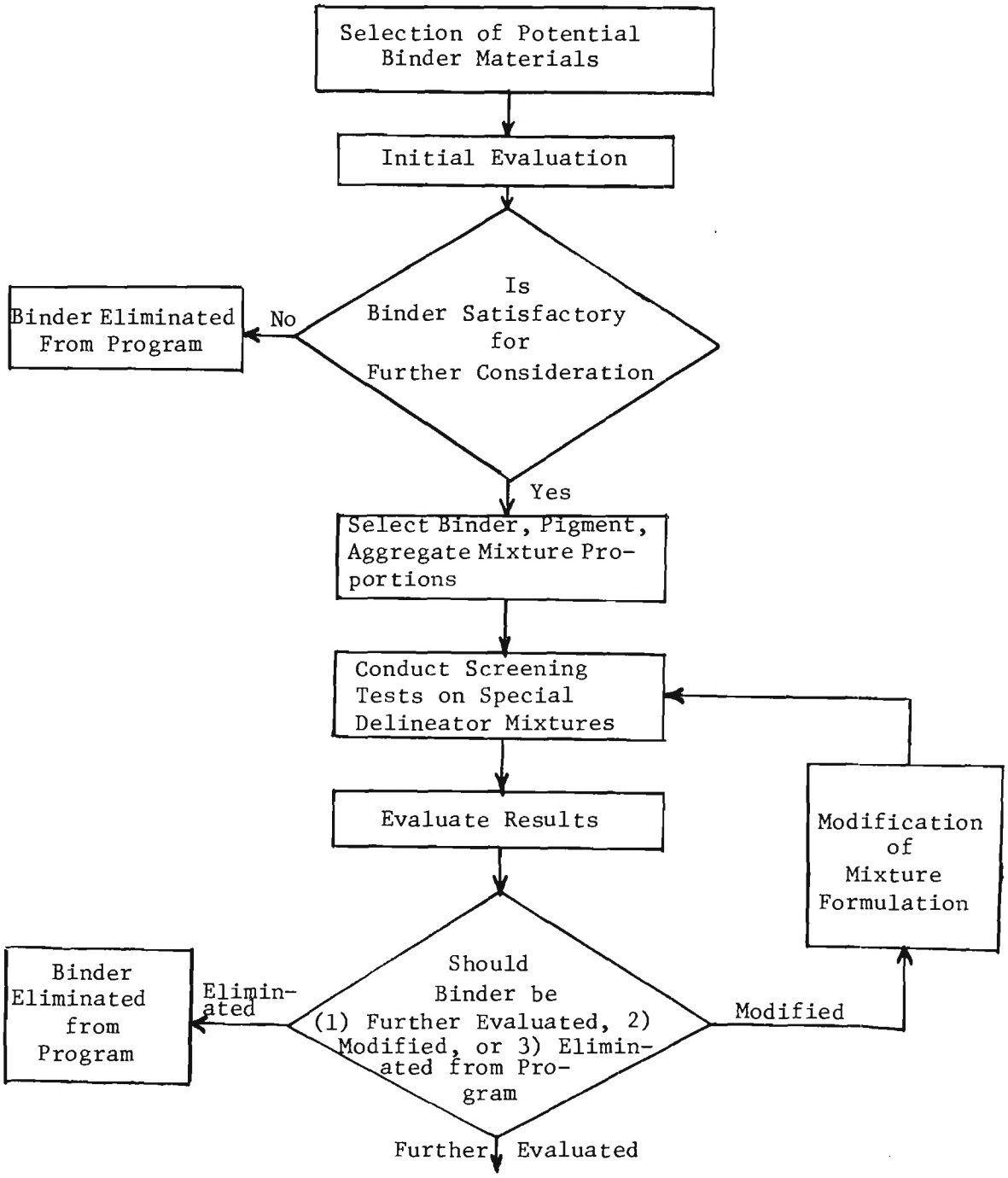


Figure 1.1. Comprehensive Activities Chart for Research Program.

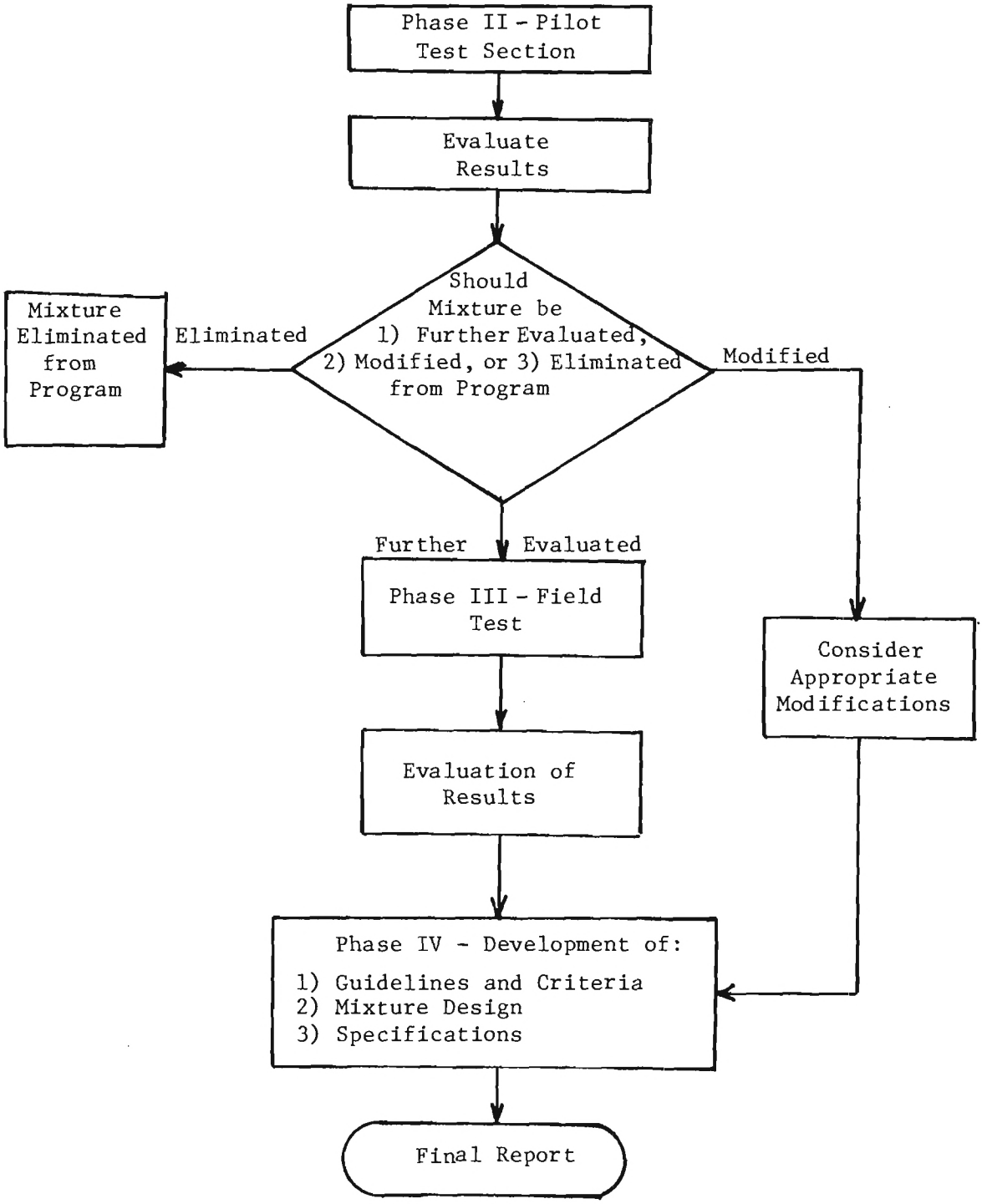


Figure 1.1. Comprehensive Activities Chart for Research Program (continued).

COMPONENT MATERIALS AND BINDER SELECTION

2.1 MATERIALS

The special delineator systems must possess a porous, open-graded texture and must have appropriate color and light reflectance quality; thus, the delineator system should be composed of the following key ingredients:

1. aggregate
2. color pigment
3. glass beads
4. binder

The aggregate used in the new porous delineator system acts primarily as an inert material which establishes the open-graded skeleton of the porous system. As with OGAFC systems, it is desirable to use an aggregate that is strong, durable and nonpolishing. The aggregate used was a high quality crushed granite gneiss commonly available in Georgia with a gradation shown in Figure 2.1. Pertinent properties of the aggregate material are summarized in Table 2.1.

Another key ingredient in the porous delineator system is pigment. The pigment is used to provide either the yellow or white color to the delineator. Identification of the pigments used in the study is presented in Table 2.2.

Glass beads were used to provide the required level of light reflectivity. The beads were placed only on the upper surface of the porous delineator system. Only one type of glass bead was used throughout the study. General properties of the glass beads used in the study are given in Table 2.2.

The binder performs the important functions of binding the porous system together, accepting and holding the pigmentation, and holding the glass beads on the surface. Various aspects of binder selection and mixture formulation will be discussed in subsequent sections of this report. Properties of the asphalt binder used are summarized in Table 2.3.

2.2 CONSIDERATIONS FOR BINDER SELECTION

Probably the most critical aspect of mixture development was formulation of appropriate binder compounds. Numerous criteria were used to facilitate initial selection and screening of potential binders and included in the following:

1. Strength, durability and toughness
2. Ability to adhere to aggregate and glass beads

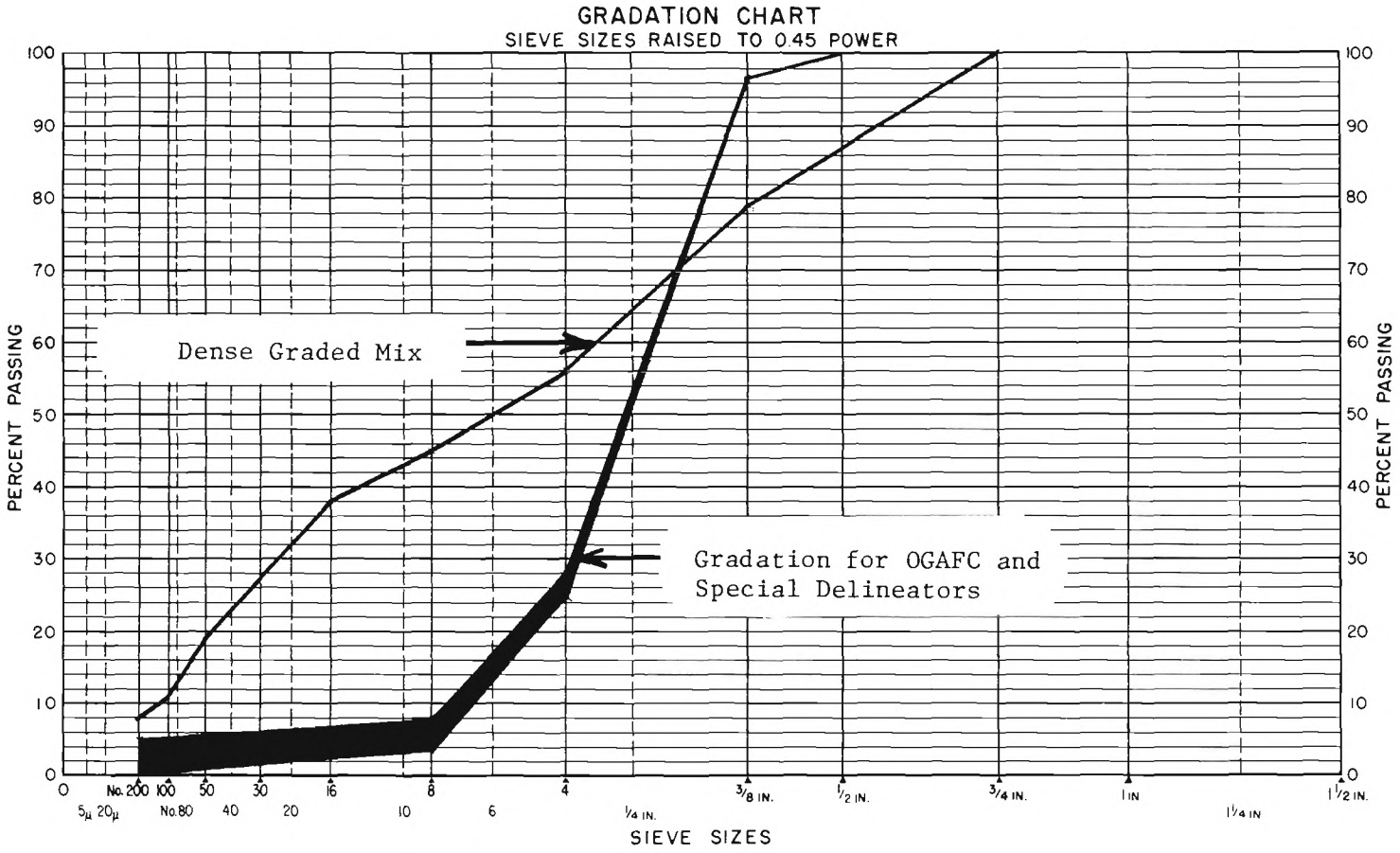


Figure 2.1. Gradation of Granitic Gneiss Aggregate.

Table 2.1. Summary of Pertinent Properties of Aggregate Used in Studies.

Producer and Location of Source:	Vulcan Materials Company Lithia Springs, Georgia	
Aggregate Material:	Granitic Gneiss	
Specific Gravity (ASTM):	Bulk	2.60
	SSD	2.62
	Apparent	2.64
Absorption, % (ASTM C127):	0.56	
Wear, % (ASTM C131):	37	
Magnesium Sulfate Soundness Loss, % (ASTM C88):		0.50
Surface Constant, K_c, for open-graded mix (Testing Procedure as per Ref. 2)		1.35

Table 2.2. General Characteristics of Glass Beads and Pigments.

Glass Beads

Supplier: 3M - Super Brite

Refractive Index: 1.5

Size: 30 to 100 mesh

Yellow Pigment

Lead Chromate

White Pigment

Titanium Dioxide and Zinc Oxide

Table 2.3. Summary of Pertinent Properties for Asphalt Cement.

Viscosity Grade: AC-20

Source: Shell Oil, obtained from Trumbull Asphalt Company, Atlanta, Georgia

Properties:

Absolute Viscosity* @ 140°F (60°C) = 1761 poises
Kinematic Viscosity*@ 275°F (135°C) = 358 centistokes
Penetration @ 77°F (25°C) = 68
Cleveland Flash Point* = 590°F (310°C)
Solubility in Trichlorocthylene = 99.9%
Specific Gravity* @ 60°F (15.5°C) = 1.017
Ring and Ball Softening Point* = 124°F (51°C)

Thin Film Residue*:

Absolute Viscosity @ 140°F (60°C) = 4072 poises
Ductility @ 77°F (25°C) = 150+ cm

* Properties determined by Georgia Department of Transportation, Materials Laboratory, Forest Park, Georgia.

3. Ability to be pigmented to white or yellow color
4. Compatibility of thermoproperties with that of asphalt
5. Workability and curing characteristics appropriate for required application methods
6. Relative cost factor

It was felt that the strength and toughness of the binder had to be at least as good as that of asphalt in order to provide adequate strength and stability to the resultant porous delineation system and also provide adequate retention to the partially exposed glass beads. Furthermore, the binder should not display significant changes in pertinent properties upon exposure to elements such as ultraviolet light, heat, hydrocarbon solvents, and moisture.

The binder was also required to permanently adhere to the aggregate and glass beads and to be pigmented to appropriate colors. The difficulty in providing a mixture which is not susceptible to "stripping" was recognized.

It was obvious that the binder materials must be formulated so as to provide the appropriate white or yellow color of conventional lane marking materials. Reasonable methods of providing the appropriate color were to pigment the binder or to use colored aggregate and a clear binder. The former approach was selected.

Another requirement of a porous delineator mixture was its property of allowing simultaneous placement with the OGAFC overlay or placement in existing OGAFC layers. Thus, the binder must possess workability and curing characteristics which facilitate production of the porous delineation system for particular job applications.

2.3 BINDER SELECTION AND PRELIMINARY SCREENING

A systematic approach was used to select promising binder compounds and to initially screen such materials. Figure 2.2 is a generalized flow diagram which depicts the various critical phases of the binder selection and preliminary screening process.

The contract for this project listed the following as materials to be considered for binders. All are thermoplastics.

1. Ionomers
2. ABS and its blends
3. Alkyd molding compounds
4. Polyamide GR

Additions to this list were made by examining the properties of the various resin types listed in Modern Plastics Encyclopedia [3] and by scanning the product literature files of the Industrial Chemistry Group of the Engineering Experiment Station at the Georgia Institute of Technology. Additions to the original list included the following:

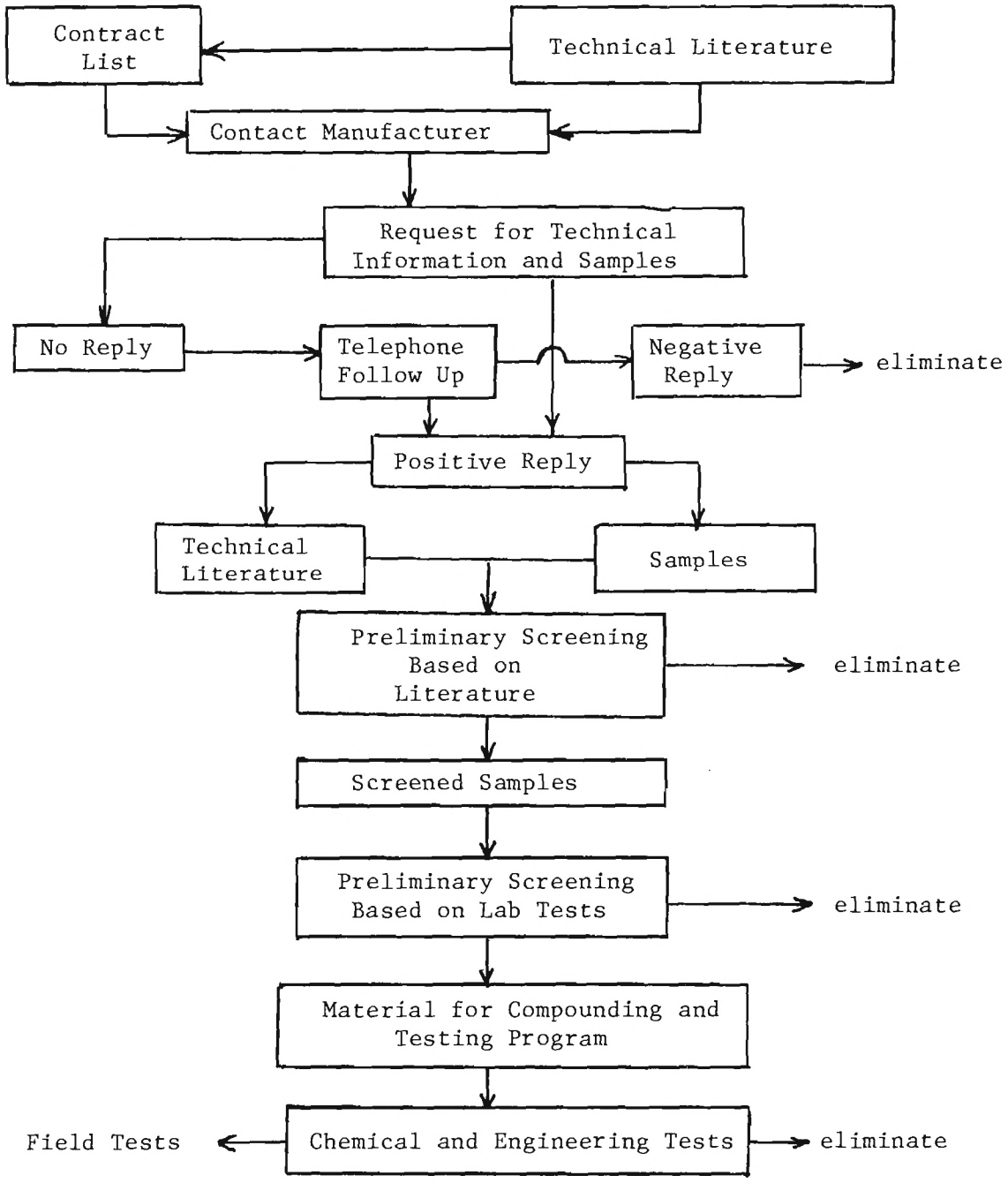


Figure 2.2. Flow Diagram for Binder Selection and Preliminary Screening.

Thermoplastic:	Acrylics
	Polyamides
	Poly(amide-imide)
	Thermoplastic polyesters
Thermosetting:	Epoxies
	Polyesters
	Polyurethanes

Listing of resin suppliers given in the Modern Plastics Encyclopedia [3] were utilized primarily because of their completeness and provisions for selection of resins based upon subclassification according to function. In this reference, each company listed as a supplier of a certain type of resin has associated with its entry, a numerical code, as follows:

1. Basic Resins
2. Casting Resins or Compounds
3. Laminating Resins or Compounds
4. Molding or Extrusion Compounds
5. Organisols and Plastisols
6. Powders (Finely Divided)
7. Solutions, Emulsions or Dispersions
8. Blends, Alloys, etc.

Attention was directed primarily to Classes 1, 5, 6, 7, and 8, although letters of inquiry were worded in a sufficiently broad manner such that other classes might be included in the recommendations forwarded by the resin suppliers.

In making inquiry to resin suppliers, attention was directed primarily to the types of polymers included in the proposal, i.e., ionomers, acrylonitrile-butadiene-styrene (ABS), alkyds, and polyimides. Under ionomers, for instance, the index lists four companies, namely Ametek/Westchester, DuPont de Nemours & Co., LNP Corporation and Union Carbide Corporation. Of these, only three were selected to be contacted; the LNP Corporation is listed as supplying only molding or extrusion compounds. At the time it was not anticipated that molding or extrusion technology would enter into the production of the lane striping material.

The number of companies contacted, according to the resin type, was as follows:

Ionomers	3
ABS Resins	32
Alkyds	35
Polyimides	12
Total	82

Each of these companies was contacted by letter, using a form letter. This letter briefly outlined the problem which was being studied,

the manner in which candidate materials would be tested and evaluated, and the types of resins primarily selected for study. Recommendations for other resins were invited, provided a clear rationale for their use could be shown. The letter requested that for each of the recommended materials, each company provide (a) product technical information, tested formulations, and performance data on both resin and formulated composites and (b) experimental samples, preferably 2 to 5 pounds, including resin and hardener, if the latter were required.

Seven companies replied negatively, five responded in a manner which left considerable question as to whether their materials might be applicable, and these were given no further consideration. There were also a number of companies which made no response whatsoever. But the number of materials for which samples were supplied, it was felt, adequate to initiate the program and see it to a successful conclusion.

Table 2.4 shows the list of companies from which samples were received, the trade names of the submitted samples, the type of resin, and initial evaluation based upon laboratory experimentation or study of the product literature.

Initially, some of the recommended materials were eliminated on the basis of unsatisfactory physical properties, such as thermal characteristics, resistance to light, moisture or solvents, etc. obtainable from manufacturer's literature. Those remaining were screened on the basis of examination of the submitted samples. All materials eliminated on the basis of information provided in the descriptive literature and/or observed characteristics of the submitted samples were dropped from further consideration.

Preliminary laboratory screening tests consisted of preparing disc-shaped test pieces from the previously described granite aggregate and a 4 to 10 percent resin binder, fabricated either by melting the resin or applying it in solution, then evaporating the solvent. Acceptance criteria were primarily toughness, flexibility, adhesive strength and porosity of the test piece. The characteristics were not quantitatively evaluated at this time, but served the purpose for an initial screening step.

An extensive series of evaluations were conducted involving the following thermoplastic materials:

6 acrylics
2 ionomers
1 chlorinated rubber
1 polyamide
1 polystyrene
1 polyurethane

These were compounded with aggregate separately, in combination with each other, and in combination with plasticizers, such as dioctyl

Table 2.4. Resin Materials Source and Initial Evaluation.

Resin Trade Name	Resin Type	Supplier	Initial Evaluation
Arochem 530	Modified Maleic	Ashland	Advantage lower melting point and application temperature, but poor adhesion to aggregate and pigments
Blendex 105A, 107A, 111A	Polyvinyl Chloride	Borg-Warner	Technical literature does not support this application. Not evaluated as test composites.
BLX 301, 311, 101	ABS Ionomer		Insoluble in aromatic solvent. Failed to melt, but decomposed.
Spenkel P49-75S	Polyurethane	Spencer-Kellogg	Isocyanate-to-polyol ratio critical. Difficult to control curing time.
Spenlite P25-60CS	Polyurethane	Spencer-Kellogg	Isocyanate-to-polyol ratio critical. Difficult to control curing time.
Somel	Thermoplastic Elastomer	Dupont	Samples and literature discouraged use of this material in this type application. Not evaluated as test composites.
Acryloid A-11 Acryloid B-48-N Acryloid B-44 Acryloid B-66[(a)] Acryloid B-67 Acryloid B-50	Acrylic	Rhom & Haas	Evaluation continued throughout research program. B-66 included in final field tests.

Table 2.4. Resin Materials Source and Initial Evaluation (continued).

Kynar	Vinylidene fluoride	Pennwalt	Melting point too high. Did not soften sufficiently to wet the aggregate. Lack of adhesion to aggregate.
Piccopale	Petroleum Derivatives	Hercules	Evaluated, but discarded in favor of proprietary hot melt glue
Piccotex Resins	Petroleum Derivatives	Hercules	Evaluated, but discarded in favor of proprietary hot melt glue
Staybelite Resins	Petroleum Derivatives	Hercules	Evaluated, but discarded in favor of proprietary hot melt glue
Surlyn [(a)]	Ionomer	Dupont	Initial difficulty with adhesion overcome by admixture with polyamide. Evaluation continued throughout research program. Included in final field tests
V-pyrol	Polyvinyl Pyrrolidone	General Aniline & Film	Samples and literature discouraged use of this material for this type application. Not evaluated as test composites.
Valox	Polyester	General Electric	Samples and literature discouraged use of this material for this type application. Not evaluated as test composites.
CPE	Chlorinated Polyethylene	DOW	Samples and literature discouraged use of this material for this type application. Not evaluated as test composites.

Table 2.4. Resin Materials Source and Initial Evaluation (continued).

Lexan	Polycarbonate	General Electric	Samples and literature discouraged use of this material for this type application. Not evaluated as test composites.
Pro-fax	Polypropylene	General Electric	Samples and literature discouraged use of this material for this type application. Not evaluated as test composites.
Hercotuf	Polypropylene	Hercules	Samples and literature discouraged use of this material for this type application. Not evaluated as test composites.
Versamid [(a)]	Polyamide	General Mills	Used as adhesion promoter with ionomer resin.
Resin QR-568	Oligomeric Acrylic	Rohm & Haas	Designed for curing urethane enamels. Not evaluated for OGAFC lane striping material.
Isochem B-40	Proprietary Formulation	Isochem	Samples and literature discouraged use of this material for this type application. Not evaluated as test composites.
T-243-R T-166-H	Proprietary Formulation	Adhesive Products Corp.	Samples and literature discouraged use of this material for this type application. Not evaluated as test composites.
SMA	Styrene-Maleic Anhydride Copolymer	Arco Chemical	Samples and literature discouraged use of this material for this type application. Not evaluated as test composites.

Table 2.4. Resin Materials Source and Initial Evaluation (continued).

Poly-bd	Polybutadiene, OH terminated	Arco Chemical	Samples and literature discouraged use of this material for this type application. Not evaluated as test composites.
Abson ABS	ABS	B.F. Goodrich	Samples and literature discouraged use of this material for this type application. Not evaluated as test composites.
Hot Melt Glue [a]	Proprietary Formulation	3M	Showed good adhesion good resistance to solvents and ultraviolet degradation, and good melt characteristics.
Pavebrite II [a]	Proprietary Formulation	Neville Chemical Co., Pittsburgh	Showed good adhesion, good resistance to solvents and ultraviolet degradation, and good melt characteristics.

Footnote: (a) Most promising binder compounds. These were investigated in Phase II.

phthalate and hydrogenated rosin ester.

Several thermosetting resins, taken from the classes of epoxies, polyesters and polyurethanes, were included in the preliminary screening tests, although their use had not been envisioned in the preparation of the proposal and contract for this project. These materials are to a certain extent incompatible with the concept of porous striping material which will perform in the same manner as the asphalt based surfacing material, since they are not subject to thermoforming. However, in view of subsequent developments, particularly the practice of preparing discrete segments of stripe in the laboratory and inlaying them into the previously laid OGAFC highway surface, it appears that the use of thermosetting resins may well be open to further consideration. Generally, the thermosets offer advantages over the thermoplastics in the areas of adhesive strength, ease of compounding, solvent resistance, etc.

At the conclusion of the binder selection and preliminary screening phase, four binders, all thermoplastics, appeared to have sufficient promise to justify their more extensive laboratory screening. These binders were:

1. Acrylic
2. Polyamide
3. Pavebrite II
4. Hot Melt Glue

LABORATORY SCREENING PROGRAM

3.1 GENERAL

At the conclusion of the preliminary screening four binders were selected as having sufficient promise to warrant additional and more rigorous evaluation. Prior to placement of any special delineators containing these binder materials in an existing pavement, it was deemed desirable to conduct extensive laboratory testing of the materials under simulated real-life environmental conditions.

The laboratory screening tests were selected to evaluate such obvious critical mixture and binder properties as:

1. strength and flexibility,
2. relative ease and compatibility of mixture preparation and placement with typical asphalt construction technology and equipment,
3. resistance to abrasion and impact caused by traffic and snowplows,
4. resistance to changes in properties as the result of exposure to solvents, deicing chemicals, sunlight, freeze-thaw, etc.,
5. thermal volume change,
6. retroreflectance and color as related to visibility under wet and dry, dry and nighttime conditions, and
7. porosity and texture.

Based on the above considerations and with reference to specific project objectives, a suite of laboratory screening tests were selected. Table 3.1 lists the twenty laboratory screening tests. A discussion of each of the screening tests is presented in following sections and more complete details of many are presented in Appendix A.

3.2 LABORATORY SCREENING TEST PROCEDURES AND RESULTS

The four specially formulated materials were subjected to the comprehensive laboratory screening program. The full suite of screening tests were not conducted on the Polyamide binder material because of its brittle nature and observed poor performance in the early stages of the Phase II, Pilot Test Section study. Where appropriate, a representative OGAFC mixture and in a few selected cases, a dense graded asphalt mixture were also subjected to the screening tests.

3.2.1 Abrasion Resistance

The abrasion resistance of promising lane marking system materials

Table 3.1. Listing of Laboratory Screening Tests

Screening Test Number	Name of Test
1	Abrasion Resistance
2	Motor Vehicle Impact Resistance
3	Solvent Resistance
4	Freeze-Thaw Resistance
5	Night Retroreflectance
6	Daylight Reflectance and Yellowness Index
7	Color and Color Retention
8	Curing Time and No-Track Time
9	Adhesion
10	Resistance to Moisture and Varying Temperature
11	Resistance to Light
12	Traffic Density
13	Pollution Factor
14	Ductility and Penetration
15	Toxicity
16	Coefficient of Linear Thermal Expansion
17	Flow Rate
18	Pot Life
19	Porosity or Permeance
20	Texture Depth

was evaluated under laboratory conditions using three testing techniques, 1) simulated snowplow action, 2) simulated wear from vehicle tires, and 3) scuffing action from slow-speed directional maneuvers of automobile tires.

Simulated Snowplow Action

For each of the mixture formulations samples 12 inches (30.5 cm) square and about 3/4 inch (1.9 cm) thick were prepared by the procedure detailed in Appendix B. These samples were subjected to multiple passes of a model snowplow. A schematic diagram of the model snowplow is depicted in Figure 3.1. The amount of abrasion resistance was evaluated visually and by the use of the telephotometer. Details of the telephotometric procedure for measuring the retroreflectance characteristics of the samples are presented in Appendix C. Results from this test are presented in Table 3.2.

Simulated Wear from Vehicle Tires

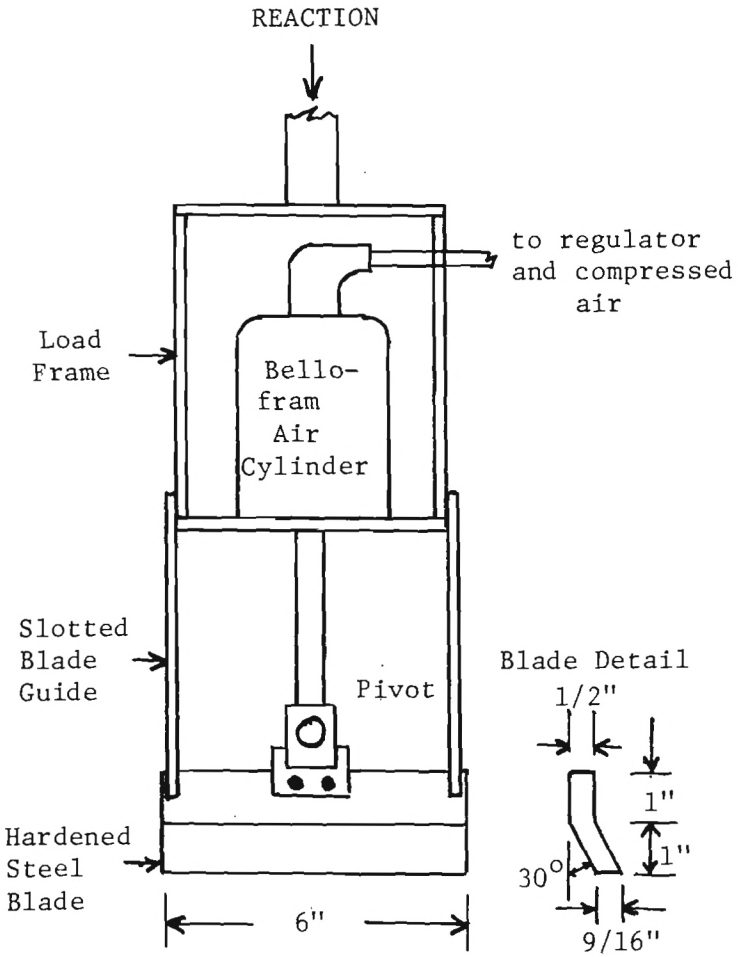
For each of the mixtures, 10 inch (25.4 cm) diameter by 1 inch (2.5 cm) high samples were prepared by the procedure detailed in Appendix B. These samples were subjected to multiple passes of the hard rubber tires of the aggregate polishing apparatus owned by the Georgia Department of Transportation in Forest Park, Georgia. A schematic diagram of the aggregate polishing equipment is depicted in Figure 3.2. Details of this testing procedure may be found in Appendix A. The wear rate was evaluated visually and by the use of the telephotometer. Details of the telephotometric procedure for measuring the retroreflectance characteristics of the samples are presented in Appendix A. Results from this test are presented in Table 3.3.

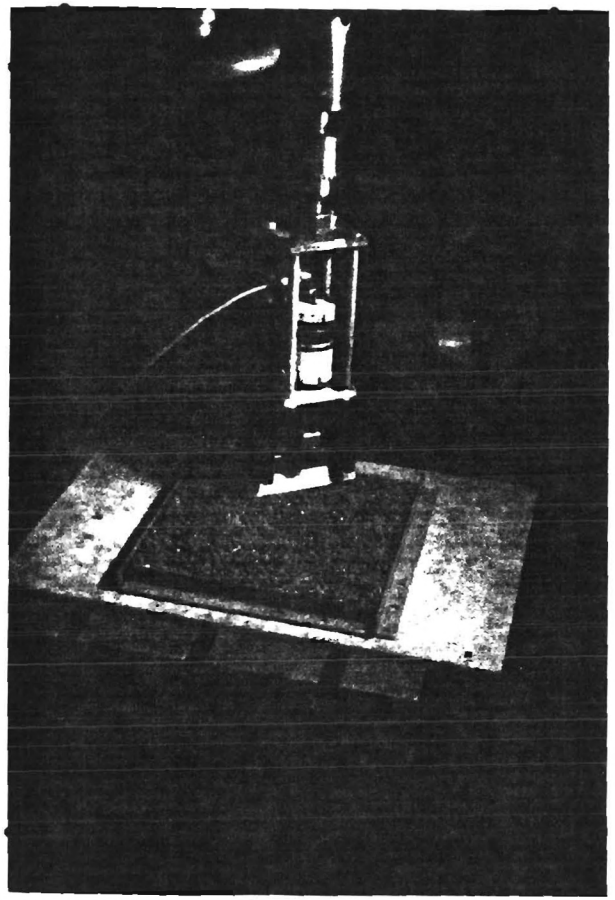
Scuffing Action

At the conclusion of the simulated snowplow action testing, the 12 inch (30.5 cm) square samples were secured to the surface of a concrete pavement. The right front tire of an automobile was placed on the top surface of the sample. The steering wheel was then cranked from the left stop to the right stop and back to the left stop a total of 3 times. The car was then backed off the sample and visual evaluation of the damage from scuffing action was made. A detailed description of this test is presented in Appendix A. Test results are presented in Table 3.4.

Observations Concerning Abrasion Test Results

a. The OGAFC samples in general did not have a very high level of resistance to the abrasion tests. The specimens abraded and/or ravelled severely from the simulated snowplow test, rutted severely under 10,000 wheel load applications and scuffed badly in the scuffing test.





NOTE: 1 in. = 2.54 cm

Figure 3.1. Schematic and Picture of Model Snowplow.

Table 3.2. Summary of Telephotometer and Visual Observations on Snowplowed Open-Graded Samples

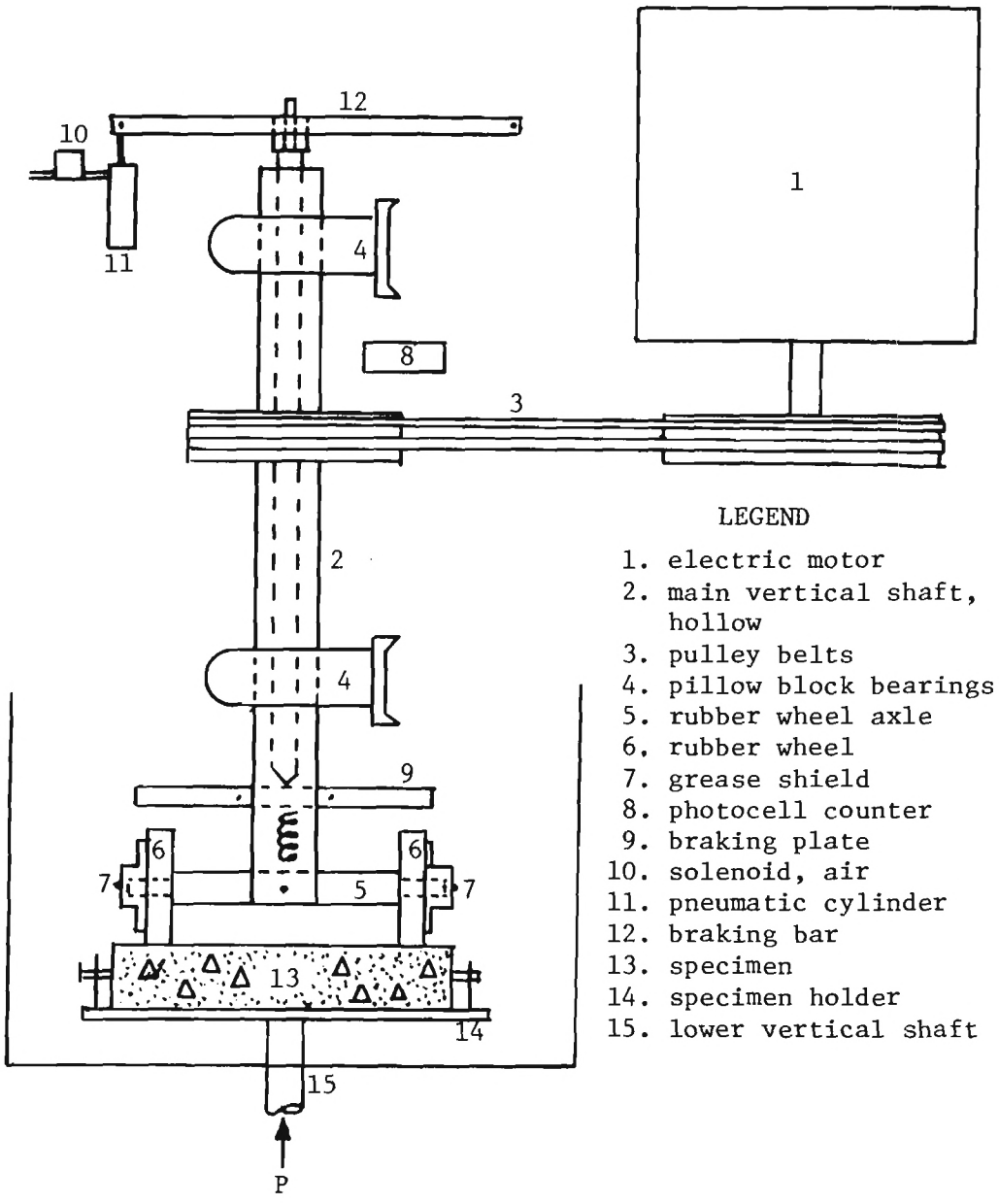
Binder Type	Mix Proportions (AWB)	Number Passes of Snowplow	Telephotometer Reading Dry	Telephotometer Reading Wet	Comments
AC-20	5.9% Asphalt	0	4.5	3.7	-
	Painted White	10	3.4	3.2	Badly abraded
AC-20	5.9% Asphalt	0	4.1	3.5	-
	Painted Yellow	10	3.2	3.1	Badly abraded
Polyamide	6% Polyamide	0	4.5	3.9	-
	4% Ionomer	10	4.4	3.3	-
	5% White Pig-	30	4.2	3.2	-
	ment	100	3.8	3.1	-
Polyamide	6% Polyamide	0	3.9	3.3	-
	4% Ionomer	10	3.2	2.9	-
	2% Yellow Pig-	30	3.3	2.9	-
	ment	100	3.5	3.1	-
Pavebrite[a]	7% Component A[b]	0	5.8	4.2	-
	3% Component B	10	4.6	3.8	-
	5% White Pig-	30	4.6	3.8	-
	ment	100	4.3	3.4	-
Pavebrite[a]	7% Component A[b]	0	4.3	3.2	-
	3% Component B	10	4.2	3.3	-
	2% Yellow Pig-	30	3.8	3.2	-
	ment	100	3.4	2.9	-
Acrylic	5% Acrylic resin	0	5.0	4.5	-
	5% Hydrogenated rosin ester	10	4.8	4.2	-
	5% White Pig-	30	4.8	3.8	-
	ment				
	0.1% Antioxi-	100	4.4	3.7	-
	dant				
	0.05% Ultra-				
	violet absorber				
Acrylic	5% Acrylic resin	0	3.7	3.3	-
	5% Hydrogenated rosin ester	10	3.9	3.2	-
	2% Yellow Pig-	30	3.6	3.0	-
	ment				
	0.1% Antioxi-	100	3.4	3.0	-
	dant				
	0.05% Ultra-				
	violet absorber				

Table 3.2. Summary of Telephotometer and Visual Observations on Snowplowed Open-Graded Samples (continued)

Binder Type	Mix Proportions (AWB)	Number Passes of Snowplow	Telephotometer Reading Dry	Telephotometer Reading Wet	Comments
Hot Melt Glue	8% Glue 5% White Pigment	0	5.5	4.2	-
		10	5.0	4.1	-
		30	4.9	3.5	-
		100	4.4	3.5	-
Hot Melt Glue	8% Glue 2% Yellow Pigment	0	3.7	3.6	-
		10	3.9	3.3	-
		30	3.4	3.3	-
		100	3.0	2.8	-

(a) Proprietary product from Neville Chemical Company, Pittsburgh, Pa.

(b) Components A and B are binder and plasticizer, respectively.



LEGEND

1. electric motor
2. main vertical shaft, hollow
3. pulley belts
4. pillow block bearings
5. rubber wheel axle
6. rubber wheel
7. grease shield
8. photocell counter
9. braking plate
10. solenoid, air
11. pneumatic cylinder
12. braking bar
13. specimen
14. specimen holder
15. lower vertical shaft

Figure 3.2. Aggregate Polishing Equipment Used to Evaluate Abrasion Resistance.

Table 3.3. Summary of Telephotometer and Visual Observations From Simulated Tire Wear Tests on Open-Graded Specimens.

Binder Type	Mix Proportions (AWB)	Number of Revolutions	Telephotometer Readings Dry	Wet	Comments
AC-20	5.9% Asphalt	0	3.8	3.3	-
	Painted Yellow	5,000	3.2	3.4	Badly rutted
AC-20	5.9% Asphalt	0	4.0	3.8	-
	Painted White	5,000	2.6	2.7	Badly rutted
Polyamide	6% Polyamide	0	3.5	3.3	-
	4% Ionomer	20,000	3.3	3.0	-
	2% Yellow Pigment				
Polyamide	6% Polyamide	0	4.9	4.1	-
	4% Ionomer	20,000	5.1	3.1	-
	5% White Pigment	50,000	4.6	3.5	-
Pavebrite[a]	7% Component A[b]	0	4.2	3.6	-
	3% Component B	20,000	4.1	3.4	Slightly rutted
	5% White Pigment	50,000	4.0	3.1	Badly rutted
Acrylic	5% Hydrogenated rosin ester	0	3.9	3.6	-
	5% Acrylic resin	20,000	4.2	3.5	Badly rutted
	5% White Pigment				
	0.1% Ultraviolet Absorber				
Acrylic	5% Hydrogenated rosin ester	0	3.2	3.0	-
	5% Acrylic resin	20,000	3.4	3.3	Badly rutted
	2% Yellow Pigment				
	0.1% Antioxidant				
	0.05% Ultraviolet Absorber				
Hot Melt Glue	8% Glue	0	3.6	3.1	-
	2% Yellow Pigment	20,000	3.1	3.0	-
Hot Melt Glue	8% Glue	0	5.2	4.2	-
	5% White Pigment	20,000	4.7	3.8	-

(a) Proprietary product from Neville Chemical Company, Pittsburgh, Pa.

(b) Components A and B are binder and plasticizer, respectively.

Table 3.4. Summary of Scuffing Action Tests on Open-Graded Specimens.

Binder Type	Comments
AC-20 White Paint	Badly abraded/ravelled surface
AC-20 Yellow Paint	Badly abraded/ravelled surface
Polyamide White	No visible damage
Polyamide Yellow	No visible damage
Pavebrite[(a)] White	Moderately abraded/ravelled surface
Pavebrite Yellow	Moderately to seriously abraded/ravelled surface
Acrylic White	Moderately to seriously abraded/ravelled surface
Acrylic Yellow	Moderate abrasion
Hot Melt Glue - White	Slight abrasion - some local ravelling
Hot Melt Glue - Yellow	Slight abrasion

(a) Proprietary product from Neville Chemical Company, Pittsburgh, Pa.

b. In general the delineator materials made with the four special binders all displayed greater abrasion resistance as evaluated by each of the 3 tests than the OGAFC. The Acrylic and Pavebrite bound mixtures did display some abrasion and rutting in the simulated tire wear and scuffing tests. The Polyamide and Hot Melt Glue mixtures suffered little if any visual damage.

c. The dry and wet telephotometer readings taken during this test did show a decrease for both the painted OGAFC and special porous delineator materials. However, the reduction in reflectance of the porous delineators after various stages of snowplowing and simulated tire wear was no greater for the porous delineators than for the painted OGAFC specimens.

3.2.2 Impact Resistance

The motor vehicle impact resistance of candidate materials was evaluated using two testing techniques; a) standard Marshall stability and flow, and b) repeated compressive loading of unconfined specimens.

General Test Procedures

The Marshall test was conducted at temperatures ranging from -4°F to 140°F (-16°C to 60°C) while the repeated load tests were conducted at 75°F and 140°F (24°C and 60°C). For the repeated load testing, apparatus schematically shown in Figure 3.3 was used. Repeated compressive loading was applied at a rate of about 40 loads per minute for a duration of about 0.2 sec. The magnitude of repeated axial stress was held at 60 psi (413 kN/m^2). The repeated loading was continued until failure occurred or a total of 50,000 loads was applied. A detailed description of each of these tests may be found in Appendix A. Test results for the two tests are presented in Tables 3.5, 3.6, and 3.7.

Observations Concerning Impact Resistance Results

a. For the test temperatures used, in general the mixtures made with the formulated binders had Marshall stability values at least as good as the OGAFC. The Pavebrite and Acrylic mixtures had stability values about the same as the OGAFC while the Hot Melt Glue and Polyamide mixtures both had stability values substantially greater than the OGAFC.

b. For all the mixtures tested, decreased test temperature was associated with an increased stability.

c. The repeated loading test caused severe permanent compressive deformation in the OGAFC samples tested at 140°F

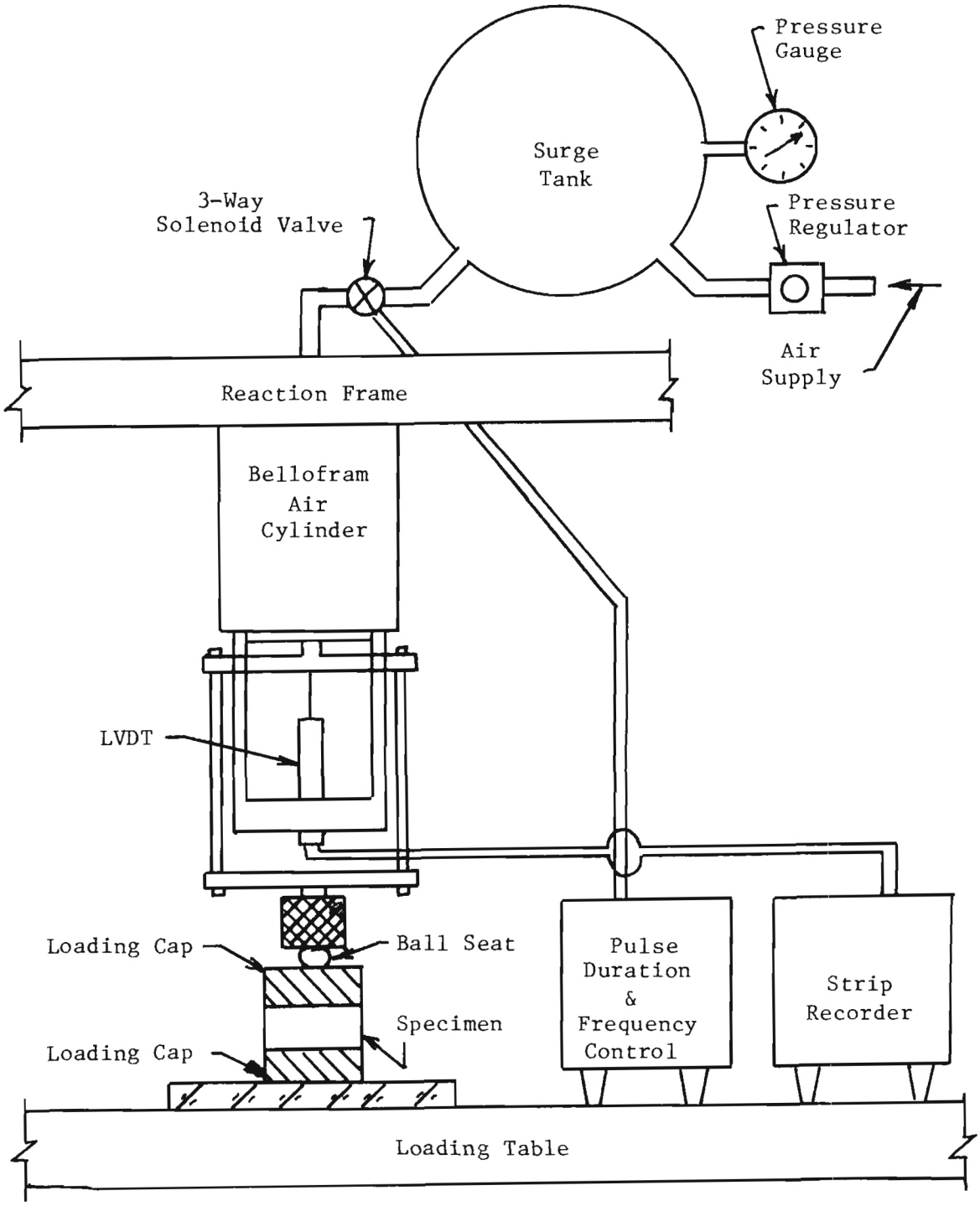


Figure 3.3. Repeated Load Equipment Used to Evaluate Impact Resistance.

Table 3.5. Impact Resistance - Specimen Summary and Testing Temperatures for Repeated Load Tests

Binder or Mix Type	Mixture Proportions (AWB)	Compacted Specimens Height Inches	Weight Grams	Density pcf	Testing Temp., °C
Dense Mix	5.93% AC-20	1-1/16	122.7	140	24
" "	" "	1-1/16	126.2	144	60
Open Graded	6.25% AC-20	1	86.6	105	60
" "	" "	1	92.7	112	24
Pavebrite	7%A,3%B,5%W.P.	1-5/32	94.6	99	60
" "	4.2%A,1.8%B,5%W.P.	1-1/16	93.7	107	60
" "	4.2%A,1.8%B,5%W.P.	1-5/32	100.7	106	24
" "	7%A,3%B,5%W.P.	1-1/32	91	107	24
Polyamide	6%V,4%S,5%W.P.	1-1/8	90.5	97	60
" "	5%V,4%S,1%DOP,5%W.P.	1-1/16	90.8	104	23
" "	5%V,4%S,1%DOP,5%W.P.	1-1/32	90	106	25
" "	5%V,4%S,1%DOP,5%W.P.	1-3/32	93	103	60
Acrylic	5%AC,5%H,5%W.P.	1-3/32	92	102	24
" "	" " "	1-1/8	93	100	60
" "	4.8%AC,3.2%H,5%W.P.	1-1/16	97	111	60
" "	4.8%AC,3.2%H,5%W.P.	1	90	109	24
Hot Melt Glue	8%HMG,5%W.P.	1-3/32	96	106	24
" "	" "	1-3/32	99	110	60

Notes: V = polyamide
S = ionomer
Y.P. = yellow pigment
W.P. = white pigment
DOP = di-octylphthalate
A = Pavebrite Component A (binder)
B = Pavebrite Component B (plasticizer)
AC = acrylic resin
H = hydrogenated rosin ester
HMG = hot melt glue

Table 3.6. Summary of Impact Resistance Repeated Loading Test Results

Cycle Number	Permanent Deformation inch	Permanent Deformation %	Elastic Deformation inch	Elastic Deformation %	Resilient Modulus E_R, ksi
Mix Designation Dense Asphalt, Sample C-7, Test Temp. 23-25°C					
10	.00833	.784	.00025	.0235	255.3
100	.01308	1.231	-	-	-
530	.0179	1.684	-	-	-
1000	.020	1.882	.000167	.0157	382.2
2000	.0232	2.184	.00025	.0235	255.3
5100	.02716	2.556	.0004	.0376	159.6
9870	.0302	2.842	.0006	.0565	106.2
16,960	.0352	3.313	.0004	.0376	159.6
53,940	.0402	3.784	0	0	∞
Mix Designation Dense Asphalt, Sample C-8, Test Temp. 60°C					
10	.01083	1.02	.00125	.118	50.8
100	.01958	1.84	.000417	.039	153.8
1017	.0279	2.626	.00083	.078	76.9
2030	.03042	2.863	.000417	.039	153.8
4633	.03317	3.122	.000625	.0588	102.0
9915	.03583	3.372	.000833	.0784	76.5
15,000	.03917	3.687	.000833	.0784	76.5
54,160	.055	5.176	.000833	.0784	76.5
Mix Designation Open-Graded Asphalt, Sample C-20, Test Temp. 24°C					
10	.00625	.625	.0019	.19	31.6
100	.0111	1.11	.0017	.17	35.3
500	.016	1.60	.00146	.146	41.1
1000	.0187	1.87	.00062	.062	96.8
2000	.0025	2.25	.00062	.062	96.8
5010	.026	2.6	.00062	.062	96.8

Table 3.6. Summary of Impact Resistance Repeated Loading Test Results (continued)

Cycle Number	Permanent Deformation inch	%	Elastic Deformation inch	%	Resilient Modulus E_R, ksi
10,000	.0279	2.79	.00021	.021	285.7
17,810	.0308	3.08	.00021	.021	285.7
53,180	.0367	3.67	0	0	∞
Mix Designation Open-Graded Asphalt, Sample C-1, Test Temp. 60°C					
10	.0142	1.42	.00192	.192	31.3
50	.0367	3.67	-	-	-
100	.03875	3.88	.0025	.25	24.0
218	.0996	9.96	.005	.50	12.0
235	.1304	13.04	.00667	.667	9.0
Badly crushed on one side					
Mix Designation Acrylic 50-50, Sample C-44, Test Temp. 24°C					
10	.0054	.494	.0050	.457	13.1
100	.0106	.969	.0042	.384	15.6
500	.0175	1.6	.00375	.343	17.5
1000	.0321	2.93	.0042	.384	15.6
1390	.0075	7.09	.0075	.686	8.7
1410	.0111	1.015	.0133	1.216	4.9
Sample Smashed, Stopped Test					
Mix Designation Acrylic 50-50, Sample C-49, Test Temp. 60°C					
10	.0021	.187	.00125	.111	54.1
100	.0033	.293	.0021	.187	32.1
525	.0062	.551	.00167	.148	40.5
1005	.0075	.67	.00167	.148	40.5
2010	.0094	.836	.00167	.148	40.5
4813	.0140	1.244	.00167	.148	40.5
9905	.0246	2.187	.00125	.111	54.1

Table 3.6. Summary of Impact Resistance Repeated Loading Test Results (continued)

Cycle Number	Permanent Deformation inch	%	Elastic Deformation inch	%	Resilient Modulus E_R, ksi
13,100	.0583	5.182	-		
		Sample Failed			
	Mix Designation Acrylic 60-40, Sample C-53, Test Temp. 24°C				
10	.0067	.67	.0021	.21	28.6
100	.013	1.3	.00167	.167	35.9
500	.018	1.8	.00125	.125	48
1000	.022	2.2	.00125	.125	48
2005	.026	2.6	.00167	.167	35.9
5850	.054	5.4	.00167	.167	35.9
9800	.092+	9.2+	.00042	.042	142.9
13,260	.125+	12.5+	-	-	-
		Sample Squeezed, Stopped Test			
	Mix Designation Acrylic 60-40, Sample C-52, Test Temp. 60°C				
10	.0067	.63	.00167	.157	38.2
100	.0158	1.49	.00167	.157	38.2
500	.0399	3.76	.00125	.118	50.8
1000	.0625	5.88	-	-	-
		Sample Failed at 1067 Cycles			
	Mix Designation Hot Melt Glue, Sample C-55, Test Temp. 24°C				
10	.0025	.23	.00271	.25	24
100	.0042	.38	.00229	.21	28.6
500	.0050	.46	.00187	.17	35.3
1000	.0054	.49	.00146	.13	46.2
1900	.0054	.49	.00187	.17	35.3
5908	.0058	.53	.00146	.13	46.2
12,455	.0061	.56	.00129	.12	50.0

Table 3.6. Summary of Impact Resistance Repeated Loading Test Results (continued)

Cycle Number	Permanent Deformation inch	%	Elastic Deformation inch	%	Resilient Modulus E_R, ksi
17,590	.0061	.56	.00146	.13	46.2
48,500	.0061	.56	.00062	.06	100.0
Mix Designation Hot Melt Glue, Sample C-57, Test Temp. 60°C					
10	.0033	.30	.0025	.23	26.1
100	.0042	.38	.0025	.23	26.1
500	.0050	.46	.0019	.17	35.3
1000	.0050	.46	.0017	.16	37.5
2076	.0050	.46	.0017	.16	37.5
7370	.0058	.53	.0012	.11	54.5
9000	.0058	.53	.0010	.09	66.7
20,040	.0063	.58	.0012	.11	54,5
61,000	.0067	.61	.0008	.07	85.7
Mix Designation Pavebrite (6%), Sample C-36, Test Temp. 24°C					
10	.0025	.216	.00021	.018	333
100	.0033	.285	.00021	.018	333
500	.0050	.432	.00083	.072	83.3
1000	.0061	.528	.00083	.072	83.3
2000	.0067	.579	.00083	.072	83.3
5000	.0075	.649	.00042	.036	166.7
11,670	.0083	.718	.00042	.036	166.7
56,650	.0096	.828	.00033	.029	206.9
Mix Designation Pavebrite (6%), Sample C-34, Test Temp. 60°C					
10	.00417	.392	.000417	.039	153.8
100	.00833	.784	.000417	.039	153.8
500	.01275	1.20	.000625	.058	103.4

Table 3.6. Summary of Impact Resistance Repeated Loading Test Results (continued)

Cycle Number	Permanent Deformation inch	%	Elastic Deformation inch	%	Resilient Modulus E_R, ksi
1000	.0175	1.647	.000833	.078	76.9
2000	.0325	3.058	.000833	.078	76.9
4900	.0692	6.513	0	-	-
	Sample Badly Squeezed, Top Cap Rotating				
	Mix Designation Pavebrite (10%), Sample C-58, Test Temp. 24°C				
10	.0025	.242	.00104	.101	59.4
100	.0058	.562	.00104	.101	59.4
500	.0108	1.047	.00104	.101	59.4
1000	.0136	1.319	.00104	.101	59.4
2000	.0157	1.52	.00104	.101	59.4
5400	.0182	1.765	.00062	.060	100
14,610	.0198	1.92	.00062	.060	100
26,300	.0211	2.05	.00062	.060	100
59,800	.0227	2.20	.00046	.045	133.3
	Mix Designation Pavebrite (10%), Sample C-28, Test Temp 60°C				
10	.00583	.504	.000833	.072	83.3
140	.01417	1.226	.000208	.018	333.3
500	.0217	1.876	.000208	.018	333.3
1000	.035	3.027	.000417	.036	166.7
3000	.084	6.92	-	-	-
	Crushed Badly on One Side				
	Mix Designation Polyamide, Sample C-31, Test Temp. 60°C				
10	.00333	.296	.00308	.274	21.9
100	.00417	.371	.00267	.237	25.3
501	.00417	.371	.00225	.20	30.0
1000	.00417	.371	.00183	.163	36.8

Table 3.6. Summary of Impact Resistance Repeated Loading Test Results (continued)

Cycle Number	Permanent Deformation inch	%	Elastic Deformation inch	%	Resilient Modulus E_R, ksi
1000	.00417	.371	.00183	.163	36.8
2000	.00458	.407	.00183	.163	36.8
5058	.00458	.407	.00583	.052	115.4
11,186	.00467	.415	.0010	.089	67.4
16,312	.005	.444	.000583	.052	115.4
52,300	.00252	.467	.000583	.052	115.4
	Mix Designation Polyamide, Sample C-41, Test Temp. 25°C				
10	.0025	.24	.0025	.24	23
100	.0030	.29	.0021	.204	29.4
500	.0033	.32	.0017	.165	36.4
1004	.0037	.36	.0012	.116	51.7
2070	.0040	.39	.0012	.116	51.7
4900	.0042	.41	.0015	.145	41.4
14,500	.0050	.48	.0008	.078	76.9
50,840	.0058	.56	.00042	.041	146.3
	Mix Designation Polyamide (DOP), Sample C-59, Test Temp. 60°C				
10	.00167	.153	.0037	.338	17.8
100	.0033	.302	.0029	.265	22.6
510	.0037	.338	.0025	.229	26.2
1255	.0042	.384	.0017	.155	38.7
2770	.0045	.411	.0017	.155	38.7
5044	.0050	.457	.0015	.137	43.8
10,000	.0054	.494	.0012	.11	54.5
14,910	.0054	.494	.00083	.076	78.9
54,800	.0063	.576	.00083	.076	78.9

Table 3.7. Impact Resistance - Summary of Marshall Stability and Flow Tests

Type Mix or Binder	Mixture Proportions (AWB)	Compacted Specimen Weight lbs.	Compacted Specimen Height Inches	Compacted Specimen Density pcf	Test Temp., °F	Corrected Stability lbs.	Flow
Dense Graded Asphalt AC-20	5.93%	2.614	2-1/2	144	140	1645	12
"	"	2.611	2-15/32	145	140	3000	14
"	"	2.638	2-1/2	145	110	2470	12
"	"	2.603	2-15/32	145	100	4400	10
"	"	2.603	2-15/32	145	77	8300	16
"	"	2.638	2-15/32	147	77	9000	8
"	"	2.609	2-1/2	144	46	> 10,000	6
"	"	2.641	2-1/2	145	44	> 10,000	6
Open Graded Asphalt AC-20	6.25%	2.035	2-1/2	112	140	780	9
"	"	2.042	2-1/2	112	140	680	15
"	"	2.039	2-7/16	115	103	1780	10
"	"	2.038	2-1/2	112	95	1950	15
"	"	2.024	2-9/16	109	77	1170	8
"	"	2.022	2-1/2	111	77	2570	8
"	"	2.036	2-1/2	112	46	6760	15
"	"	2.047	2-1/2	113	46	6000	11
"	"	2.042	2-1/2	112	-4	> 10,000	-
"	"	2.034	2-17/32	110	-4	> 10,000	-

Table 3.7. Impact Resistance - Summary of Marshall Stability and Flow Tests (continued)

Type Mix or Binder	Mixture Proportions (AWB)	Compacted Specimen Weight lbs.	Height Inches	Density pcf	Test Temp., °F	Corrected Stability lbs.	Flow
Polyamide	6%V,4%S,2%Y.P.	1.928	2-7/16	109	140	8400	3
"	" " 5%Y.P.	2.077	2-9/16	111	140	7800	4
"	" " 2%Y.P.	1.959	2-9/16	105	77	> 10,000	-
"	" " 5%W.P.	2.010	2-9/16	108	77	> 10,000	-
"	5%V,5%S,5%W.P.	2.138	2-5/8	112	140	9300	8
"	" " 2%Y.P.	1.986	2-9/16	107	140	9050	4
"	4%V,6%S,5%W.P.	2.108	2-5/8	110	140	7890	12
"	" " 2%Y.P.	2.037	2-3/4	102	140	6900	7
"	5%V,4%S,1%D, 5%W.P.	1.896	2-5/16	113	140	6900	6
Pavebrite	7%A,3%B,5%W.P.	2.007	2-1/2	110	140	1370	11
"	" " "	1.902	2-7/16	107	77	> 10,000	13
"	4.2%A,1.8%B,5%W.P.	2.060	2-5/8	108	140	1640	10
Acrylic	3%AC,3%H,5%W.P.	1.978	2-9/16	106	140	680	6
"	" " "	1.961	2-7/16	111	77	3780	6
"	5%AC,5%H,5%W.P.	1.973	2-1/2	109	140	1660	6
"	" " "	1.971	2-7/16	111	77	2780	6

Table 3.7. Impact Resistance - Summary of Marshall Stability and Flow Tests Tests (continued)

Type Mix or Binder	Mixture Proportions (AWB)	Compacted Specimen			Test Temp., °F	Corrected Stability lbs.	Flow
		Weight lbs.	Height Inches	Density pcf			
Hot Melt Glue	5.3%HMG,3.3%W.P.	1.903	2-5/16	113	140	3080	11
"	6%HMG,2%Y.P.	1.806	2-1/4	110	140	2950	6
"	10%HMG,3.3%Y.P.	1.881	2-5/16	112	140	3240	7
Hot Melt Glue	8%HMG,4%W.P.	1.957	2-3/16	123	140	9370	20
"	8%HMG,5%W.P.	2.013	2-1/2	111	140	1520	10
"	8%HMG,5%W.P.	1.903	2-3/8	110	77	3160	7

Notes:
V = polyamide resin
S = ionomer resin
Y.P. = yellow pigment
W.P. = white pigment
D = di-octylphthalate
A = Pavebrite Component A (binder)
B = Pavebrite Component B (plasticizer)
AC = acrylic resin
H = hydrogenated rosin ester
HMG = hot melt glue

(60°C) and excessive permanent deformation after N = 53,000 when the temperature was 77°F (25°C). Compared to the OGAFC, similar permanent deformation was exhibited by the Acrylic and Pavebrite mixtures although the Pavebrite mixtures appeared to be slightly more resistant to development of permanent deformation at lower temperatures. The Hot Melt Glue and Polyamide mixtures exhibit excellent resistance to any repeated load-associated permanent deformation at both test temperatures used.

3.2.3 Solvent Resistance

The resistance of the various mixture to dissolving in a hydrocarbon solvent (kerosene) was evaluated.

General Test Procedure

The test procedure consisted of subjecting 4 inch (10.2 cm) diameter by 2.5 inch (5.4 cm) high Marshall samples to 1 hour and 24 hours of complete immersion in kerosene. Following the immersion period Marshall stability and flow were determined at a testing temperature of 140°F (60°C). Additionally, determination was made of any weight-loss of the binder due to dissolving in the kerosene. Details of this test can be found in Appendix A. Test results are presented in Table 3.8.

Observations Concerning Solvent Resistance Results

a. The OGAFC and Pavebrite samples completely disintegrated after 1 hour immersion in kerosene.

b. The Acrylic samples became very soft after 1 hour immersion and had a Marshall stability of 50 lbs. (23 kg).

c. The Polyamide and Hot Melt Glue samples were not adversely affected even after 24 hours of immersion. Little if any binder was dissolved and high Marshall stability was noted after the immersion.

3.2.4 Freeze-Thaw Resistance

The resistance to freeze-thaw damage of various mixtures was evaluated. Samples were prepared as for the lap adhesion test (see Adhesion Test). The samples were cycled between -30°F and 140°F (-34°C and 60°C), at 24 hours per cycle for 168 hours. The samples were then tested for adhesive bond utilizing the pull-test described in the Adhesion Test section. Results were as follows:

Table 3.8. Summary of Solvent Resistance Test.

Binder Type	Mixture Proportions (AWB)	Soaking Period hrs.	Initial wt., g	Wt. After Soaking, g	Wt. Loss g	Corrected[c] Stability lbs.	Flow	Comments
Polyamide	6%V, 4%S, 5%W.P.	1	943.5	943.5	0	2275	4	-
"	" " "	24	927.5	927.5	0	1920	20	-
AC-20	6.25%	1	977.2	(a)	(a)	0	-	Asphalt dissolved
Pavebrite	7%A, 3%B, 5%W.P.	1	883.7	(a)	(a)	0	-	Pavebrite dissolved
Acrylic	5%AC, 5%H, 5%W.P.	1	900.3	900.3	0	50	-	Very soft, but not dissolved
Hot Melt Glue	8%HMG, 5%W.P.	1	911.6	897.6	14.0	1700	12	-
Hot Melt Glue	8%HMG, 3.2%W.P.	24	982.0	981.0	1.0	1200	11	-

Note: (a) samples dissolved during soaking

(b) V = polyamide resin
S = ionomer resin
Y.P. = yellow pigment
W.P. = white pigment
D = di-octylphthalate
A = Pavebrite Component A (binder)
B = Pavebrite Component B (plasticizer)
AC = acrylic resin
H = hydrogenated resin ester
HMG = hot melt glue

(c) Test Temperature = 140°F (60°C)

Material	Pull Test Stress, lb/in^2 Not Cycled	After Freeze-Thaw
Acrylic	190	72
Hot Melt Glue	257	210
Pavebrite	160	6
Polyamide	(a)	(a)

3.2.5 Night Retroreflectance

The dry and wet night reflectance characteristics of the various porous delineator materials were evaluated using the telephotometer and associated procedures described in Appendix C.

A summary of the retroreflectance data taken as part of the Abrasion Resistance testing is presented in Tables 3.2 and 3.3.

3.2.6 Daylight Reflectance and Yellowness Index

The Photovolt Reflectance Meter (ASTM E 97) is used, with Diffuse Reflectance Head, No. 610Y and three tri-stimulus filters, amber (A), blue (B), and green (G). Each filter is calibrated separately, using a white porcelain enameled plaque secondary standard. The reflectance head is then placed on the sample, and reflectance is determined with each of the filters inserted, in turn.

The daylight luminous reflectance of the sample corresponds to the value obtained with the green (G) filter.

The yellowness index is calculated from the three reflectance values determined above, using the equation:

$$Y = \frac{A - B}{G} \qquad (3.1)$$

where Y is the yellowness index and A, B and G are the reflectance values for the three tri-stimulus readings, using amber, blue, and green filters, respectively.

Test results are summarized in Table 3.9.

3.2.7 Color and Color Retention

Test pieces of the resin yellow pigment formulations, without aggregate, were prepared, and their colors were matched with chips on the FHWA Yellow Color Tolerance Chart. Samples were then exposed to (a) 100% Relative Humidity at room temperature for 24 hours,(b) immersion in kerosene for 24 hours, and (c) high intensity ultraviolet

(a) Eliminated because of poor serviceability in Phase II, Pilot Test Sections.

Table 3.9. Summary of Daylight Reflectance and Yellowness Index Test Results.

Binder	Pigment	A	B	G	Y
Acrylic	White	8.0	9.0	23.0	-.04
	Yellow	7.0	1.0	8.0	-
Pavebrite	White	6.0	7.0	20.0	-.05
	Yellow	7.0	1.0	7.0	-
Hot Melt Glue	White	11.0	9.0	22.0	0.09
	Yellow	6.0	1.0	8.0	-
Polyamide	White	4.0	8.0	20.0	-0.2
	Yellow	5.0	1.0	8.0	-

NOTE: $Y = \frac{A - B}{G}$

where: Y = Yellowness Index
A = Reflectance with amber filter
B = Reflectance with blue filter
G = Reflectance with green filter

light for 200 hours. Following exposure, the test pieces were again matched against chips of the FHWA Color Tolerance Chart, with results as shown in Table 3.10.

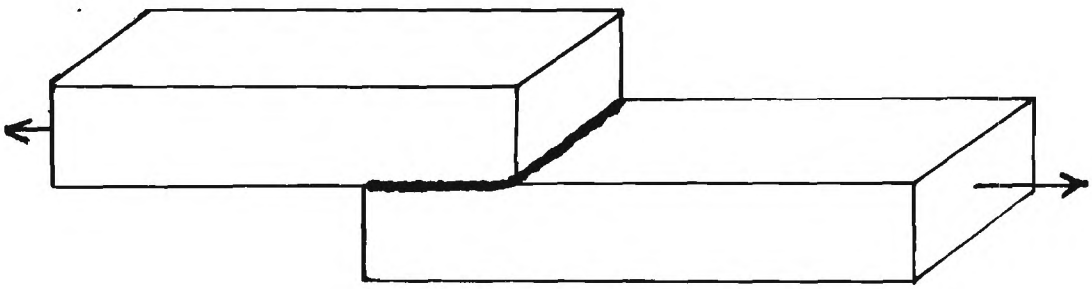
3.2.8 Curing and No-Track Time

This screening test is not applicable to the thermoplastic materials being considered, and was not performed.

3.2.9 Adhesion

Concrete tablets 1 inch by 1 inch by 3.5 inches (2.5 cm by 2.5 cm by 8.9 cm) were sawed from regular concrete blocks. This size is a slight departure from the size of the AASHTO Method T250-6, Bond Strength because it was more suitable for use in the Instron testing machine than were the 2 inch by 3.5 inch by 7 inch (5.1 cm by 5.1 cm by 17.8 cm) size of the AASHTO Method T250-6, Bond Strength.

The resin binders were prepared with pigments, plasticizers, etc., but without aggregate. The hot, plastic mix was used to cement two of the concrete test blocks together, with a 1 inch by 1 inch (2.5 cm by 2.5 cm) lap joint, as shown in the following figure.



The test piece thus formed was allowed to stand overnight to reach full ambient thermal equilibrium, then was mounted in an Instron tester, using a jig devised to apply tensile force longitudinally (arrow). The observed load at failure of the bond is also the value of the failure stress in pounds per square inch, since the cross-sectional area of the lap joint is 1 square inch. A loading rate of 200 lb/min (90.7 kg/min) was used, with the sensitivity of the instrument set at 0.2 lb (0.1 kg).

Table 3.10. Summary of Color and Color Retention Test Results.

Material	Color[a] (Initial Reading)	Moisture	Effect of Solvent[b]	Color of Ultraviolet
Acrylic	Green Limit H^+	None	None	Dark Limit V^-
Pavebrite	Green Limit H^+	None	None (dissolves)	Strong Limit C^+
Hot Melt Glue	Green Limit H^+ (slightly darker)	None	None (dissolves)	None
Polyamide	(c)	(c)	(c)	(c)

(a) FHWA Yellow Color Tolerance Chart

(b) Kerosene soaking

(c) Polyamide samples were not tested because of early failure of the material in the Pilot Field Test Section.

The test pieces were examined subsequent to failure to determine whether failure occurred within the resin, within the concrete block, or between resin and concrete.

Results are shown in Table 3.11.

3.2.10 Resistance to Moisture and Varying Temperature

Test pieces were prepared identical to those used for the Adhesion Test. These pieces were immersed in water for a period of 1 week at room temperature (75°F). Once each day, the pieces were removed and transferred to a chill cabinet at a temperature of 0°F (-18°C). After reaching that temperature, they were returned to the water bath. At the end of the week, the pieces were allowed to equilibrate at ambient room temperature overnight, then were tested for adhesion in the manner of the Adhesion Test. At these temperatures the water had no adverse effects.

Results are summarized in Table 3.12.

3.2.11 Resistance to Light

Samples were prepared as tensile strength bars for elongation determination. The tensile strength bars were similar to the specimens used for ductility testing of asphalt cement (ASTM D 113). The samples were exposed to ultraviolet radiation from a high intensity mercury arc tube lamp for 168 hours. Elongation was created using the Instron Tester and the values obtained compared with those obtained for identical unexposed control specimens.

Results are summarized in Table 3.13.

3.2.12 Traffic Density

The effect of traffic density was evaluated by the repeated load and Marshall stability testing conducted as part of the Motor Vehicle Impact Resistance tests.

3.2.13 Pollution Factor

The developed binder systems were examined for resistance to moisture and resistance to light. No degradation of the components was observed that could be interpreted as indications of hydrolysis or photolysis to a degree that would give rise to degradation products which might serve as pollutants to the environment.

A slight amount of thermal degradation may occur during production of the striping material, as occurs with asphalt when heated; however, the effect is temporary and appears to leave no residue of products which might subsequently serve as pollutants.

Table 3.11. Summary of Adhesion Test Results.

		Load, lbs.	Avg. Stress, psi
1.	Acrylic and hydrogenated rosin ester	92 88 90 86 88 Average 88.8	88.8
2.	Acrylic and hydrogenated rosin ester plus silane adhesion promoter	122 120 120 122 Average 121	121
3.	Hot Melt Glue	115 118 Average 116.5	116.5
4.	Hot Melt Glue plus yellow pigment @ 30 phr	255 259 Average 257	257
5.	Hot Melt Glue plus Silane adhesion promoter	110 112 Average 111	111
6.	Pavebrite	80 76 67 72 Average 73.75	74
7.	Polyamide(a)		
8.	Pavebrite plus yellow pigment @ 30 phr	70 70 Average 70	70
9.	AC-20	7	7

phr = parts per hundred of resin by weight

(a) Polyamide samples were not tested because of early failure of the material in the Pilot Field Test Section.

Table 3.12. Summary of Results from Moisture and Varying Temperature Test.

Material	Observed Test Effects	
	Low Temp. (0^{o} to 80^{o}F)	High Temp. (100^{o} to 140^{o}F)
Acrylic-HRE	No effect	Softening & separation within glue joint
Acrylic-HRE plus silane adhesion promoter	No effect	Softening & separation within glue joint
Hot Melt Glue	No effect	Some softening with weakening of adhesive bond
Hot Melt Glue plus pigment @ 30 phr	No effect	Some softening with weakening of adhesive bond
Hot Melt Glue plus silane adhesion promoter	No effect	Some softening with weakening of adhesive bond
Pavebrite	No effect	Softening & separation within glue joint
Pavebrite plus pigment @ 30 phr	No effect	Some softening with weakening of adhesive bond
Polyamide	(a)	(a)

Note: (a) Polyamide samples were not tested because of early failure of the material in the Pilot Field Test Section.

Table 3.13. Summary of Resistance to Light Test Results.

Sample	Treatment	Elongation, %
Acrylic	--	210
	UV	225
Pavebrite	--	over 250
	UV	over 250
Hot Melt Glue	--	23
	UV	40
Polyamide	(a)	(a)

(a) Polyamide samples were not tested because of early failure of the material in the Pilot Field Test Section.

3.2.14 Ductility and Penetration

Because of the nature of the thermoplastic materials used in these formulations, shear tests as described in ASTM D-732 yielded no informative data. Standard penetration and elongation tests were substituted for shear tests as indications of the plasticity of the material and its response to changes in temperature, presence of moisture, effect of light, etc.

Ductility specimens were fabricated as per ASTM D-113. The specimens were then pulled in tension at room temperature with the Instron Testing Machine until failure. Results are summarized in Table 3.14.

The penetration test conducted at $77^{\circ}F$ ($25^{\circ}C$), a measure of consistency, was applied to the formulated binders using a conventional Penetrometer as per ASTM D 5. Results are summarized in Table 3.14.

3.2.15 Toxicity

The list of TLV's (threshold limit values) compiled by the American Conference of Governmental Industrial Hygienists has been examined to determine the possible inclusion on this list of materials utilized in the formulation of the above developed systems. None of the materials thus utilized were included in said list.

3.2.16 Coefficient of Linear Thermal Expansion

Bar specimens of the pigmented resins were tested for linear thermal expansion in accordance with ASTM Method D 696-70.

Results are summarized in Table 3.15.

3.2.17 Flow Rate

Flow rate measurements were made, using a Plastometer, in accordance with ASTM Method D 1238-70.

Results are summarized in Table 3.16.

3.2.18 Pot Life

Pot life was determined by repeating the plastometer test on molten resins over a period of 10 hours. In addition, yellowness index of the white material was measured before and after the 10 hour melt period.

Results are summarized in Table 3.16.

Table 3.14. Summary of Ductility and Penetration Test Results .

Test Sequence	Composition	Elongation of 76.2 mm Specimen mm	Elongation of 76.2 mm Specimen %	Penetration @ 77°F(25°C) (0.1 mm)
1	Resin Hot Melt Glue 90% Hydrogenated rosin ester 10% Pigment - chrome yellow 2 phr	12.5	16.4	12
2	Resin Hot Melt Glue 90% Hydrogenated rosin ester 10% Pigment - Titanium dioxide 2 phr	11.6	15.2	16
3	Resin Polyamide 60% Ionomer 40% Pigment - Chrome yellow 2 phr	0.65	0.85	2.4
4	Resin Polyamide 60% Ionomer 40% Pigment - Titanium dioxide 2 phr	0.65	0.85	0.5
5	Resin (see notes) Acrylic 60% Hydrogenated rosin ester 40%	14	18.4	20.5
6	Resin (see notes) Pavebrite 60% Plasticizer 40% Pigment - 40 phr	--	>250	17
7	Resins Only			
	Hot Melt Glue	--	165	5
	Polyamide/Ionomer (60/40)	--	5	.5
	Asphalt	--	>250	80
	Asphalt/Pigment (60/40)	--	72	45

NOTES: Both the Pavebrite and the plasticized acrylic exhibited brittleness under shock. The 3-inch elongation test strips could be flexed, twisted, and stretched; but, if dropped onto a hard surface from 4 to 5 feet, they readily fractured.

phr = parts per hundred resin

Table 3.15. Summary of Coefficient of Linear Thermal Expansion Test Results.

Binder Compound	Pigment Color	77°F L_0, in.	-20°F L_1, in.	ΔL	ΔT	$\alpha = \frac{\Delta L}{L_0 \Delta T}$, in/in/°F
Acrylic	White	8.79	8.32	0.47	97°F	5.51×10^{-4}
	Yellow	8.86	8.61	0.25	97°F	2.91×10^{-4}
Pavebrite	White	8.97	8.44	0.53	97°F	6.09×10^{-4}
	Yellow	8.96	8.37	0.59	97°F	6.79×10^{-4}
Hot Melt Glue	White	7.55	7.12	0.43	97°F	5.87×10^{-4}
	Yellow	7.15	6.45	0.70	97°F	10.09×10^{-4}
Polyamide		(a)	(a)	(a)	(a)	(a)

(a) Polyamide samples were not tested because of early failure of the material in the Pilot Field Test Section.

Table 3.16. Summary of Flow Rate and Pot Life Data.

Sample	Temp (°C)	Total Load Including Piston (g)	Time (sec)	Weight (gm)	Flow Rate, gm/10 min. (Initial)	Flow Rate, gm/10 min. (After 10 hrs.)	Yellowness Index[a] (Initial)	Yellowness Index[a] (After 10 hrs.)
Acrylic								
(Yellow)	120	1130	50	7.0	84	84		
(Yellow)	130	678	25	7.5	180	154		
(White)	118	1130	42	8.3	118	102	-0.04	-0.22
Pavebrite								
(Yellow)	120	678	10	7.6	456	504		
(Yellow)	130	495	8	8.0	600	642		
(White)	115	495	24	8.7	217	262	-0.05	0.22
Hot Melt Glue								
(Yellow)	117	1130	23	7.3	190	201		
(Yellow)	127	678	18	7.3	243	260		
(White	125	1130	35	8.3	142	160	0.09	0.16
(White	133	678	110	8.3	45	73		
Polyamide	(b)	(b)	(b)	(b)	(b)	(b)	(b)	(b)

(a) Yellowness Index - see Table 3.9
(b) Polyamide was not tested due to early failure in Pilot Test Section

3.2.19 Porosity or Permeance

General Test Procedure

The porosity of the various mixtures was calculated directly by using the Marshall stability specimen compaction data. The permeance of the open-graded mixtures was determined by use of an outflow meter similar to the one developed by Doty [4] and shown schematically in Figure 3.4. Detailed discussion of these two test procedures may be found in Appendix A. Test results are summarized in Tables 3.17 and 3.18.

Observations Concerning Test Results

a. The porosity or void content of all the mixtures prepared with the specially formulated binders (Polyamide, Acrylic, Pavebrite, and Hot Melt Glue) was slightly greater than the OGAFC mixture.

b. The outflow times which are a measure of permeance were greater for the mixtures prepared with the special binder formulation ranging 3.9 to 6.4 seconds compared to 2.1 seconds for the OGAFC mixture. Greater outflow time would indicate a slightly lower permeance or permeability.

3.2.20 Texture Depth

The texture depth of the various mixtures was determined.

General Test Method

The general method for texture depth determination is the sand patch test, similar to the one described in Reference 4. Details of the test used can be found in Appendix A. Results are summarized in Table 3.19.

Observations for Test Results

The test results indicate that the texture depth for the porous mixtures prepared with the specially formulated binders is slightly less (range of texture depth = 0.051 to 0.084 inch (.013 to 0.21 cm)) than for the OGAFC mixture.

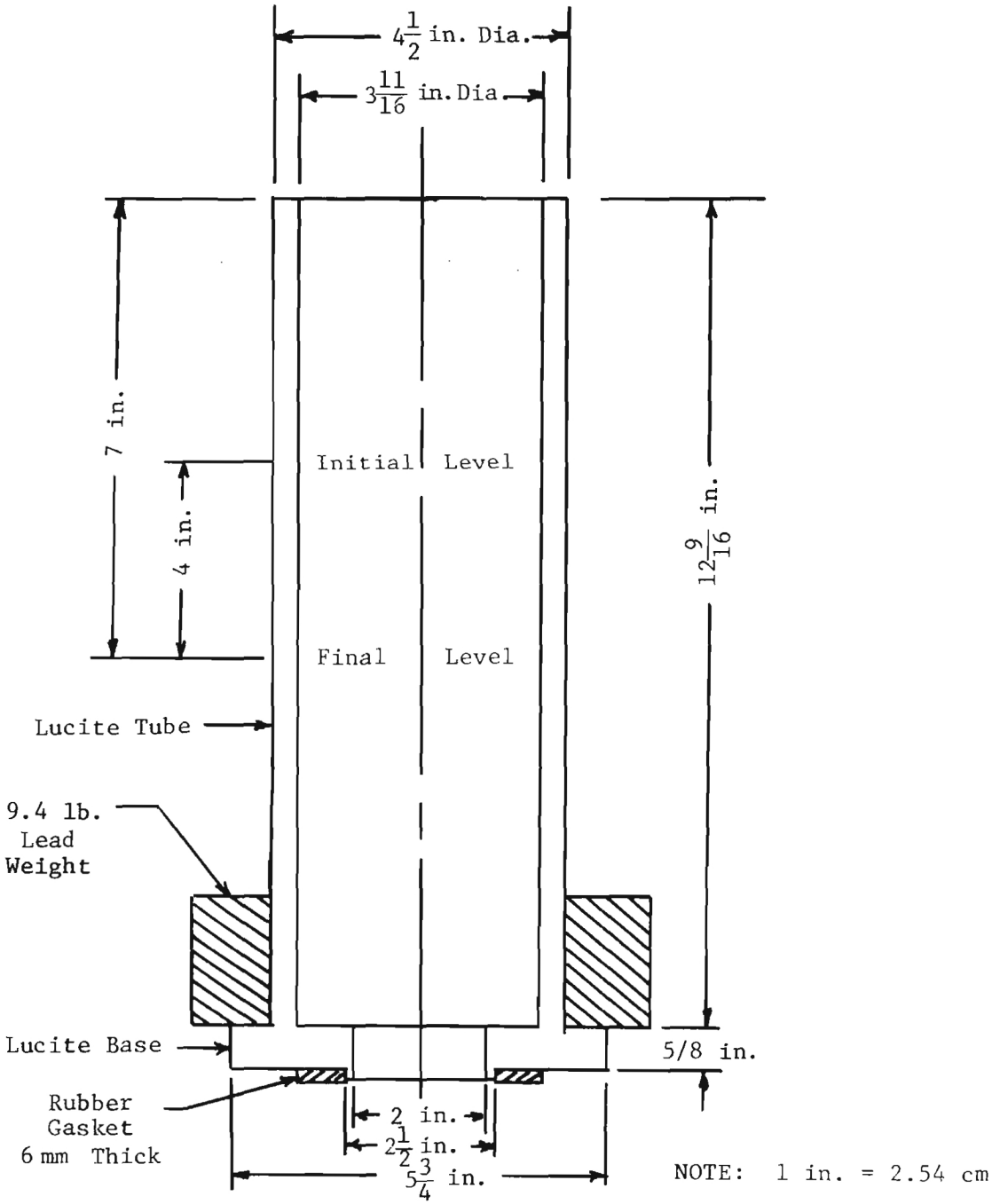


Figure 3.4. Schematic Diagram of Outflow Meter.

Table 3.17. Summary of Air Void Content of Marshall Specimens

Sample Number	Type Mix or Binder	Air Void Content (Porosity), %
D-5	Dense Mix	6.84
D-6	Asphalt	7.00
D-7	"	7.00
D-8	"	6.92
D-9	"	7.88
D-10	"	5.76
D-13	"	7.04
D-14	"	8.12
D-1	Open Graded	26.4
D-2	Asphalt	24.5
D-3	"	26.2
D-4	"	26.4
D-11	"	27.0
D-12	"	26.6
D-15	"	28.8
D-16	"	26.5
D-17	"	26.6
D-18	"	27.5
D-23	Polyamide	-
D-24	"	-
D-25	"	29.8
D-26	"	32.0
D-27	"	29.4
D-28	"	30.4
D-29	"	-
D-30	"	-
D-50	"	28.9
D-40	Pavebrite	30.8
D-41	"	32.7
D-45	"	34.3
D-46	Acrylic	35.4
D-47	"	32.7
D-48	"	32.1
D-49	"	30.4

Table 3.17. Summary of Air Void Content of Marshall Specimens (continued)

Sample Number	Type Mix or Binder	Air Void Content (Porosity), %
D-57	Hot Melt Glue	30.5
D-58	"	-
D-59	"	-
D-60	"	23.4
D-61	"	31.5
D-62	"	31.8

Table 3.18. Summary of Outflow Meter Test Results Conducted on Open-Graded Mixes.

Sample Number	Binder Type	Outflow Time[(a)], sec.
B-1	AC-20	2.1
B-2	AC-20	2.1
B-7	Polyamide	5.2
B-11	Polyamide	4.5
B-15	Pavebrite	4.9
B-16	Pavebrite	6.4
B-17	Acrylic	4.2
B-18	Acrylic	4.2
B-19	Hot Melt Glue	3.8
B-20	Hot Melt Glue	3.9

Note: (a) average of two determinations.

Table 3.19. Summary of Texture Depth Determinations by Sand Patch Method

Sample Number	Binder Type	Average Texture Depth, (in.)
A-3	AC-20	0.096
A-4	AC-20	0.094
A-5	Polyamide	0.065
A-7	Polyamide	0.062
A-10	Pavebrite	0.066
A-11	Pavebrite	0.084
A-12	Acrylic	0.059
A-13	Acrylic	0.065
A-14	Hot Melt Glue	0.057
A-15	Hot Melt Glue	0.051

3.3 CONCLUSIONS BASED ON LABORATORY SCREENING TESTS

Based on preliminary screening of the various candidate binder materials, four binder materials appeared to have sufficient promise to subject them to the more rigorous suite of screening tests. The four binder materials, all thermoplastics, were:

1. Acrylic
2. Hot Melt Glue
3. Pavebrite
4. Polyamide

Based on the various imposed requirements for the special porous delineator systems, it appeared that the systems should be composed of the following ingredients:

1. properly graded and high quality aggregate
2. binder
3. pigment
4. glass beads

In addition to the above-listed key ingredients, it was felt that with the Acrylic and Polyamide binder compounds improvments could be made to light resistance and weathering by adding an ultraviolet absorber and an antioxidant.

Based on strength and flexibility, color, and porosity (or permeance) considerations, the mix proportions for the various ingredients were established. In general it was found that the binder content had to be in the range of 8 to 10 percent based on the weight of aggregate. The aggregate gradation used was basically that recommended by FHWA for OGAFC mixtures [2].

The amount of pigment required depended on the pigment color and the binder type. It was found that more white pigment had to be used than yellow. It was also found that the pigment content had a significant effect on binder and mixture strength characteristics. This is probably explained by the reduced film thickness created by the substantially increased surface area. Pigment content selected (based on the weight of aggregate) was 2 percent for the yellow and 3 to 5 percent for the white.

Based on the results of the laboratory screening tests conducted on the special porous delineator materials, other important conclusions can be made:

1. The four thermoplastic binders selected can be pigmented to the appropriate yellow and white colors required of lane striping materials. The color of the yellow pigmented systems at the selected pigment content was found to conform satisfactorily with the central color of the FHWA Highway Yellow Color Tolerance Chart. The color was

found to be retained without appreciable effect of thermal cycling and moisture exposure. Ultraviolet radiation produced slight effects on color.

2. Sprinkling the glass beads on the surface of the porous delineator system immediately after mixing at elevated temperatures appears to provide a satisfactory method for developing light reflectance characteristics.

3. Based on the telephotometrically determined retroreflectance readings taken after various stages of the laboratory screening tests, the specially formulated porous delineator system materials have light reflectivity under wet and dry conditions as good as or better than the painted and beaded OGAFC samples.

4. Under wet conditions, the special porous delineators had better light reflectivity than the painted and beaded stripes placed on dense graded asphalt specimens.

5. Porosity and permeance of the special delineator systems were similar to that of the OGAFC system.

6. All four binder materials could be formulated and proportioned in mixtures having properties such as abrasion and impact resistance, strength, etc., which were at least as good as or better than the OGAFC mixtures.

7. Concerning abrasion and impact resistance, the Pavebrite and Acrylic mixtures had the least resistance and the Polyamide had the best resistance.

8. Resistance to solvents, such as gasoline and motor oils that might be encountered on the highway, was indicated by laboratory studies utilizing kerosene. In the case of Pavebrite, solvent resistance was low, but as good as asphalt. In all other cases, solvent resistance was much superior to that of asphalt.

9. Freeze-thaw resistance of all systems was excellent, showing little effect of thermal cycling on adhesive bond strength.

10. Adhesion of all binder-pigment systems to aggregate (or concrete) was found to be satisfactory. It is anticipated that no deleterious effect on adhesion will be produced by moisture and varying temperature.

11. All systems showed minimal light-induced changes in brittleness and color.

12. No evidence of the production of pollution factors was shown with any of the samples, and the components of all samples were found to be non-toxic with reference to standard lists of threshold limit values of toxicity.

13. Coefficients of linear thermal expansion were found to be similar to asphalt cement.

14. Flow rates of all systems were such as to provide for ease of compounding and application to highway striping.

15. All binder-pigment systems except Acrylic had workability characteristics reasonable for compounding and highway applications.

3.4 RECOMMENDATIONS BASED ON LABORATORY SCREENING TESTS

Based on the various stages of the binder selection, binder screening and porous delineator system materials evaluation, it appeared that the four binder materials (Acrylic, Hot Melt Glue, Pavebrite and Polyamide) possess properties and characteristics adequate enough to warrant further evaluation under full-scale highway conditions. Thus, special porous delineator systems fabricated from these four binder materials were recommended for placement in the Phase II, Pilot Test Section for more rigorous in-service evaluation.

The limited laboratory results obtained wherein thermosetting materials were used as binder materials seemed to indicate that further consideration might be given to this class of binders. However, time and resources did not allow further consideration of these binders during the project.

Based on the limited quantity of special porous delineators to be placed in Phase II, Pilot Test Sections, and the special handling and mixing requirements for the binders and other mixture ingredients (compared to conventional OGAFC mixes), it decided that the delineator systems would be prefabricated in the laboratory and then transported to the job site.

PILOT TEST SECTIONS

4.1 GENERAL

In order to further evaluate the potential of candidate porous delineator materials for providing adequate long-term serviceability under actual service conditions, the porous delineator materials composed of the four previously mentioned binder compounds were placed in a small test section.

4.2 LOCATION AND DESCRIPTION OF PILOT TEST SECTION

The site selected for the pilot test section is located on the west-bound entrance ramp of the Stone Mountain Freeway-Mountain Industrial Boulevard Interchange. The site location is shown in Figure 4.1 and is about 12 miles (19 kilometers) east of the Atlanta, Georgia business district.

The pavement at the site is composed of an OGAFC surface, asphaltic concrete leveling course, and a portland cement-aggregate base layer. A pavement cross-section is shown in Figure 4.2. In the longitudinal direction, the pavement surface slopes about 2 percent to the west.

A traffic count made at the site indicated a traffic volume in excess of 10,000 vehicles per day with about 10 to 15 percent truck traffic.

4.3 PILOT TEST SECTION CONSTRUCTION DETAILS

Construction of the pilot test section took place during the early part of June, 1976. Primary manpower and equipment was provided by the Georgia Department of Transportation (GDOT). In order to accelerate the wear-rate of the various lane marking materials, the control items and the special porous delineators were placed diagonally across the pavement at an angle of about 60^{o} with the pavement edge.

To serve as a standard and for comparative purposes, control lane markers consisting of yellow and white varieties of beaded paint, foil-backed temporary reflective tape, and cold applied thermoplastic reflective tape were placed on the OGAFC surface at one end of the test section. The control lane markers were spaced about 3 feet (1 meter) apart.

To install the special porous delineator materials in the OGAFC surface a continuous 4 inch (10 cm) wide and about 5/8 inch (1.6 cm) groove was cut diagonally across the pavement using GDOT pavement grinder equipped with diamond saws. A total of eight continuous grooves each about 20 feet (6 meters) long and 3 feet (1 meter) apart was cut. Each of the grooves was thoroughly washed and dried. A thin layer of hot AC-20 paving grade asphalt cement was then placed in the bottom of

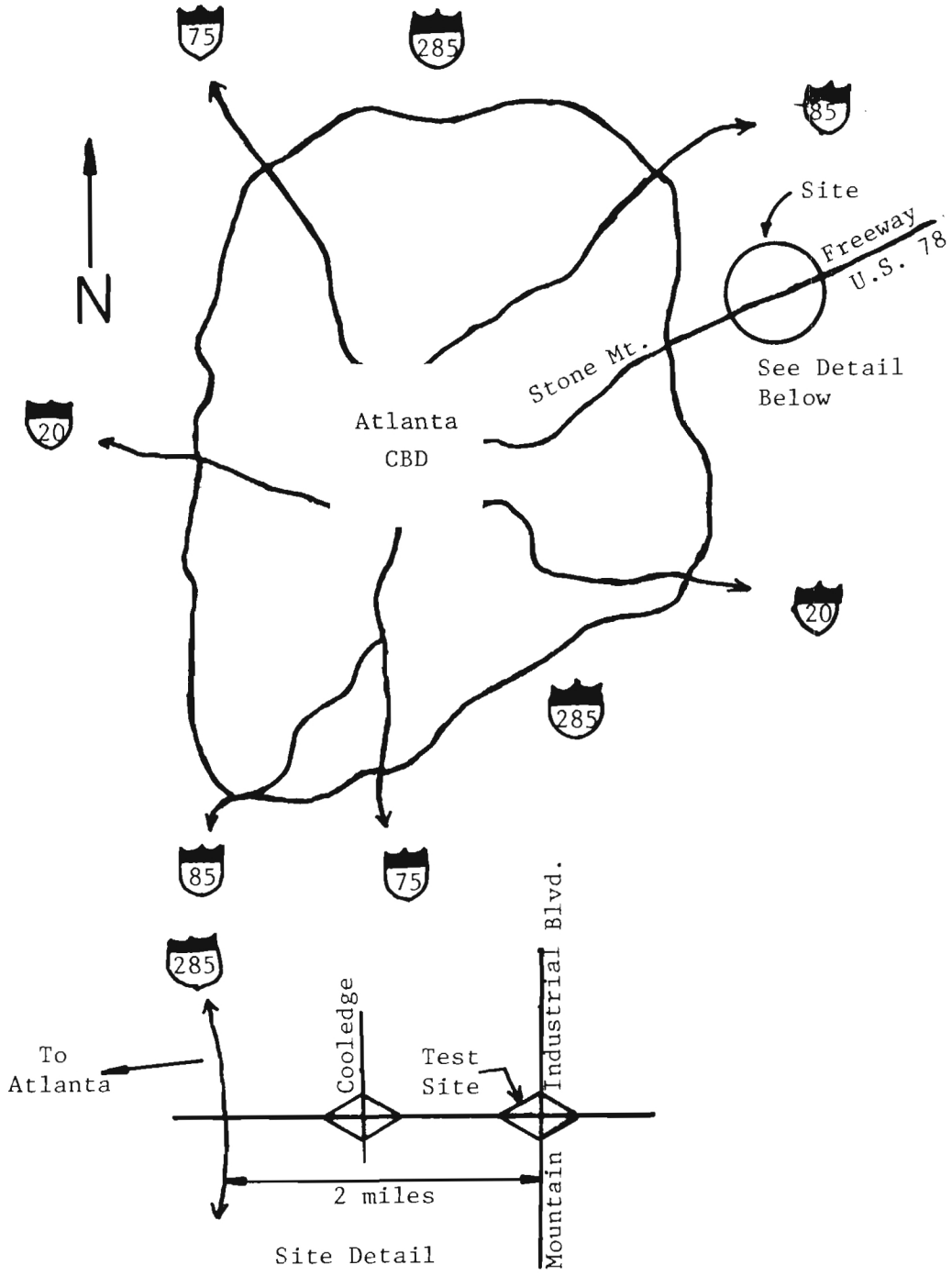


Figure 4.1. Location of Pilot Test Section Relative to City of Atlanta, Georgia.

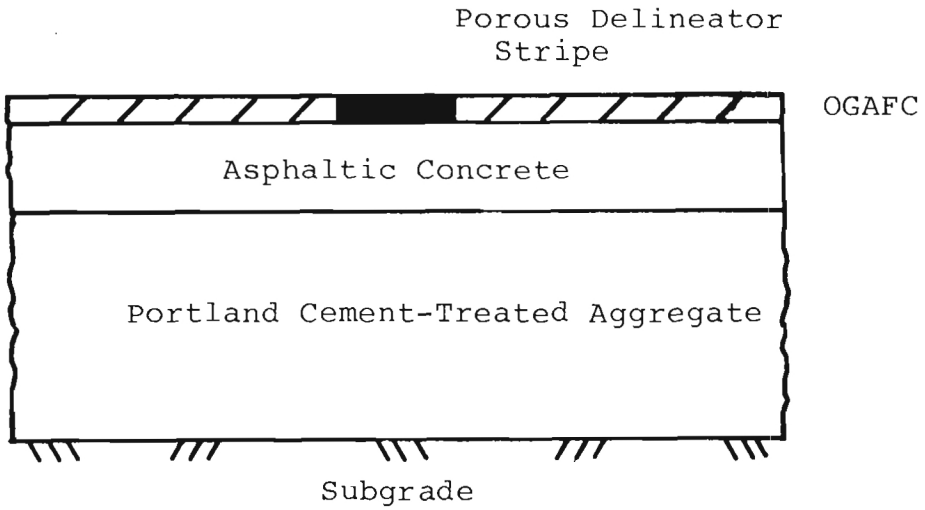


Figure 4.2. Cross-Section of Pavement at Pilot Test Section Site.

of each groove to act as an adhesive. Figure 4.3 shows construction.

Prior to construction, blocks of the special porous delineator materials were prefabricated in the Georgia Tech, School of Civil Engineering Materials Laboratory. Each of the prefabricated blocks were 15 inches (38 cm) long, 4 inches (10 cm) wide, and 0.625 inches (1.6 cm) thick. A summary of the mixture proportions used for each of the porous delineator systems is presented in Table 4.1.

These prefabricated blocks of the special porous delineator materials were placed in the prepared groove. A small vertical pressure was applied to each block to insure contact with the asphalt adhesive in the bottom of the groove.

At the ends of each groove not occupied by the porous delineator, an asphaltic concrete patching mix was placed and compacted.

Figure4.4 presents a layout of the completed pilot test section and a cross-section showing a typical porous delineator stripe in the grooved pavement.

4.4 DETAILS OF TESTING AND MONITORING OF PILOT TEST SECTION

Subsequent to installation, the serviceability of the special porous delineator materials and control items were monitored for a period of about 1 year. Extensive observation and monitoring was accomplished during the first 3 months of service. After this, only periodic observations were made.

For the pilot test section, the following types of monitoring were used:

1. subjective visual examination
2. photographic logging (35 mm still and super 8 mm movie) for both day and night
3. telephotometric recording of dry and wet-night retro-reflectance.

Telephotometric equipment developed by Tooke and Hurst [5] and described elsewhere in this report was used at night to evaluate the retroreflectance of the control and special porous delineator material stripes under both dry and wet conditions. The wet condition was created by thoroughly wetting each strip with water sprayed from a garden hose.

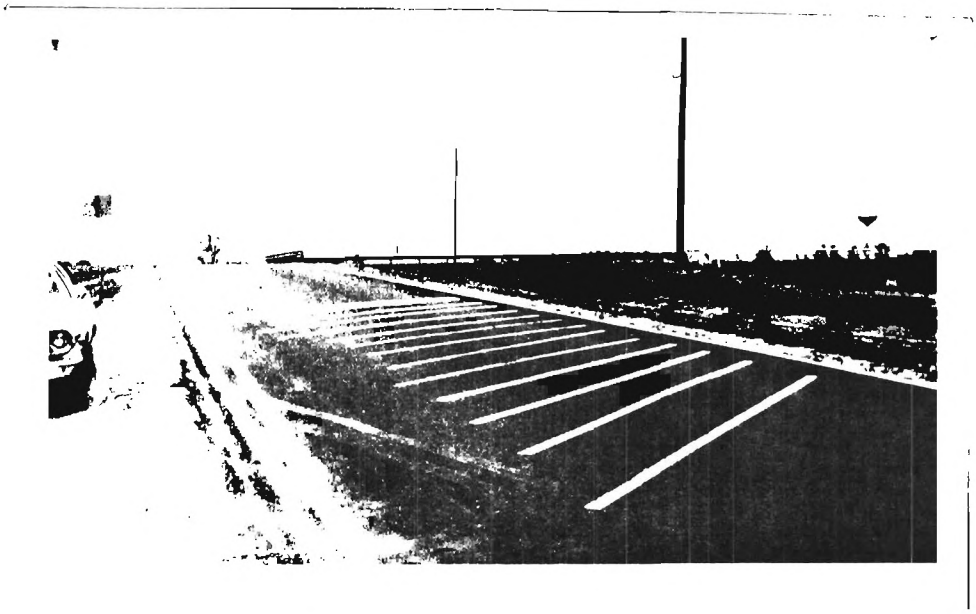
The telephotometer was mounted on a heavy duty tripod. This apparatus was placed at the side of the road and aligned with the longitudinal axis of the delineator stripe being monitored. To monitor the retroreflectance the telephotometer was focused at the near end of the delineator stripe. The telephotometer unit was then slowly rotated in a vertical plane thereby moving the light beam and viewing region

a. Cutting Groove in OGAFC

b. Placing AC-20 Asphalt Adhesive

Figure 4.3. Pictures of Pilot Test Section Construction.

c. Placing Porous Delineators



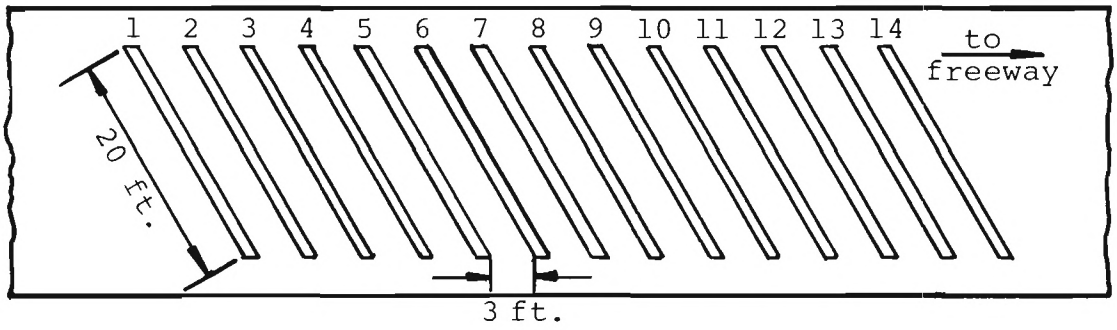
d. Finished Test Section

Figure 4.3. Pictures of Pilot Test Section Construction (continued).

Table 4.1. Summary of Mixture Proportions for White and Yellow Porous Delineator Systems Used in Pilot Test Sections.

Delineation System	Mixture Proportions by Weight				
	Binder	Aggregate	White	Yellow	Glass Beads
Acrylic	10.0	100.0	5.0	2.0	(a)
Hot Melt Glue	10.0	100.0	5.0	2.0	(a)
Pavebrite	10.0	100.0	5.0	2.0	(a)
Polyamide	10.0	100.0	5.0	2.0	(a)

(a) Glass bead application rate was about 50 grams per square ft. of porous delineator.



KEY:
1 - yellow beaded paint
2 - white beaded paint
3 - white thermoplastic tape
4 - yellow thermoplastic tape
5 - white reflectorized foil tape
6 - yellow reflectorized foil tape
7 - yellow Acrylic porous delineator
8 - yellow Hot Melt Glue porous delineator
9 - yellow Pavebrite porous delineator
10 - yellow Polyamide porous delineator
11 - white Acrylic porous delineator
12 - white Hot Melt Glue porous delineator
13 - white Pavebrite porous delineator
14 - white Polyamide porous delineator

Figure 4.4. Pilot Test Section Layout.

from the near end to the far end of the delineator stripe. This caused a continual change of the angle of incidence between the light source and telephotometer axis and the delineator surface. Figure 4.5 depicts a schematic of the telephotometer set-up and monitoring technique used at the Pilot Test Section site. The telephotometer readings were continuously recorded on a Brush strip chart recorder.

Super 8 mm movies and 35 mm color slides were taken of the various delineator stripes simultaneously with the telephotometric readings. After each delineator stripe was completely monitored in dry and wet conditions, a thin layer of a dry mixture of sand and calcium chloride (9 parts sand to 1 part calcium chloride by weight) was placed on the surface of each delineator stripe.

4.5 RESULTS FROM PILOT TEST SECTION STUDY

Two types of results were obtained concerning the serviceability of delineator materials at the pilot test section. One type was based on visual observations at the site and of the photographic logs. The other type was based on the results of the telephotometric examination which could be quantitized and thus were somewhat more objective in nature.

Visual Examinations

Based on the visual examinations over the first year of service, pertinent observations can be made concerning the performance of the various materials at the test site:

Raveling:

1. Both yellow and white Polyamide porous delineators started raveling badly soon after installation. However, after some initial raveling, very little additional raveling has occurred.

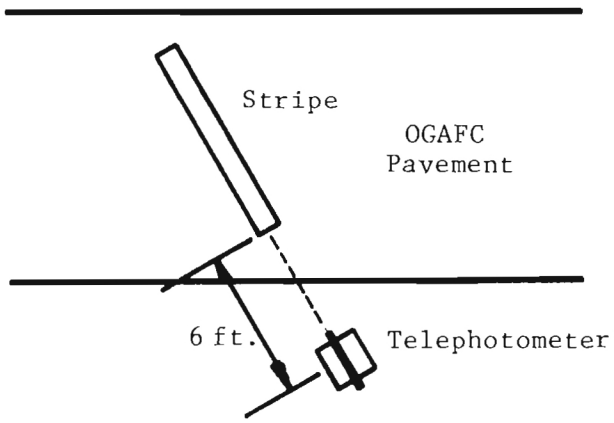
2. The Hot Melt Glue porous delineators exhibited virtually no raveling during the first 6 months but then started to display slight raveling.

3. Pavebrite porous delineators have raveled at almost a constant rate since installation although the yellow delineators have raveled more than the white ones.

4. Acrylic porous delineators have exhibited virtually no raveling.

Color:

1. For the yellow delineators, the Polyamide has held its color much better than the others. Acrylic has shown some loss of color while Hot Melt Glue and Pavebrite have shown



Plan View

NOTE: 1 meter = 3.28 ft.

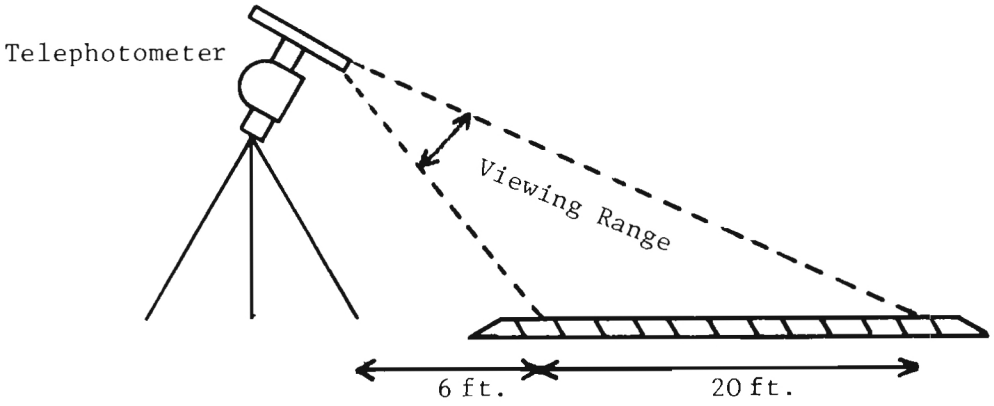


Figure 4.5. Schematic of Telephotometer Monitoring Setup at Pilot Test Section.

the greatest color loss.

2. For the white porous delineators, Acrylic, Hot Melt Glue, and Polyamide have held their color while the Pavebrite has a slight yellow cast.

Wet-Night Visibility:

1. During the first 3 months of service, in all cases, the observations of visibility under wet-night conditions indicated that the porous delineators were superior to the paint and reflector tape control items.

Abrasion or Wear:

1. After about 1 year of service, a close-up examination of the Hot Melt Glue, Acrylic and Pavebrite porous delineator surfaces revealed a substantial loss of pigmented binder from areas of the aggregate surface which have been in contact with vehicle tires. Much of the upper surface of the aggregates was completely devoid of binder. The Polyamide porous delineators however, exhibited almost no loss of binder from its surface.

Rutting or Permanent Deformation:

1. None of the special porous delineators have exhibited any rutting or permanent deformation.

Telephotometric Evaluation of Retroreflectance

An important aspect of the serviceability and performance of the porous delineators is their ability to provide wet-night visibility. As outlined earlier, the telephotometer was used to evaluate the retroreflectance of the porous delineators under both dry and wet-night conditions. The continuous recording of relative retroreflectance of a particular porous delineator was transferred to a graphical form such as the one shown in Figure 4.6. The vertical axis of these plots is a linear scale of relative retroreflectance. A standard of white temporary reflector tape was used for calibration each monitoring trip. Figure 4.6 also shows the response of the calibration material.

In order to interpret the retroreflectance data, relative retroreflectance values were taken from the various graphical plots at a scale distance of 20 feet (6 meters) from the telephotometer. At this distance and for the geometry of the set-up, the angle of light incidence is about 1^0.

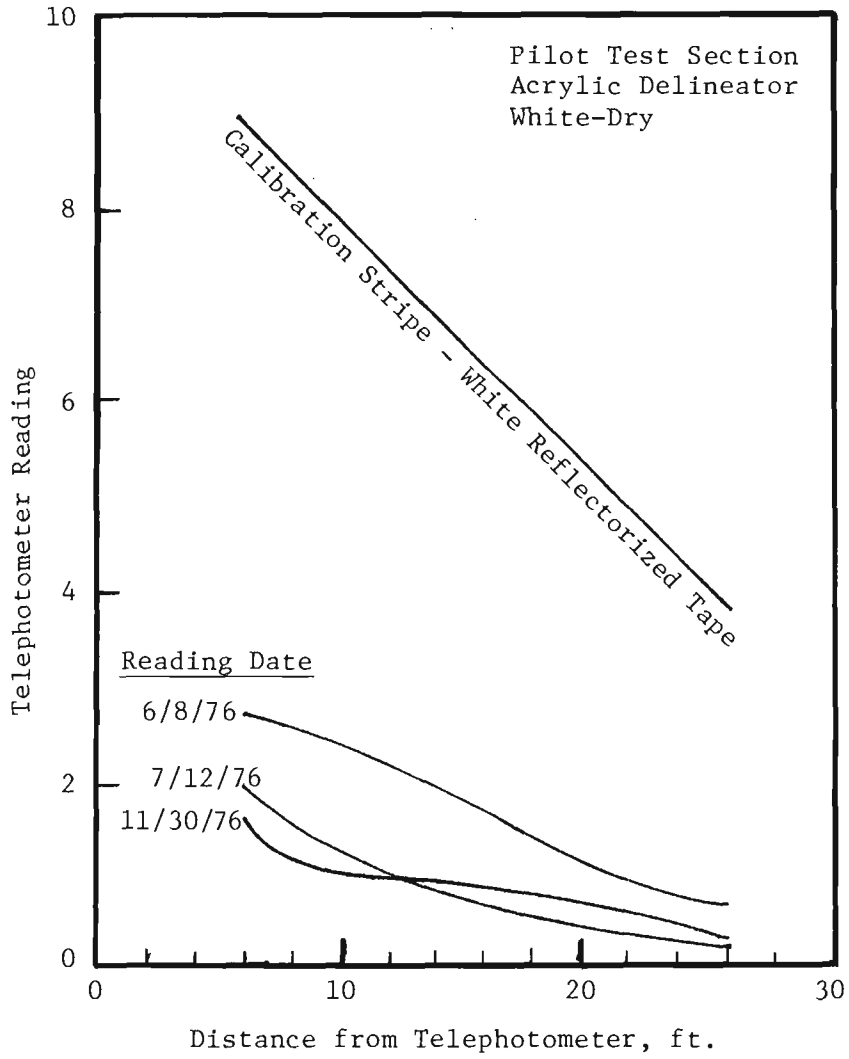


Figure 4.6. Typical Recording of Telephotometric Readings.

A convenient method for examining the influence of service time, delineator type and wet vs. dry condition is to calculate a Reflectance Ratio using the data taken from the various telephotometer reading plots and the following equation:

$$\text{Reflectance Ratio} = \frac{\text{telephotometric reading for delineator}}{\text{telephotometric reading for new, beaded paint in dry condition}}$$

Thus, a ratio less than one represents a lower telephotometric reading and retroreflectance (and implied lower visibility) compared to new paint and a ratio greater than one represents a delineator system with better retroreflectance and visibility than the new beaded paint stripe. In Table 4.2, Retroreflectance Ratios have been presented for both white and yellow delineator systems for the three observation dates shown.

Observations

Although a number of interesting comparisons can be made using the telephotometer data (Retroreflectance Ratios), Table 4.2, the following appear to be significant with respect to the objectives of this project:

1. The dry condition retroreflectance of the white and yellow paint and the wet condition retroreflectance of the yellow paint remained about the same for the June 8 to Nov. 30, 1976 period. However, the wet condition retroreflectance of the white paint decreased substantially during the period.

2. Immediately after construction the dry condition retroreflectance of all white porous delineator systems PDS was greater than the white paint; all yellow PDS had a dry-condition retroreflectance slightly less than the yellow paint.

3. In the wet condition immediately after construction, the white Acrylic and white Hot Melt Glue PDS all had retroreflectance values greater than the white paint whereas the white Pavebrite and Polyamide PDS and all yellow PDS had wet-condition retroreflectance less than the white and yellow paint respectively.

4. After the 6 month service period, all PDS displayed a dry-condition retroreflectance somewhat lower than the white or yellow paint, respectively.

5. After the 6 month service period, the white Acrylic and Hot Melt Glue PDS displayed better wet-night retroreflectance than the 6 month old white paint. All other PDS displayed

Table 4.2. Retroreflectance Readings of Various Delineators at Pilot Test Section.

DELINEATOR SYSTEM	COLOR	RETROREFLECTANCE RATIOS					
		June 8, 1976		July 12, 1976		Nov.30, 1976	
		Dry	Wet	Dry	Wet	Dry	Wet
Conventional Stripping							
Beaded Paint	White	0.8	0.6	0.8	0.15	0.8	0.15
	Yellow	1.1	0.5	0.9	0.5	1.1	0.5
Thermoplastic Tape	White	0.1	0.05	0.1	0.1	0.35	0.4
	Yellow	0.1	0.1	0.3	0.15	0.6	0.1
Foil-Backed Tape	White	5.0	0.95	4.4	0.85	2.8	0.35
	Yellow	2.9	0.95	2.45	0.4	1.3	0.3
Porous Delineation sytems							
Acrylic	White	1.2	1.1	0.8	0.35	0.5	0.35
	Yellow	0.75	0.4	0.5	0.2	0.7	0.25
Hot Melt Glue	White	1.7	1.3	0.8	0.75	0.5	0.45
	Yellow	0.45	0.4	0.35	0.2	0.4	0.3
Pavebrite	White	1.65	0.55	0.8	0.3	0.6	0.1
	Yellow	0.6	0.3	0.4	0.2	0.35	0.2
Polyamide	White	1.0	0.5	0.6	0.1	0.6	0.1
	Yellow	0.65	0.4	0.3	0.15	0.6	0.3

slightly lower wet-night retroreflectance than the respective yellow or white paint.

4.6 CONCLUSIONS BASED ON THE PILOT TEST SECTION RESULTS

After the Pilot Test section had been in service about 2 months, it was necessary to select two of the four PDS for installation in the Virginia test sections. At the end of July, 1976, the Acrylic and Hot Melt Glue PDS appeared to be providing the best service.

Other conclusions based on the results from the Pilot Test section study include:

1. There appears to be no adverse effect of deicing salt and sand mixture on performance of porous delineators.

2. After 6 months of service some of the porous delineator systems were not providing superior wet-night visibility compared to beaded paint. It appears that this is primarily due to a great loss of glass beads and pigmented binders from the reflective surface of the delineators. More wear-resistant binder formulations such as the Polyamide and more wear-resistant glass beads appear to be a desirable alteration of the porous delineators.

3. The installation technique in general seemed to be satisfactory; however, since most raveling seemed to occur at the edges of the prefabricated blocks, a better installation technique may be to place continuous stripes of the porous delineator.

FIELD TEST SECTIONS

5.1 GENERAL

A major phase of the research program was devoted to evaluating the most promising special porous delineator systems under real-life field service conditions for at least one full winter in an area subjected to moderate snowplow activity and moderate traffic density.

Based on the serviceability history of the four PDS in the Pilot Test section, Hot Melt Glue and Pavebrite were selected for placement in the Field Test sections. Pavebrite was selected instead of Acrylic (Acrylic had better performance in the Pilot Test section) because of its better availability and because it has necessary workability at much lower temperatures. The Hot Melt Glue PDS was used in three of the test sections and Pavebrite PDS was used in the fourth test section but in a more limited quantity.

5.2 LOCATION AND DESCRIPTION OF SITE USED FOR FIELD TEST SECTIONS

The site selected for the field test sections was in northwest Virginia on U.S. Route 50 about 60 miles west of Washington, D.C. and about 4 miles west of Winchester, Virginia. The site location is depicted in Figure 5.1. At the particular site selected, U.S. Route 50 is a winding and somewhat hilly 4-lane divided highway with partially controlled access which generally runs in an east-west direction. The roadway is an asphaltic concrete surfaced flexible pavement, 24 ft. (7.3 meters) wide in each direction with very narrow unpaved shoulders. The traffic volume at the site is about 5,000 vehicles per day in each direction with substantial heavy truck traffic.

Various short sections of the east-bound lanes had been re-surfaced with OGAFC in the summer of 1975. In the summer of 1976, a section of the west-bound lane, about 2.1 miles (3.4 kilometers) long starting at Virginia secondary highway 608 was surfaced with OGAFC. It was this 2.1 mile (3.4 kilometer) stretch that was used as the primary test site. A short test section in the east-bound lane about 1,000 ft. (305 meters) long which had been surfaced with OGAFC the previous summer was also used.

A total of 6 test sections were used at the site. The five test sections located in the west-bound lanes were each about 2500 ft. (760 meters) long. As previously noted, a 1,000 ft. (305 meters) test section was located in the east-bound lanes. Two of the test sections served as control sections. A general layout of the test sections and the delineator materials used in each is illustrated in Figure 5.2.

5.3 DETAILS OF CONSTRUCTION OF FIELD TEST SECTIONS

5.3.1 Prefabrication of Porous Delineator Systems

The Hot Melt Glue and Pavebrite porous delineator systems were prefabricated in the Georgia Tech, School of Civil Engineering Materials

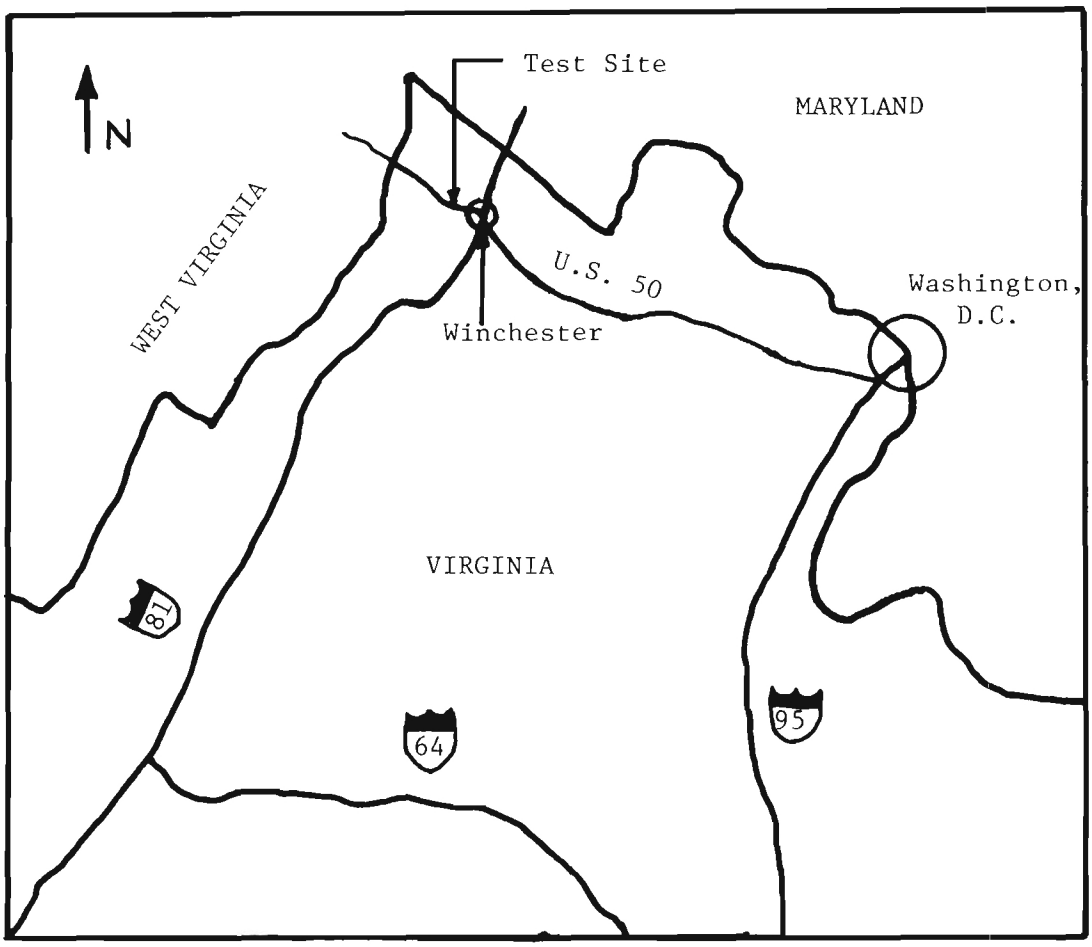
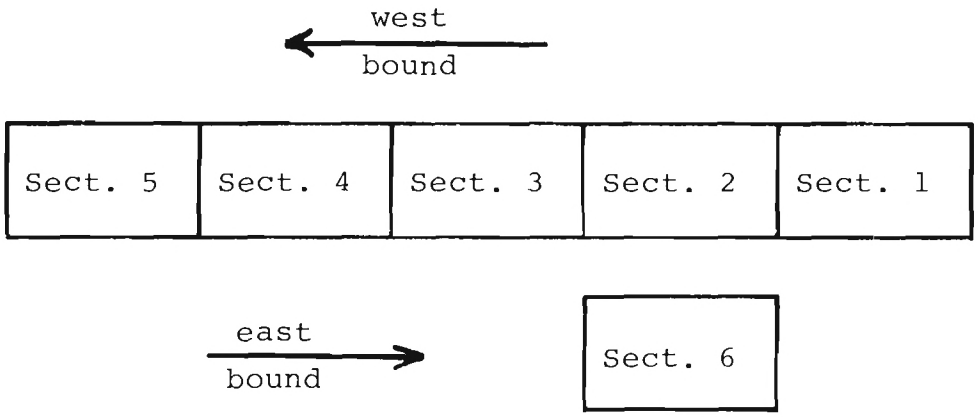


Figure 5.1. General Location of Field Test Sections on U.S. 50 West of Winchester, Virginia.



Sect. 1 - Control Section, beaded white paint on dense asphalt pavement

Sect. 2 - Hot Melt Glue, simultaneously placed with OGAFC overlay

Sect. 3 - Control Section, beaded white paint on OGAFC surface

Sect. 4 - Hot Melt Glue, placed in grooves after construction of OGAFC surface

Sect. 5 - Hot Melt Glue Replicate Section, placed in groove after construction of OGAFC surface

Sect. 6 - Pavebrite, placed in groove after construction of OGAFC surface

Figure 5.2 . Layout of Virginia Field Test Sections.

Laboratory. Discrete blocks of the porous delineator materials 15 inches (38 cm) long by 4 inches (10 cm) wide by 0.75 inches (1.9 cm) thick were made using the procedure detailed in Appendix B. The mixture proportions used for the prefabricated blocks are summarized in Table 5.1.

5.3.2 Simultaneous PDS and OGAFC Overlay Placement

One objective of the research project was to develop a PDS which could be placed at the same time as a new OGAFC overlay. Arrangements were made with the Virginia Department of Transportation and the contractor doing the OGAFC overlay to use the first 2,500 ft. of the 2.1 mile long OGAFC section. The construction of the test section, designated as Test Section 2, was accomplished on August 10 and 11, 1976. The construction sequence for this PDS - OGAFC overlay section was as follows:

1. Overlay the inside lane of the 24 ft. (7.3 meters) wide west-bound roadway. Care was taken during the tacking and paving to leave the centerline location clear.

2. The exact location for each 15 ft. (4.6 meters) long centerline stripe was laid out. A 3:5 stripe to skip ratio was used.

3. A thin layer of hot, paving grade AC-20 asphalt was placed where the Hot Melt Glue PDS centerline stripe was to be located. The asphalt layer which served as an adhesive was slightly less than 0.1 inch (0.25 cm) thick, slightly more than 4 inches (10 cm) wide and about 15 ft. (4.6 meters) long, Figure 5.3.

4. Exactly twelve of the prefabricated PDS blocks were carefully placed on the AC-20 asphalt adhesive and firmly pressed downward onto the adhesive, Figure 5.3.

5. A double layer of conventional masking tape was placed on the upper surface of the Hot Melt Glue PDS to act as protection of the reflectorized surface during the tack coat, paving and rolling operations, Figure 5.3.

6. The OGAFC overlay was then placed on the outside lane of the west-bound roadway. The overlay operations (tacking, paving, and rolling) progressed without any delay due to the presence of the PDS centerline stripe. A small amount of OGAFC mix left by the paver had to be removed from the upper surface of the PDS stripe prior to the rolling operation.

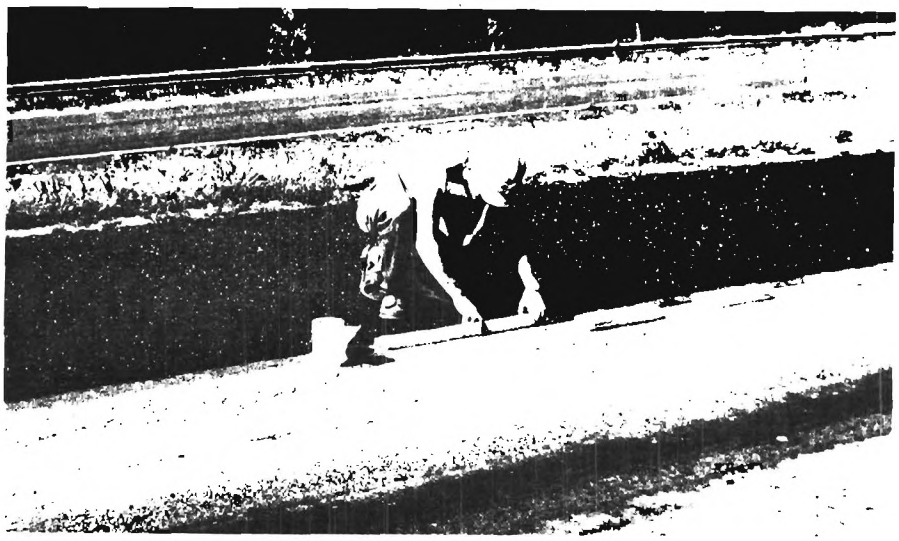
7. Reflectorized foil-backed delineator tape was placed at the centerline location. This tape provided temporary center-

Table 5.1. Summary of Mixture Proportions for White Porous Delineator Materials Placed in Virginia Test Sections.

Delineator System	Mixture Proportions by Weight			
	Binder	Aggregate	Pigment	Glass Beads
Hot Melt Glue	8.0	100	3.2	(a)
Pavebrite	10.0	100	5.0	(a)

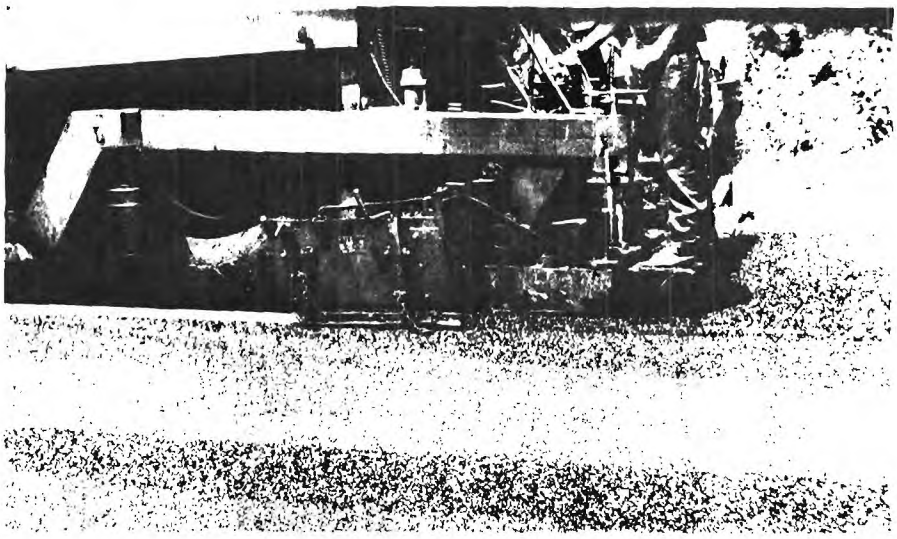
(a) Glass bead application rate was about 50 grams per square ft. (about 540 grams per square meter) of porous delineator.

a. Placing AC-20 Asphalt Adhesive

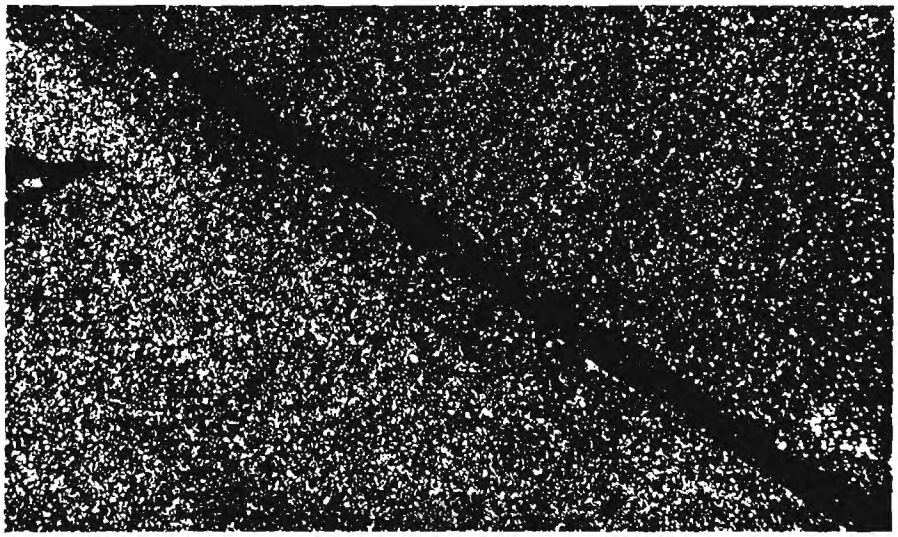


b. Placing Porous Delineator Blocks

Figure 5.3. Pictures of Virginia Field Test Section Construction.



c. OGAFC Paving Around Porous Delineator



d. Appearance of Porous Delineator Immediately After Passing of Paver

Figure 5.3. Pictures of Virginia Field Test Section Construction (continued).

e. Removal of Masking Tape Used for Surface Protection

f. Appearance of Newly Constructed OGAFC with Porous Delineator Insert

Figure 5.3. Pictures of Virginia Field Test Section Construction (continued).

line delineation. Traffic was immediately allowed back on the roadway.

8. The following morning, the masking tape and reflectorized tape were removed from the surface of the PDS, Figure 5.3.

Overall the test section construction went very smoothly. A number of pertinent observations were made during the sequence of construction events which may be useful in such future endeavors.

1. The preplaced 15 ft. (4.6 meters) PDS stripes in general did not move about during construction operations even though trucks and the paver actually rode on top of them periodically. In a couple of cases, the last two 15 inch (38 cm) prefabricated blocks moved longitudinally about 1/2 inch (1.3 cm) in the direction of movement of the paving operation. The AC-20 paving grade asphalt appeared to be adequate for bonding the PDS blocks in place.

2. Some difficulty was encountered in removing the double layer of masking tape. The masking tape did, however, appear to provide adequate protection to the surface of the PDS.

3. For the first few days excess asphalt tracked badly from the OGAFC overlay. This excess asphalt tended to slightly obliterate the PDS stripe. However, after about a week the asphalt tracking ceased and the asphalt on the PDS stripe was quickly worn away by traffic.

4. In some areas, the OGAFC overlay was slightly thicker than the 3/4 inch (1.9 cm) thick PDS stripe, thus leaving the PDS stripe in a slight depression.

5.3.3 Placement of PDS stripes in Existing OGAFC

Another major objective of the research project was to develop PDS which could be placed in existing OGAFC. Thus three of the test sections were constructed with this objective in mind. The approach used for construction of PDS stripes in existing OGAFC surfaced pavements was to place the prefabricated blocks of PDS into a groove cut to the appropriate width, depth, and length. Grooving was accomplished with a pavement surface grinder equipped with multiple diamond saws. Test Sections Number 4, 5 and 6 were constructed in this manner during the period November 8 to 12, 1976. The construction procedure was similar to that used in construction of the Pilot Test Section, previously described.

The detailed step-by-step approach was as follows:

1. The position on the pavement surface where grooves were to be cut was identified. In general, the old paint stripe

served to establish this position. Also, it was desirable to cut out the old paint stripe to eliminate its effect on retroreflectance. A stripe to gap ratio of 3:5 was used throughout.

2. The grooving equipment was positioned and the grooving depth carefully set. The groove was then cut. The resulting groove was about 4-1/8 inch (10.5 cm) wide, 3/4 inch (1.9 cm) deep and about 15.5 ft. (4.7 meters) long. Water was used during the grooving operation to cool the diamond cutters.

3. After the groove was cut, the groove was thoroughly washed out and allowed to dry. In some instances, flame from a "weed burner" was used to facilitate drying of the groove.

4. A thin layer of RC-250 rapid curing cutback asphalt was placed in the bottom of the groove to act as an adhesive. Upon evaporation of the solvent, the RC-250 has an asphalt residue of similar character to the AC-20 paving grade asphalt used in Test Section 2.

5. Exactly twelve of the 15 inch (38 cm) long prefabricated blocks of the PDS were placed in the groove. Each block was firmly pressed into place. Care was taken to insure adherence of the RC-250 to the PDS and the dense graded asphalt pavement substrate.

6. In Test Sections 4 and 5 a total of one hundred twenty 15 ft. (4.6 meters) Hot Melt Glue PDS stripes were placed. In Test Section 6, a total of seventeen 15 ft. (4.6 meters) long Pavebrite PDS stripes and eight 15 ft. (4.6 meters) long Hot Melt Glue stripes were placed.

7. At each end of the grooves, it was necessary to fill in with a cold asphalt-aggregate patching material after the PDS stripe had been placed. This material was placed and thoroughly compacted with a Marshall compaction hammer so that a smooth surface was produced.

The construction of Test Sections 4, 5 and 6 took a total of about 4 days. Some of the difficulties encountered were primarily related to the weather, which was cold and damp. Temperatures ranged from early morning lows of less than $30^{o}F$ ($-1^{o}C$) to afternoon highs of about $45^{o}F$ ($7^{o}C$). On at least one day, operations were hindered repeatedly by snow.

A number of pertinent observations concerning the construction operations are as follows:

1. Some difficulty was encountered relative to cutting a groove to the correct depth. Nonuniform roadway crown

contributed greatly to this.

2. It was often difficult to thoroughly dry the groove within a reasonable length of time. This was partly due to the weather conditions. Major contributing factors are however, the excess water used in cutting and cleaning the groove compounded by the storage capacity of the porous OGAFC.

3. The Pavebrite PDS were extremely brittle at the time of installation. This was mainly due to the low temperatures. Because of the brittle nature of the Pavebrite PDS, it was virtually impossible to insure uniform and complete contact between the PDS and the substrate. Attempts to preheat each of the prefabricated Pavebrite PDS prior to installation were not very successful. Because of the brittle nature of the Pavebrite PDS and an anticipated early failure, only a limited quantity was placed in Test Section 6. It should be noted that the problem of brittleness was not encountered when the Pavebrite PDS was installed in the Georgia Pilot Test Section. During the Georgia installation, temperatures ranged 70 - 80°F (21 to 27°C) and no brittleness was noted.

5.4 EVALUATION OF FIELD TEST SECTIONS

The primary objective of the field test sections was to evaluate the serviceability and performance of the selected PDS installed in new and existing OGAFC. The PDS centerline stripping materials were evaluated over a period of about 1 year. Periodic visits were made to the test site. Table 5.2 summarizes the construction, monitoring visit and observation schedule.

Techniques utilized in monitoring of serviceability included visual inspection, photographic logging and telephotometric reading of retroreflectance. A description of each technique follows.

5.4.1 Visual Inspection

The PDS materials were visually inspected during every visit. Visual inspection was made from a car traveling at about 50 mph and from close-up by personnel on foot. Inspection was normally done by Dr. Quentin L. Robnett, Mr. Ray Tooke and various FHWA staff. Particular attention was given to any obvious forms of physical distress being displayed by the PDS materials. Also the relative delineation provided by the PDS compared to the beaded paint sections during day and night time and for both dry and wet conditions was made. A visual inspection rating form, Figure 5.4 was completed by each observer during each site visit.

Results of the visual inspections are summarized in Table 5.3.

Table 5.2. Summary of Activities at Virginia Test Site.

Date	Activity
May, 1976	Section 1 centerline and edge stripe painted.
July, 1976	Planning and coordination visit to test site - final selection of location.
August 9-12, 1976	2.1 mile section of U.S. 50 overlayed with OGAFC and Test Section 2 constructed with Hot Melt Glue PDS. A total of sixty-two 15 ft. stripes placed.
August 16, 1976	White painted and beaded centerline stripe placed on Test Sections 3, 4 and 5.
August 19-20, 1976	Monitoring visit. Complete monitoring of Test Sections 1, 2 and 3 conducted. Monitoring operations included daytime (dry condition) visual and photographic observations and night-time (dry and wet conditions) visual, photographic, and telephotometric observations.
November 8-12, 1976	Installation of PDS centerline stripes in Test Sections 4, 5 and 6. This installation consisted of cutting and groove in the existing OGAFC and placing the PDS in the groove.
December 8-9, 1976	Monitoring Visit. Monitoring of Test Sections 1, 2, 3, 4, 5 and 6. Because of night-time below freezing temperatures, monitoring was conducted under dry conditions only. Complete visual, photographic, and telephotometric monitoring was accomplished, however.
Winter, 1976-1977	Periodic snowplowing and deicing chemical application by Virginia Department of Highways. Test site was snowplowed 24 times with steel tipped blade and chloride deicing chemical placed 17 times.
February 3-4, 1977	Monitoring Visit. Monitoring of Test Sections 1, 2, 3, 4, 5 and 6. Because of night-time below freezing temperatures, monitoring was conducted under dry conditions only. Complete visual, photographic, and telephotometric monitoring was accomplished, however.

Table 5.2. Summary of Activities at Virginia Test Site (continued).

Date	Activity
June 21-22, 1977	Monitoring Visit. Monitoring of Test Sections 1,2,3,4 5 and 6. Monitoring operations included daytime (dry condition) visual and photographic observations and night-time (dry and wet condition) visual, photographic, and telephotometric observations.

EVALUATION FORM

Name of Evaluator _____ Date _____

Type of Porous Delineator _____ Time
day evaluation _____
night evaluation _____

Weather Conditions (circle one)

clear	temp.	20°F
partly cloudy		40
overcast		60
rainy		80

1. Close-up appearance of porous delineator materials (day-time conditions)
   a. uniformity of color: 1 (good) 2 (fair) 3 (poor)
   b. color retention: 1 (good) 2 (fair) 3 (poor)
   c. ravelling and/or crumbling of delineator stripe: 1 none 2 slight 3 moderate 4 severe
   d. cracking of delineators: 1 none 2 slight 3 moderate 4 severe
   e. loss of adhesion to pavement: 1 none 2 slight 3 moderate 4 severe
   f. apparent snowplow damage: 1 none 2 slight 3 moderate 4 severe

2. Relative night reflectance of special porous delineators to paint stripe on OGAFC.
   a. Dry Pavement

1	2	3	4	5
much worse	slightly worse	about same as paint	slightly better	much better

   b. Wet Pavement

1	2	3	4	5
much worse	slightly worse	about same as paint	slightly better	much better

3. Rate in order from best to worst the quality of the delineator systems in the various test sections. (1 = best; 7 = worst).

a. dry	b. wet
Section 1 _____	Section 1 _____
Section 2 _____	Section 2 _____
Section 3 _____	Section 3 _____
Section 4 _____	Section 4 _____
Section 5 _____	Section 5 _____
Section 6 _____	Section 6 _____

4. Comments by Evaluator:

Figure 5.4. Evaluation Form Used for Subjective Evaluation of Field Test Sections.

Table 5.3. Summary of Visual Examinations on Virginia Test Sections.

Visit Date	Summary of Visual Examination
Aug. 19, 1976	Visual examination was made by Robnett and Tooke. Close-up appearance of PDS (day-time, dry) indicated a good uniformity of color, good color retention, no raveling, crumbling, or cracking, no loss of adhesion, and no apparent snowplow damage. Evaluations of the relative night reflectance of PDS compared to paint on OGAFC indicated the PDS (Sect. 2) was slightly better in a dry condition and much better in a wet condition. The delineation quality of the three sections was rated best to worst in order: (dry) Sect. 2 > Sect. 3 > Sect. 1; and for wet, Sect. 2 > Sect. 3 > Sect. 1. Other comments were: "neatness and high contrast of PDS lines, some asphalt tracking".
Dec. 8, 1976	Visual examination was made by Robnett and Tooke. Close-up appearance of PDS (day-time, dry) indicated a fairly good uniformity of color, good color retention, no raveling, crumbling or cracking of delineators in Sections 2, 4 and 5 however in Section 6 there was moderate to severe raveling and crumbling of the Pavebrite delineator materials. There was no loss of adhesion and only slight apparent snowplow damage and this occurred in Section 6. Evaluations of the relative night reflectance of PDS compared to paint on OGAFC indicated the PDS for all sections was much better in a dry condition and much better in a wet condition. The delineation quality of the six sections was rated from best to worst in order as: (Only dry condition ratings were made)(Sect. 4 and Sect. 5) > Sect. 2 > Sect. 1 > Sect. 3 > Sect. 6. Other comments were "durability and wet-night visibility appeared to be unique among the various striping media".
Feb. 3, 1977	Visual examination was made by Robnett and Tooke and FHWA staff, Chollar and Harrigan. Close-up appearance of the PDS (day-time, dry) indicated a fairly good to good uniformity of color, a good to fairly good color retention,

Table 5.3. Summary of Visual Examinations on Virginia Test Sections (continued).

only slight raveling or crumbling and cracking of delineators, no loss of adhesion to the pavement and slight apparent snowplow damage in Sect. 2. The Pavebrite PDS were badly raveled.

Evaluations of the relative night reflectance of the PDS compared to paint on OGAFC indicated a much better rating from three of the evaluators and a slightly better to much better rating for the fourth evaluator. Again, only dry condition ratings were made.

The delineation quality of the three sections were rated from best to worst in order as: Sect. 2 > (Sect. 4 and 5) > Sect. 3 > Sect. 1 > Sect. 6.

June 21, 1977

Visual examination was made by Robnett, Chollar (FHWA), and Nunemaker (FHWA). Close-up appearance of the two PDS materials, Hot Melt Glue and Pavebrite (day-time, dry), indicated a substantial difference in the relative serviceability of the two materials. The Hot Melt Glue had a moderately good to good uniformity of color, a good to poor color retention, none to slight raveling, crumbling, and cracking, no loss of adhesion to pavement, and none to slight apparent snowplow damage. The Pavebrite PDS, Sect. 6, had moderately good to poor uniformity of color, poor to very poor color retention, severe raveling and crumbling, and slight to severe cracking, moderate to severe loss of adhesion to the pavement, and slight snowplow damage. Close-up examination of the various PDS revealed a substantial loss of glass beads and binder from the upper surface of the PDS.

Evaluation of the relative night reflectance of the two PDS materials compared to paint on OGAFC indicated the Hot Melt Glue was slightly worse to about the same as paint in dry condition, and ranged from about the same as paint to much better than the paint in the wet condition. For the Pavebrite PDS the rating was slightly worse to about the same in the dry condition and ranged from slightly worse to slightly better in the wet condition.

The delineation quality of the six test sections was rated in order in both the dry condition and the wet condition. The ratings given by raters A, B and C are shown below. Enclosure by parentheses indicates the same subjective rating.

Table 5.3. Summary of Visual Examinations on Virginia Test Sections (continued).

Rater A

Dry-(Sect. 1, Sect. 2, Sect. 4, Sect. 5) > Sect. 3 > Sect. 6

Wet-(Sect. 2, Sect. 4, Sect. 5) > (Sect. 1, Sect. 3, Sect. 7)

Rater B

Dry - Sect. 1 > Sect. 3 > (Sect. 4, Sect. 5) > Sect. 2 > Sect. 6

Wet - (Sect. 1, Sect. 2, Sect. 4, Sect. 5) > Sect. 3 > Sect. 6

Rater C

Dry - (Sect. 1, Sect. 3) > (Sect. 2, Sect. 4, Sect. 5) > Sect. 6

Wet - (Sect. 2, Sect. 3, Sect. 4, Sect. 5) > Sect. 6 > Sect. 1

5.4.2 Photographic Logging

Extensive photographic logging was made of the test sections during each visit. The photographic logging served to establish a permanent record of site conditions. Both 35 mm color slides and super 8 mm color and black and white movies were taken. A Nikormat 35 mm camera was used for the color slides and a Minolta Super 8 mm Model D10 camera was used for the movies.

Photographs were taken both during daytime (dry conditions) and night-time (dry and wet conditions). The night-time 35 mm slides and super 8 mm movies were in general, taken immediately after the telephotometric readings. The night-time photographic work used artificial lighting provided by the car headlights and the telephotometer lamp. The 4 headlights of the car were focused on a position about 40 ft. (12 meters) ahead of the car.

The super 8 mm movies taken at night used Kodak Tri-X Reversal film (ASA 160) while the daytime film was Kodak Ektachrome (ASA 125). The 35 mm slide film was Kodak Ektachrome with tungsten (ASA 125). The super 8 mm movies were taken from inside the car with the car moving at a speed of about 25 mph (40 kph). The 35 mm slides were taken with the car stopped.

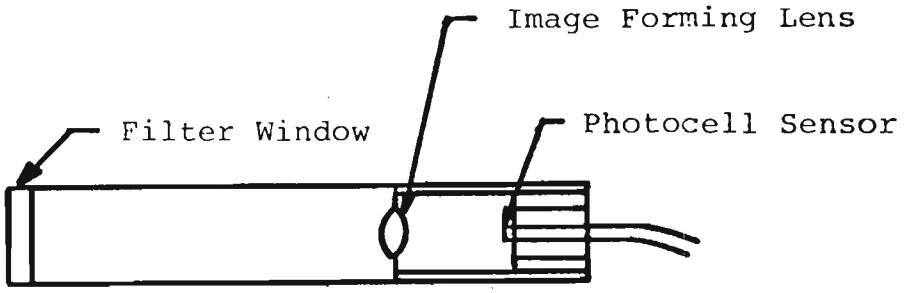
5.4.3 Telephotometric Monitoring

Telephotometric equipment developed by Tooke and Hurst [5] and previously described was used at night to evaluate the retro-reflectance of the PDS stripes and beaded paint control sections (Test Sections 1 and 3) under both dry and wet conditions.

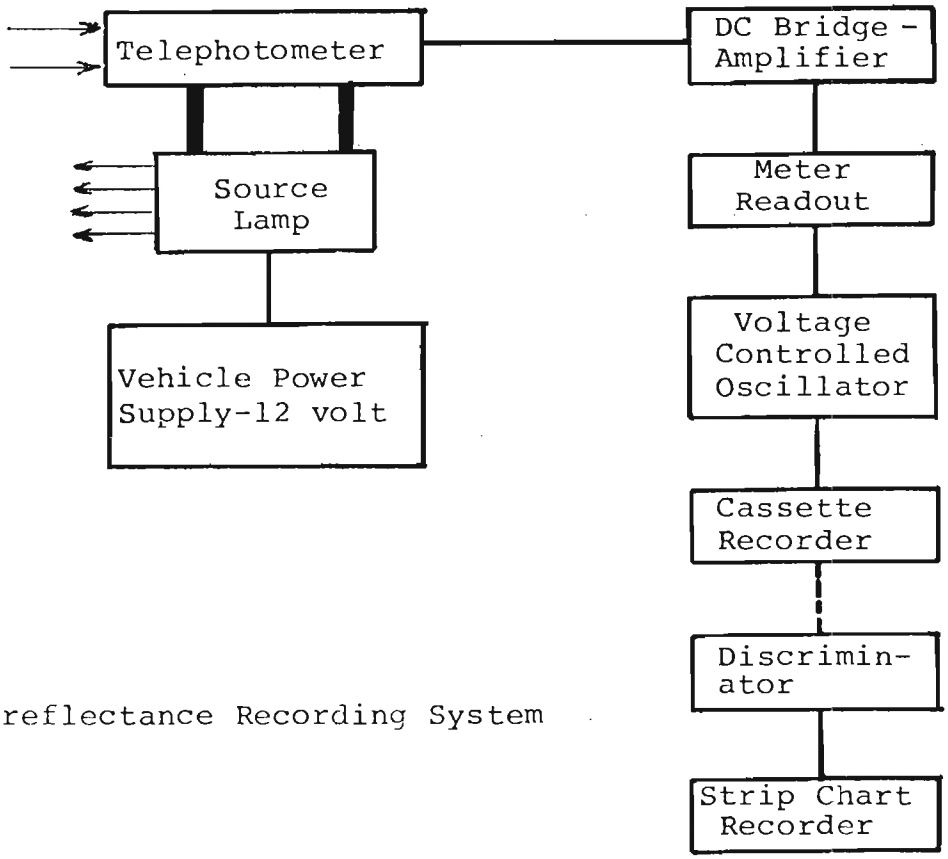
A schematic diagram of the telephotometer and the associated recording equipment is shown in Figure 5.5. Figure5.6 depicts the telephotometer unit attached to the left side of the car. Figure 5.7 illustrates a schematic of the automobile-telephotometer-roadway layout. A detailed description of the telephotometer can be found in Appendix C of this report.

The telephotometric readings were taken from the automobile traveling at a speed of about 25 mph (40 kph) with the telephotometer aimed at a position approximately 40 ft. (12 meters) in front and about 3 ft. (0.9 m) to the left of the automobile. During telephotometric monitorings, only the 12 volt single lamp was used as the artificial light source.

A water truck equipped with a spray bar was used to provide the wet condition. Only a strip about 2 ft. (0.3 meters) wide centered on the centerline was wetted. In order to insure complete wetting, one pass of the water truck was made prior to any telephotometric readings. Telephotometric readings were then made with the automobile-telephotometer unit following about 200 ft. (60 meters) behind the



Telephotometer Unit
(section view)



Retroreflectance Recording System

Figure 5.5. Section View of Telephotometer and Schematic of Retroreflectance Recording System.

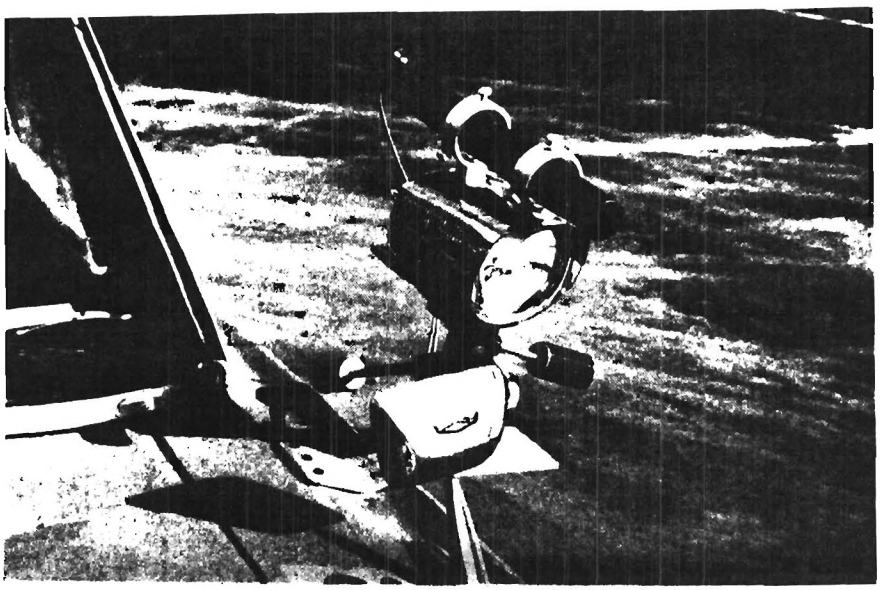


Figure 5.6. Picture of Telephotometer Unit Mounted on Automobile

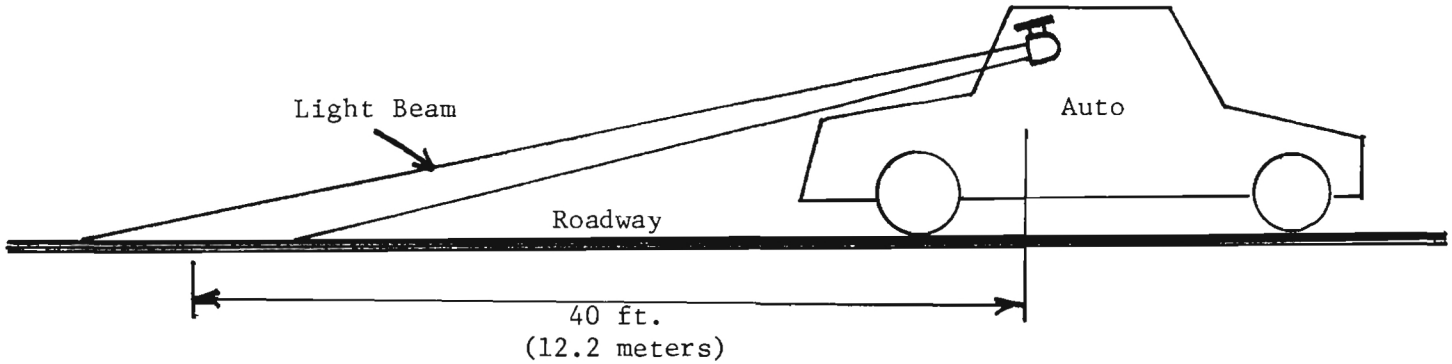


Figure 5.7. Schematic Diagram of the Car-Telephotometer-Roadway Layout.

water truck.

The telephotometric readings taken during each pass were recorded on cassette tape. Later these readings were placed on a strip chart recording.

5.5 PRESENTATION AND DISCUSSION OF RESULTS FROM EVALUATION VISITS

As noted in the previous section of this report, three techniques were used to evaluate the performance of the various test sections at the Virginia test site. The visual observations are subjective in nature. The photographic logging served to provide a somewhat permanent record of visual conditions.

The telephotometric data was quantifiable and thus was of a nature that could be used to determine relative effects of time, different materials, and wet or dry pavementsurface condition.

The results of each of these evaluation techniques will now be presented and discussed.

5.5.1 Visual Inspection

Immediately after installation of the PDS in the various test sections, in general the PDS striping materials exhibited extremely high contrast and excellent delineation qualities. In particular, it was apparent that the PDS possessed substantially better wet-night visibility than did the painted sections.

As the amount of service time increases it was obvious that the PDS lost some of its initial contrast and delineation qualities. The Pavebrite PDS in Section 6 displayed excessive early raveling. As noted earlier, this excessive raveling was believed due to the excessive brittleness of the Pavebrite PDS during the low temperature installation. This excessive early raveling was not noted during observation of the Georgia Pilot Test Section.

At the end of the observation period, the night reflectance and overall delineation quality of the Hot Melt Glue PDS was rated slightly worse to about the same as the painted sections in the dry condition. In the wet condition, however, the raters evaluated the PDS as about the same as to much better than the painted sections. In particular, the PDS was much better in the wet condition than the paint-on dense asphalt, Section 1. It should be noted that the painted sections were repainted in May, 1977, shortly before the last visual inspection.

Another pertinent observation made in June, 1977, was that the upper surface of the Hot Melt Glue (HMG) PDS although not displaying any apparent snowplow damage did appear to have lost some glass beads and white binder. It is believed that this loss is due primarily to the abrasive action to vehicle tires.

5.5.2 Photographic Logging

All photographic records taken during day time turned out very well. The general trends of serviceability for the various delineator materials however were difficult to ascertain from the 35 mm color slides and Super 8 mm movies.

The photographic records taken at night for both wet and dry conditions under artificial lighting were of poor quality primarily due to an insufficient amount of light. Thus, it can be concluded that no valid evaluation of the serviceability and performance of the various delineator materials can be made based on photographic records.

5.5.3 Telephotometric Readings

The telephotometric readings taken during each visit and each pass were recorded on cassette tape. Later these findings were placed on strip chart recordings.

A typical strip chart recording of the retroreflectance of the centerline delineators in one test section is depicted in Figure 5.8. The vertical scale of this recording is established through a calibration technique as described in Ref. 5 and is expressed as Specific Intensity with units of candle power per foot candle ($\frac{cd}{fc}$). Specific Intensity (SI) is a measure of the intensity of a reflecting surface for a given amount of illumination and a given point of observation; that is,

$$SI = \frac{\text{Intensity of projected area}}{\text{Illuminance on projected area}} \qquad (5.1)$$

As noted in Figure 5.8, each peak represents the Specific Intensity of a particular stripe in the test section of concern.

All the Specific Intensity data collected from the telephotometric monitoring were taken from the strip chart recording and were later used for statistical evaluation. Table 5.4 summarizes the average and standard deviation of the Specific Intensities for each of the test sections for all visits.

Thus, after all visits had been made, a tremendous volume of telephotometric data, expressed as Specific Intensity, were available. As part of the overall evaluation, it was desired to determine the following:

1. Time effects (What influence did exposure time have on the relative retroreflectance of the various delineator materials?)

2. Material effects (What was the influence of the various delineator materials on retroreflectance?)

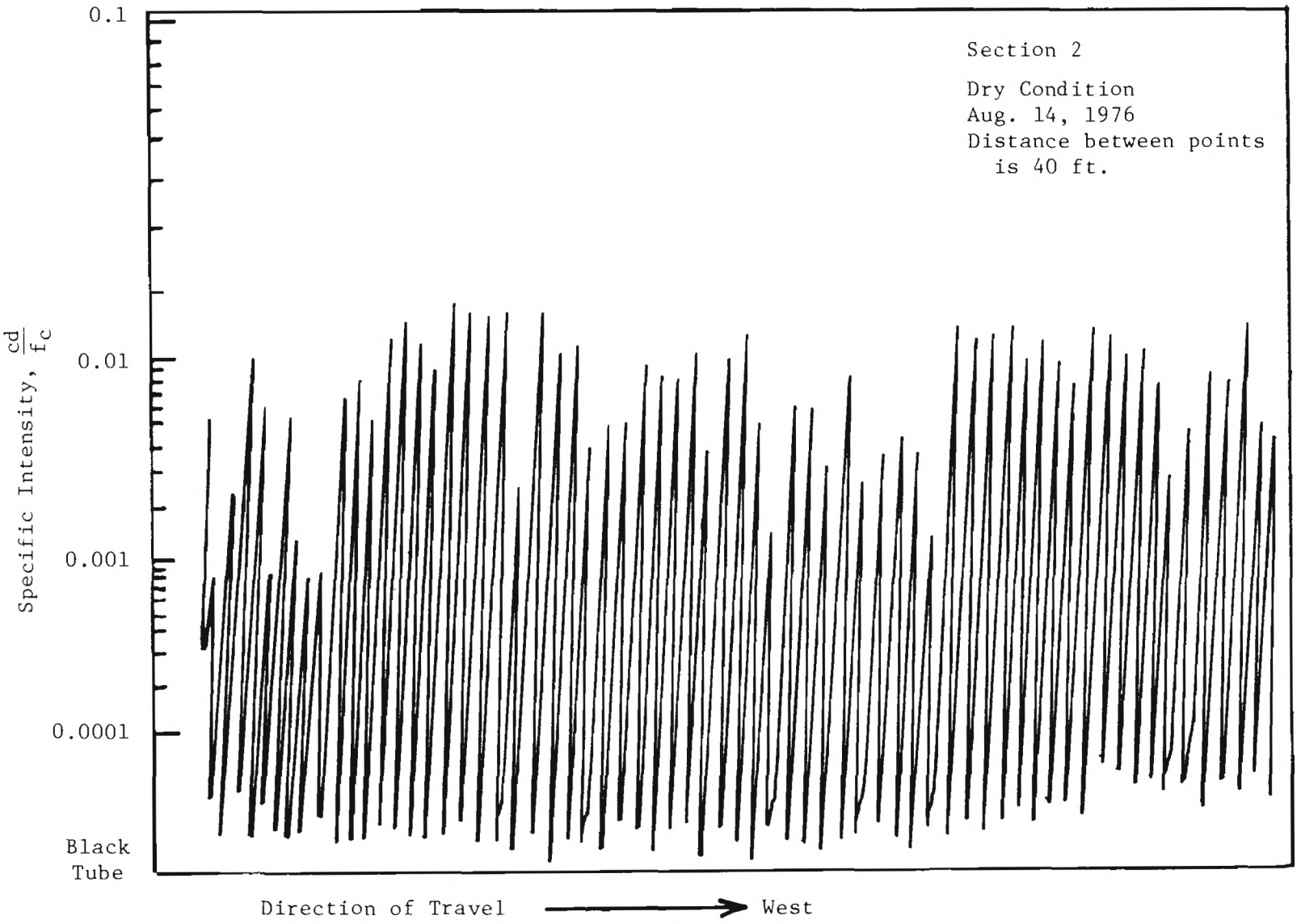


Figure 5.8. Typical Plot of Telephotometer Readout for Test Section 2.

Table 5.4. Summary of Retroreflectance Data for Virginia Test Sections.

Visit Date	Test Section	Surface Condition	Specific Intensity Average for Section, $\frac{cd}{fc}$	Specific Intensity Standard Deviation
August, 1976	1	D	0.0188	0.0111
		W	0.0005	0.0005
	2	D	0.0039	0.0025
		W	0.0032	0.0023
	3	D	0.004	0.0057
		W	0.0029	0.0043
December, 1976	1	D	0.0042	0.0044
		W	-	-
	2	D	0.0010	0.0010
		W	-	-
	3	D	0.0002	0.0001
		W	-	-
	4	D	0.0024	0.0024
		W	-	-
	5	D	0.0034	0.0036
		W	-	-
February, 1977	1	D	0.0024	0.0028
		W	-	-
	2	D	0.0006	0.0001
		W	-	-
	3	D	0.0002	0.0001
		W	-	-
	4	D	0.0009	0.0008
		W	-	-
	5	D	0.0008	0.0006
		W	-	-

Table 5.4. Summary of Retroreflectance Data for Virginia Test Sections. (continued)

June, 1977	1	D	0.0587	0.0274
		W	0.0009	0.0008
	2	D	0.0022	0.0019
		W	0.0008	0.0006
	3	D	0.0047	0.0032
		W	0.0009	0.0005
	4	D	0.0012	0.0007
		W	0.0007	0.0004
	5	D	0.0013	0.0010
		W	0.0010	0.0004

NOTE: Because of the rapid deterioration of test section Number 6, only limited data were taken and it was not included in the statistical evaluation.

In order to objectively ascertain the relative effects of time and material on retroreflectance, the telephotometric data were subjected to statistical analysis.

The statistical analysis technique that appeared to have most promise for examining the effects of time and material was Duncan's New Multiple Range test. Details of this statistical method can be found elsewhere [6]. It should be pointed out that this method permits objective decisions as to which differences are statistically significant and which are not.

The results of this statistical analysis done at a level of significance of 5% are presented in Table 5.5 and 5.6. Table 5.5 contains the results for material effects and Table 5.6, the results for time effects. The average or mean Specific Intensity (SI) for each case is placed in parentheses and the average or mean SI values arranged in ascending order from left to right in the tables. Any of the average (or mean) SI values underscored by the same line are not significantly different while any of the average (or mean) SI values not underscored by the same line are significantly different. For example, in Table 5.5 for the August visit, dry condition, Section 3 had the lowest mean SI (0.0033) while Section 1 had the highest (0.0267) with Section 2 intermediate. However, Section 2 and 3 although with different mean SI values were not significantly different (i.e., underscored by same line), but they had significantly lower SI values than Section 1.

Based on this statistical analysis, certain pertinent observations can be drawn concerning material and time effects. Following are pertinent observations concerning material effects:

1. For the August, 1976 visit (immediately after installation) Section 1 (paint and dense asphalt) had the best dry Specific Intensity, but the worst wet Specific Intensity. For wet conditions, Section 2 (HMG) had a slightly better mean SI than Section 3 (paint OGAFC) but was not significantly different (at the 5% level).

2. For the December, 1976 visit (shortly after Sections 4 and 5 were installed) only dry conditions were evaluated. No wet condition measurements were made due to freezing weather. Section 1 (paint on dense asphalt) had the best SI and Section 3 (paint on OGAFC) the worst SI. Section 4 and 5 (HMG in groove) had slightly lower SI than Section 1 (paint on dense) with Section 5 (HMG in groove) not being significantly different from Section 1 (paint on dense). It should be noted that Sections 4 and 5 had significantly higher SI values than Section 2 which is to be expected since Section 2 was in service for about 3 months while Sections 4 and 5 were relatively new.

Table 5.5. Summary of Results of Duncan's New Multiple Range Test for Material Effects.

August, 1976 Visit - Dry Condition

Sect. 3	Sect. 2	Sect. 1
(.0033)	(.0052)	(.0267)

August, 1976 Visit - Wet Condition

Sect. 1	Sect. 3	Sect. 2
(.0005)	(.0029)	(.0032)

December, 1976 - Dry Condition

Sect. 3	Sect. 2	Sect. 4	Sect. 5	Sect. 1
(.0002)	(.0010)	(.0024)	(.0034)	(.0042)

February, 1977 - Dry Condition

Sect. 3	Sect. 2	Sect. 5	Sect. 4	Sect. 1
(.0002)	(.0006)	(.0007)	(.0007)	(.0019)

June, 1977 - Dry Condition

Sect. 4	Sect. 5	Sect. 2	Sect. 3	Sect. 1
(.0012)	(.0013)	(.0022)	(.0047)	(.0587)

June, 1977 - Wet Condition

Sect. 4	Sect. 2	Sect. 1	Sect. 3	Sect. 5
(.0007)	(.0008)	(.0009)	(.0009)	(.0010)

NOTE: Numbers in parentheses are average (mean) Specific Intensity values.

Table 5.6. Summary of Results of Duncan's New Multiple Range Test for Time Effects.

Section 1 - Dry

Date	Feb.'77	Dec. '76	August'76	June '77
Mean SI	(.0019)	(.0042)	(.0267)	(.0587)

Section 1 - Wet

Date	August '76	June '77
Mean SI	(.0005)	(.0009)

Section 2 - Dry

Date	Feb.'77	Dec. '76	August'76	June '77
Mean SI	(.0006)	(.0010)	(.0022)	(.0052)

Section 2 - Wet

Date	June '77	August'76
Mean SI	(.0008)	(.0032)

Section 3 - Dry

Date	Feb.'77	Dec. '76	August'76	June '77
Mean SI	(.0002)	(.0002)	(.0033)	(.0047)

Section 3 - Wet

Date	June ' 77	August '76
Mean SI	(.0009)	(.0029)

Section 4 - Dry

Date	Feb.'77	June '77	Dec. '76
Mean SI	(.0007)	(.0012)	(.0024)

Section 5 - Dry

Date	Feb.'77	June '77	Dec.'76
Mean SI	(.0007)	(.0013)	(.0034)

NOTE: Numbers in parentheses are average (mean) Specific Intensity values.

3. For February, 1977 visit only dry conditions were evaluated. No wet condition measurements were made due to freezing weather. Section 1 (paint on dense) still displayed the highest mean SI and Section 3 (paint on OGAFC) the lowest. Section 2 (HMG in new OGAFC) and Section 4 and Section 5 (HMG in groove) did not have a significantly different SI but all were significantly less than Section 1.

4. For the June, 1977 visit, evaluated under dry conditions, Section 1 (paint on dense) had the highest SI which was significantly greater than the other sections, but this was expected since Section 1 and Section 3 (paint on OGAFC) were repainted during May of 1977. For the other sections, no significant differences existed in the mean SI values, although as expected Section 3 (new paint on OGAFC) was slightly higher than the others.

5. For the June, 1977 visit, evaluated under wet conditions, Section 5 (HMG in groove) had the highest mean SI but it was not significantly higher than Section 2 (HMG in new OGAFC) Section 1 (new paint on dense asphalt) or Section 3 (new paint on OGAFC), but all were significantly higher than Section 4 (HMG in groove). Section 4 and Section 2 were not significantly different. It is not known why Section 4 displayed much lower mean SI than the other sections. Section 4 and Section 5 were supposedly identical, replicate sections.

Based on the statistical analysis, the following are pertinent observations concerning time or exposure effects:

1. Section 1 (paint on dense asphalt, repainted in May of 1977). For the dry condition, if the June, 1977 visit is excluded, the mean SI values decreased with time and exposure as would be expected. Also as expected, the June, 1977 mean SI is significantly higher. For the wet condition, the mean SI for the June, 1977 visit is significantly greater than August, 1976. This should expected since the section was repained in May, 1977.

2. Section 2 (HMG placed in new OGAFC). For the wet condition the August, 1976 mean SI was significantly greater than June, 1977. This trend was expected and shows that time and exposure caused a reduced retroreflectance.

3. Section 3 (paint on OGAFC, repainted in May, 1977). For the dry condition, June, 1977, mean SI was significantly higher than earlier readings as expected since new paint was applied in May, 1977. Time and exposure did reduce the retroreflectance as measured by SI as indicated by the fact that August, 1976 had a significantly higher SI than

Dec., 1976 and Feb., 1977 readings. For the wet condition, even though Section 3 was repainted it had a significantly greater SI in August, 1976 than June, 1977. The reasons for this trend are not known.

4. For Section 4 and Section 5 (HMG in groove) no wet condition readings were taken in Dec., 1976 and Feb., 1977. Thus, time effects for the observation period can be looked at in terms of dry condition only. The results show that Dec., 1976 mean SI value for each section is significantly greater than Feb., 1977 or June, 1977 values. February and June SI values were not significantly different from one another. Thus, time and exposure conditions have caused a reduced retroreflectance in these sections.

PROJECT CONCLUSIONS AND RECOMMENDATIONS

Based upon the results of this research project, it is concluded that the combined system of an OGAFC surface and a special porous delineator centerline stripe will provide superior centerline wet-night delineation compared to conventional beaded paint on a dense graded asphalt surface. The results also demonstrate that for an equivalent period of service time, the OGAFC-PDS provide better wet-night delineation than conventional beaded paint used with the OGAFC. Even after almost 1 year of service, the OGAFC-PDS provided about the same wet-night delineation as did "new" beaded paint used on OGAFC.

It is recommended that the comparative performance of the OGAFC-PDS be studied for longer periods of time. Although the installation cost of PDS is not available at this time, it would seem that initial cost would be substantially more than conventional delineation materials. To be economically attractive over a period of time, the PDS would thus have to have a much longer service life than conventional systems. The results of this project have not demonstrated the life expectancy of "optimumly designed and installed" PDS. Thus, it appears that additional field test sections are needed in order to determine service life and resulting overall economics. As part of additional testing, it seems reasonable to suggest that more efficient installation techniques and equipment be developed. Other recommendations are as follows:

1. Additional study and consideration be given to selecting the "optimum" gradation, refractive index, size, and wear resistance of glass beads.

2. Additional study should be made concerning the desirability of using thermosetting binders rather than the thermoplastic binders. The limited study of these materials indicated that thermosetting binders will present additional difficulties in application techniques and equipment.

3. In general it is recommended that strong and tough binder compounds be used in the PDS. The project results indicated that tougher thermoplastic binders such as the Polyamide provide greater wear resistance at the PDS-tire contact points and thus longer service life.

4. It is recommended that appropriate consideration be given to the low temperature brittleness of many thermoplastic binder compounds.

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APPENDIX A
DETAILED TESTING PROCEDURES FOR THE SCREENING TESTS

1.1 GENERAL

The details of the twenty screening tests which were used to aid in evaluating the potential of promising porous delineator system materials are presented in this appendix.

2.1 SCREENING TEST PROCEDURES

2.1.1 Abrasion Resistance

The abrasion resistance of promising OGAFC lane marking system materials was evaluated under laboratory conditions. Three testing techniques were used for the abrasion resistance evaluation:

- simulated snowplow action
- simulated wear from vehicle tires
- scuffing action from slow-speed directional maneuvers of vehicles

Simulated Snowplow Action

For each of the mixtures, samples 12 inches (30.5 cm) square and about 3/4 inch (1.9 cm) thick were prepared by the procedure detailed in Appendix B. These samples were subjected to multiple passes of a model snowplow. A schematic diagram of the model snowplow is depicted in Figure A.1.

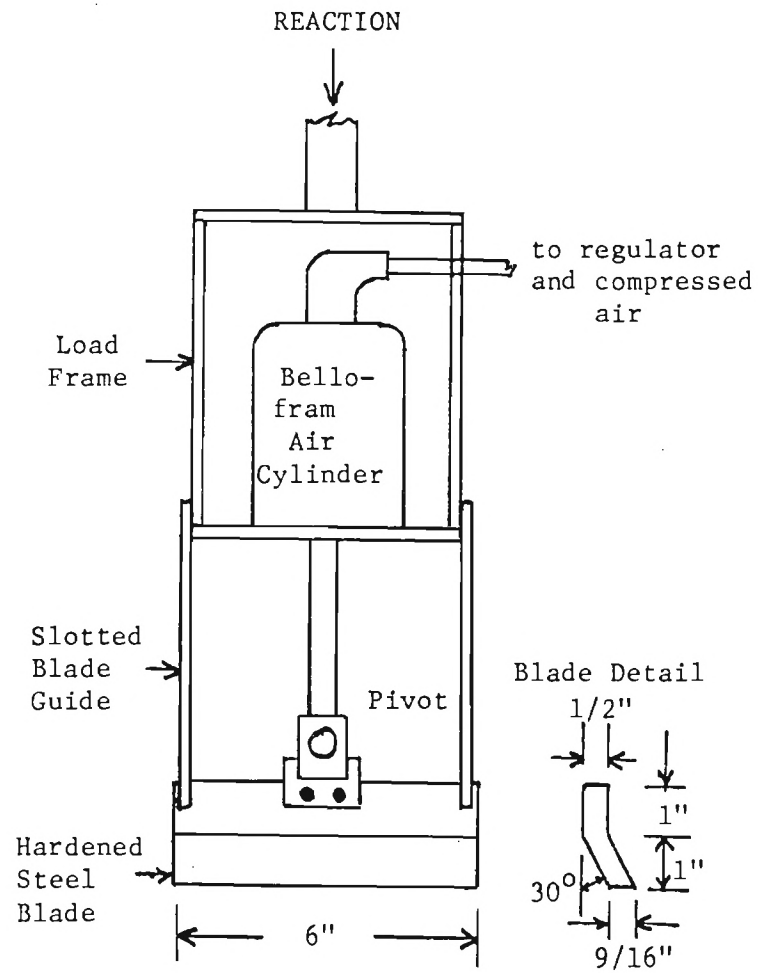
The model snowplow blade was placed on the surface of one of the 12 inch square samples and the blade positioned to make a 60^{o} angle with the direction of blade movement. A downward load of about 30 pounds per linear inch (5.4 kg/in.) of blade was applied using compressed air and a Bellofram air cylinder. The blade was then moved back and forth across the surface of the sample for the desired number of passes. A pass was defined as one complete back and forth cycle.

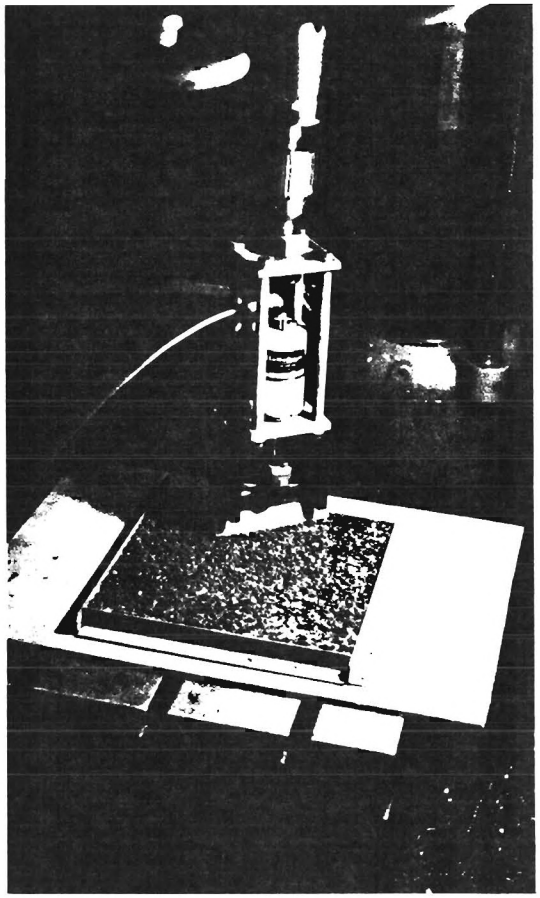
The complete step-by-step testing sequence for the simulated snowplow evaluation of abrasion resistance consisted of the following:

1. Take initial dry and wet telephotometric readings (see Test 5 for telephotometric evaluation procedure) and a close-up 35 mm picture.

2. Apply 10 passes of the model snowplow.

3. Take telephotometric readings for dry and wet conditions and a close-up 35 mm picture.





NOTE: 1 inch = 2.54 cm

Figure A.1. Schematic and Picture of Model Snowplow.

4. Apply an additional 20 passes of the model snowplow.

5. Repeat Step 1.

6. Apply an additional 50 passes of the model snowplow.

7. Repeat Step 1.

Simulated Tire Wear Test

The abrasive action of vehicle tires passing over the delineator systems was simulated by using an aggregate polishing device developed and owned by the Georgia Highway Department and located at the Materials Laboratory in Forest Park, Georgia. Ten inch (25 cm) diameter samples of the delineator system materials were prepared as outlined in Appendix B. These samples were then placed in the equipment depicted schematically in Figure A.2. The hard rubber tires were then placed against the surface of the sample and the total load adjusted to 26 pounds (11.8 kg). This created a contact pressure of about 28 psi (193 kN/m^2). A large electric motor was used to rotate the vertical spindle at about 550 rpm which created a tire application rate of about 1100 per minute. It should be noted that the tire travelled in a circular track with a diameter of about 6 inches (15.2 cm).

The complete step-by-step evaluation procedure which included telephotometric readings and photographs consisted of the following:

1. Take initial dry and wet telephotometric readings (see Test 5 for procedure) and a close-up 35 mm picture.

2. Apply 5,000 passes of the hard rubber tires of the aggregate polishing equipment.

3. Take telephotometric readings for dry and wet conditions and close-up 35 mm picture.

4. Apply an additional 15,000 passes of the hard rubber tires.

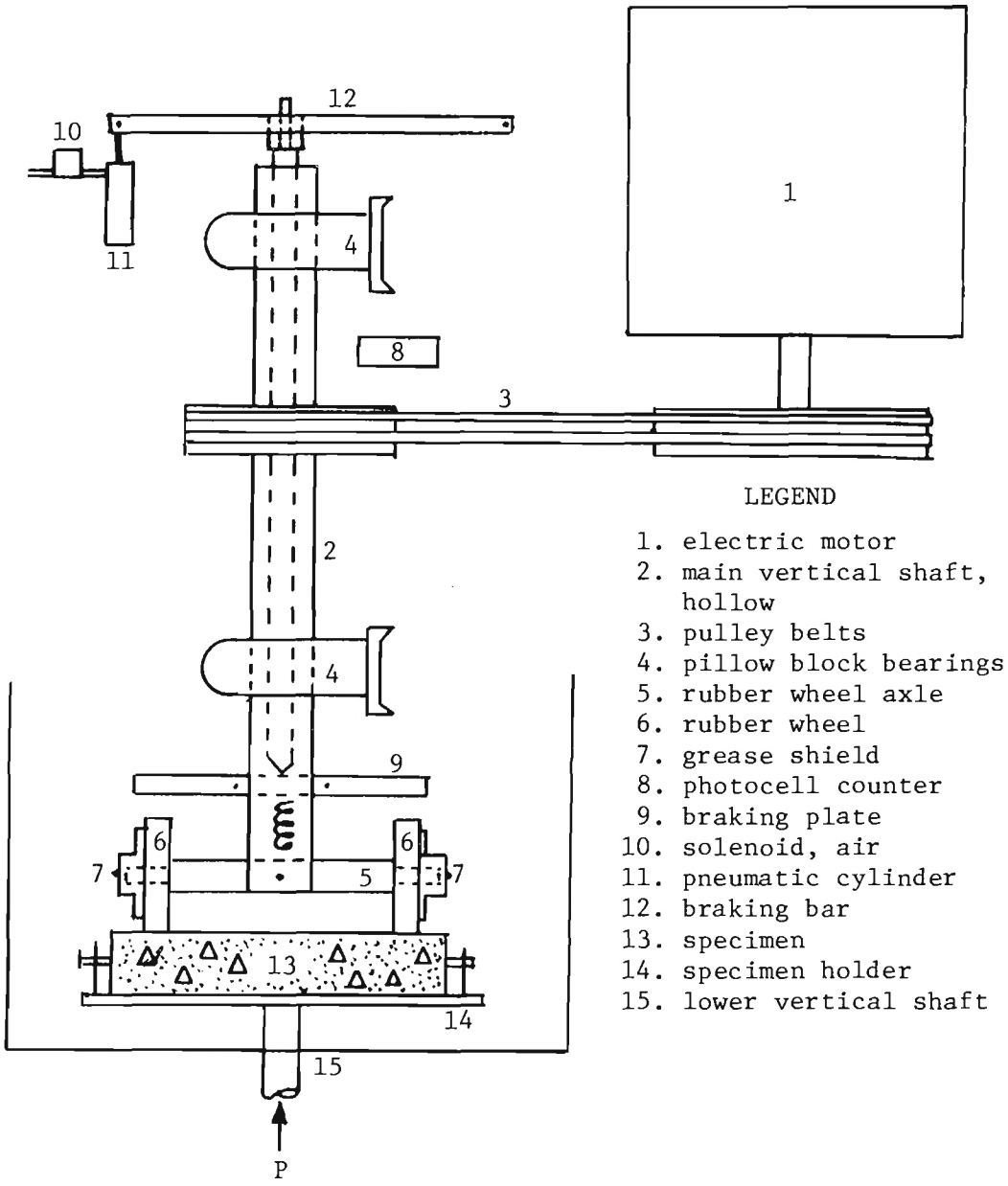
5. Repeat Step 3.

6. Apply an additional 30,000 passes of the hard rubber tires.

7. Repeat Step 3.

Scuffing Action Test

The scuffing action test used to evaluate the scuffing action from slow-speed directional maneuvers of vehicles was conducted with the front tire of a passenger car and the 12 inch (30.5 cm) square



LEGEND

1. electric motor
2. main vertical shaft, hollow
3. pulley belts
4. pillow block bearings
5. rubber wheel axle
6. rubber wheel
7. grease shield
8. photocell counter
9. braking plate
10. solenoid, air
11. pneumatic cylinder
12. braking bar
13. specimen
14. specimen holder
15. lower vertical shaft

Figure A.2 . Aggregate Polishing Equipment Used to Evaluate Abrasion Resistance.

samples used in the simulated snowplow resistance tests. The 12 inch (30.5 cm) square samples were placed in an angle iron frame and bolted to a flat concrete pavement. The right front tire of a 1974 Plymouth Satellite station wagon (Goodyear steel-belted radial tire with inflation pressure of 28 psi (198 kN/m^2) was placed on the sample, Fig. A.3. The steering wheel was then slowly cranked from the left stop to the right stop and back to the left stop a total of three times. The car was then backed off the sample. The testing temperature used was ambient which ranged from 70° to 80°F (21° - 27°C).

2.1.2 Motor Vehicle Impact Resistance

The motor vehicle impact resistance of promising OGAFC lane marking system materials was evaluated under laboratory conditions. Two testing techniques were used to evaluate the impact resistance; Marshall stability and flow and repeated dynamic loading of unconfined compression samples.

Marshall Stability and Flow

Marshall specimens were made from the various materials following the procedure recommended in ASTM Procedure D-1559 and AASHTO T-245, except that 25 blows per side were used for compaction. Following compaction, the specimens were allowed to cool and then removed from the mold. Prior to testing, the temperature of the specimens was adjusted to the desired magnitude. Subsequently, the specimens were tested for Marshall stability and flow using the procedure recommended in ASTM D-1559 and AASHTO T-245.

Repeated Dynamic Load Testing

Cylindrical specimens, 2 inches (5.1 cm) in diameter and approximately 1 inch (2.5 cm) high were made from the various materials following the procedure detailed in Appendix B. The specimens were compacted to approximately the same density as the Marshall specimens discussed in previous paragraphs.

The testing procedure used to examine the repeated load characteristics of the various materials is similar to that used by Robnett and Thompson [8] for repeated loading of cohesive soil samples. A schematic diagram of the test equipment is shown in Figure A.4.

Two identical specimens of each material were tested. One specimen was tested at 77°F (25°C) and the other at 140°F (60°C). The axial loading was developed by using compressed air and a Bellofram air cylinder, Figure A.4. No confining pressure was applied. The duration of the loading pulse and the repetition rate was controlled by an electrically actuated solenoid valve. All testing was performed at an application rate of 40 applications per minute with a load duration of approximately 0.2 seconds. An axial stress of 60 psi (413 kN/m^2) was used for all testing.

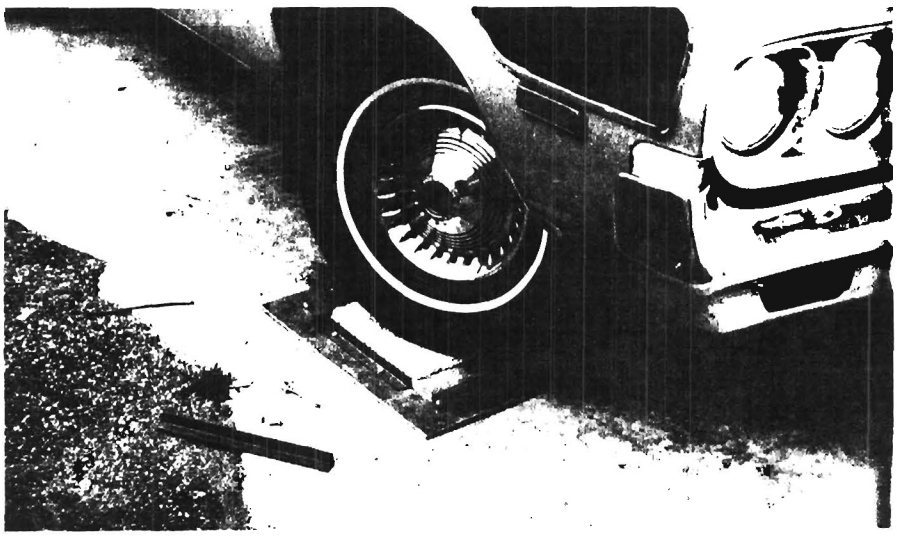


Figure A.3. Picture of Scuffing Test Set-up.

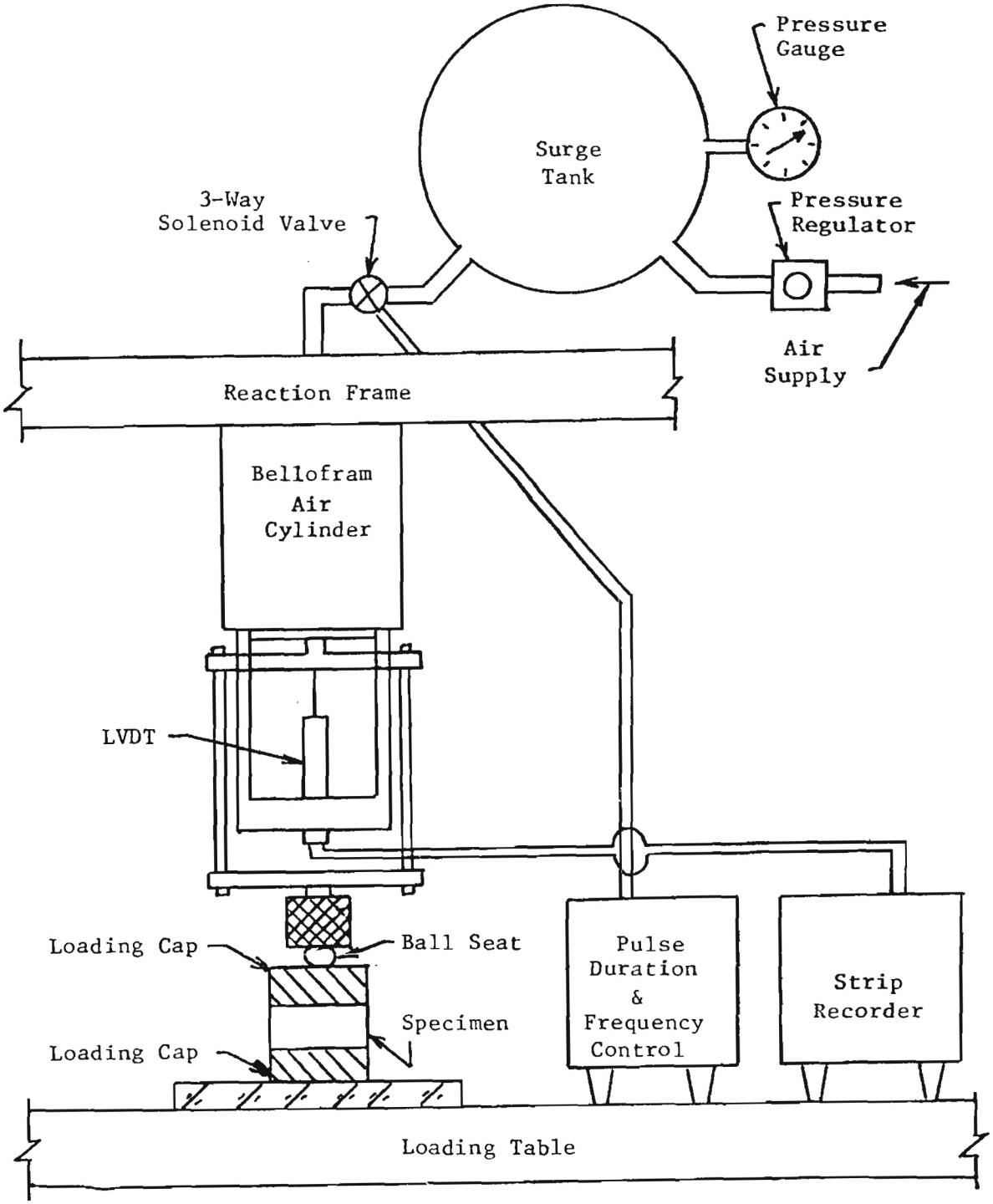


Figure A.4. Repeated Load Equipment Used to Evaluate Impact Resistance.

Axial deformation of the specimens was monitored by one centrally mounted LVDT connected to a continuous strip chart recorder, Figure A.4. Thus, a permanent record of both permanent and elastic deformation at any loading cycle was obtained. An oscilloscope and load-cell were used for calibration of the axial loading and measurement of the load-time pulse duration.

Temperature control was achieved by means of an insulated box equipped with an internal thermostat temperature control. The box was used only for samples tested at $140^{o}F$ ($60^{o}C$). The ambient room temperature was $75 - 79^{o}F$ ($24 - 26^{o}C$) so that samples were tested without use of the temperature chamber. The temperature control chamber totally surrounded the specimens in all sides. The loading device extended downward through a hole in the top.

The step-by-step testing procedure was as follows:

1. The specimen was placed inside the temperature control chamber atop the loading plate. The temperature was set to $140^{o}F$ ($60^{o}C$) and the specimens allowed to sit for at least one hour to ensure constant temperature throughout the specimen. Note: The temperature chamber was not used with samples tested at $75^{o} - 79^{o}F$ ($24^{o} - 26^{o}C$).

2. The reaction-frame was lowered and secured in a position such that the loading piston was about 1 inch (2.5 cm) from its minimum extension (to minimize volume of air flow).

3. The axial loading device was checked to ensure that it fit snugly atop the steel ball-bearing on the loading cap. The sample was adjusted so that there is no eccentricity between the loading device and the sample.

4. The position of the LVDT body was adjusted to ensure that the measured axial deformation would be within the linear range of the LVDT.

5. The recording pen was zeroed on the strip-chart recorder and an appropriate paper speed and scale were selected.

6. Cyclic loading was initiated at an application rate of 40 per minute.

7. A continuous recording was made the first one hundred stress cycles.

Thereafter, the recorder was turned on to record approximately 10 cycles at each of the following number of stress cycles: 500; 1,000; 2,000; 5,000; 10,000; 20,000; and 50,000. Whenever excessive plastic deformation occurred such that the loading cap rotated excessively, the testing was stopped.

2.1.3 Solvent Resistance

The solvent resistance of the promising delineator materials was evaluated using a procedure which consisted of subjecting 4 inch (10.2 cm) diameter by 2.5 inch (5.4 cm) high Marshall specimens prepared by the Marshall procedure to 1 hour and 24 hours of complete immersion in kerosene. Following the immersion period Marshall stability and flow (ASTM D-1559 and AASHTO T-245) were determined at a testing temperature of 140°F (60°C). Additionally, determination was made of any weight-loss of the binder due to dissolving in the kerosene.

2.1.4 Freeze-Thaw Resistance - (see main text)

2.1.5 Night Retroreflectance

The dry and wet night reflectance characteristics of the various materials were evaluated using a telephotometer. The retro-reflectance characteristics were evaluated at various stages of the laboratory program. In particular, retroreflectance was used in conjunction with the simulated snowplow resistance and simulated vehicle wear tests. The retroreflectance characteristics were monitored with a spotlight and a telephotometer. Appendix C contains a comprehensive description of the telephotometer and the retro-reflectance test.

2.1.6 Daylight Reflectance and Yellowness Index

The standard method for daylight reflectance and yellowness index provided in AASHTO Designation T 250-74 was followed for this determination. A Photovolt meter (ASTM E-97) was used for reflectance measurements.

Approximately 100-gram samples of the pigmented resins were weighed, heated at 218 $\pm$ 2°C (425 $\pm$ 3°F) for 4 hours, thoroughly stirred, then cast into patties in 1 pint round paint can lids. After cooling to room temperature, the patties were removed from the lids, and reflectance was determined, using Diffuse Reflectance head No. 610 Y, and the three tristimulus filters, A (amber), B (blue), and G (green). Each filter was calibrated with the porcelain enameled plaque secondary standard.

Daylight luminous reflectance corresponds to the value obtained with the G filter. The yellowness index, Y, is calculated from the values of A, B and G, using the following formula:

$$Y = (A - B)/G, \qquad (A.1)$$

where Y is the yellowness index and A, B and G are the reflective values for the three tri-stimulus readings.

2.1.7 Color and Color Retention - (see main text)

2.1.8 Curing Time and No-Track Time - (see main text)

2.1.9 Adhesion - (see main text)

2.1.10 Resistance to Moisture and Varying Temperature - (see main text)

2.1.11 Resistance to Light - (see main text)

2.1.12 Traffic Density - (see main text)

2.1.13 Pollution Factor - (see main text)

2.1.14 Ductility and Penetration - (see main text)

2.1.15 Toxicity - (see main text)

2.1.16 Coefficient of Linear Thermal Expansion - (see main text)

2.1.17 Flow Rate - (see main text)

2.1.18 Pot Life - (see main text)

2.1.19 Porosity or Permeance

The porosity or permeance of the various porous delineator systems was determined by two separate procedures; porosity calculated by weight-volume relations and use of outflow meter similar to the one developed by Doty [4].

Porosity Determination

Using the batch weights, compacted densities, and known or determined specific gravities, it was possible to calculate air void content and porosity of the compacted Marshall specimen.

Use of Outflow Meter

The procedure for determining relative porosity or permeance of the various porous delineator materials and a typical OGAFC consisted of the following:

1. Place the 12 inch (30.5 cm) square by 3/4 inch (1.9 cm) thick specimen made for abrasion resistance testing on a soft impermeable rubber pad.

2. Place the outflow meter shown schematically in Figure A.5 in the center of the upper surface of the specimen.

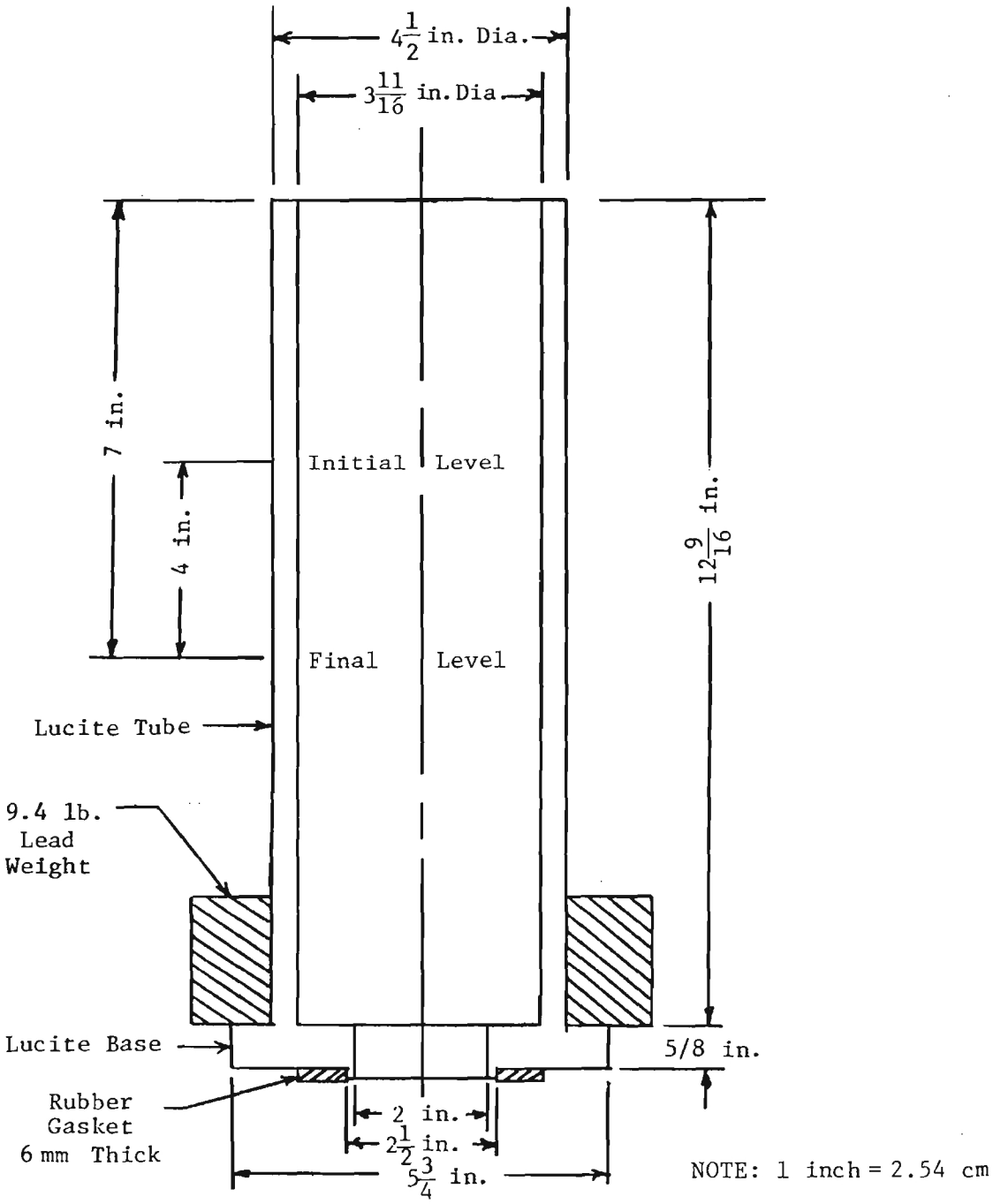


Figure A.5. Schematic Diagram of Outflow Meter.

3. Fill the outflow meter. Record the time required for the water to drop from a position 10 inches (25.4 cm) above the specimen to 6 inches (15.2 cm) above the surface. Elapsed time was determined by observation and a hand-held stop watch. The outflow value was recorded as elapsed time in seconds.

2.1.20 Texture Depth

The texture depth of the various promising OGAFC lane marking system materials was determined by a sand patch method. The procedure used was similar to the one described in Reference 4.

The sand patch method used consisted of the following:

1. Ten inch (25.4 cm) diameter specimens were made in the laboratory.

2. The circular specimen was placed on a flat and level surface.

3. A piece of masking tape was placed on the vertical circumferential surface to prevent sand from running out the side of the specimen.

4. The specimen weight was determined.

5. Dry Ottawa sand (Number 50 size) was then slowly poured on the surface of the sand so that the upper surface of the sand corresponded with the high points of the aggregate in the entire surface of the specimen.

6. The specimen and sand system were then weighed.

7. The average texture depth was then calculated using the following equation:

$$T_D = \frac{W_{SS} - W_S}{A_S} \times \frac{1}{\gamma_S} \qquad (A.2)$$

where

T_D = texture depth

W_{SS} = weight of specimen plus sand

W_S = weight of specimen

A_S = effective area of circular specimen

γ_S = loose unit weight of sand, = 94.9 lb/ft^3 (1520 $\frac{kg}{m^3}$).

APPENDIX B
METHODS USED FOR SPECIMEN PREPARATION

1.1 GENERAL

This appendix contains a detailed description of the methods used for preparing mixtures and making specimens. These specimens were later used in the laboratory screening tests.

2.1 MIXTURE PREPARATION

Dense and Open-Graded Asphalt Mixtures

The mix proportions were those determined by the Georgia Department of Transportation for the aggregates used. The aggregate and asphalt were heated to 290°F ± 10°F (143°C ± 5°C). AC-20 asphalt cement was added to the aggregate for the open-graded mix. at a proportion of 6.25 percent by weight of aggregate for the open-graded mix and at a proportion of 5.6 percent by weight of the total mix for the dense graded mix. Thorough mixing was accomplished by hand using a spoon and mixing bowl.

Polyamide Mixtures

The polyamide-ionomer mixtures was made by first mixing the polyamide, ionomer, di-octyl phthalate (DOP), antioxidant, and ultravoilet absorber together, then combining this mixture with preheated aggregate. The aggregate was heated to 500°F (260°C) before mixing and the heat of the aggregate was used to melt the thermo-plastic binder. The batch was then thoroughly mixed.
Mixture proportions are presented below: (all percentages are on aggregate weight basis).

Mixture A	Mixture B
Polyamide--6%	Polyamide--5%
Ionomer--4%	Ionomer--4%
White Pigment--5%	DOP--1%
or	
Yellow Pigment--2%	Antioxidant--0.1%
	Ultraviolet absorber--0.05%
	White Pigment--5%
	or
	Yellow Pigment--2%

Pavebrite Mixtures

Mixtures prepared with the two component Pavebrite II binder were made by thoroughly combining the two components[a] and the

(a) Components A and B are binder and plasticizer, respectively.

pigment. This mixture was then thoroughly blended with aggregate which had been preheated to 425°F (218°C). Mixture proportions used were as follows: (All percentages are on an aggregate weight basis).

Component A	7%
Component B	3%
White Pigment	5%
or	
Yellow Pigment	2%

Acrylic Mixtures

Mixtures prepared with the plasticized acrylic resin binder were made by first thoroughly combining the acrylic resin with aggregate preheated to 600°F (315°C). Then a blended mixture of hydrogenated rosin ester, antioxidant, ultraviolet absorber, and pigment was added and thoroughly blended.

These mixtures were made with the following proportions. (All percentages are on an aggregate weight basis).

Acrylic resin	5%
Hydrogenated rosin ester	5%
Antioxidant	0.1%
Ultraviolet absorber	0.05%
White Pigment	5.0%
or	
Yellow Pigment	2.0%

Hot Melt Glue Mixtures

Hot Melt Glue mixtures were prepared by adding premelted glue [melted at 300°F (150°C)] and pigment simultaneously to preheated aggregate (400°F)(204°C). This mixture was then thoroughly blended by hand.

The Hot Melt Glue mixtures were made with the following proportions (all percentages are on an aggregate basis).

Hot Melt Glue	8%
White Pigment	5%
or	
Yellow Pigment	2%

3.1 SPECIMEN PRODUCTION

Abrasion Resistance Test Specimens

Two types of specimens were prepared for abrasion resistance testing; 10 inches (25.4 cm) diameter by 3/4 inch (1.91 cm) thick circular specimens and 12 inches (30.5) by 12 inches (30.5 cm) by 3/4 inch (1.91 cm) thick square specimens. In both cases, the hot,

plastic mixture was placed in a steel mold, smoothed with a trowel and the surface sprinkled with glass beads. Fifty grams of glass beads were applied to the square specimens and 39 grams to the circular ones yielding a distribution of 50 grams per square foot (0.054 g/cm^2) in both cases. Bead application was done by hand with a salt shaker to give uniform coverage of the specimen. A liquid silicon spray was used on the molds and compaction plates to facilitate release of the sample.

The specimen was then compacted by placing a thick steel plate on the surface, placing the mold mixture and plate in a hydraulic testing machine and applying a 20,000 lb. (9072 kg) load to the center of the steel plate. The static load was left on the specimen for 5 minutes.

Motor Vehicle Impact Resistance Specimens

For the motor vehicle impact resistance evaluation, two types of specimens were used; namely, 4 inch (10.2 cm) diameter by 2.5 inch (6.4 cm) high Marshall specimens and 2 inch (5.1 cm) diameter by 1 inch (2.54 cm) high specimens.

a. Marshall Specimens

Marshall samples were made using the standard equipment for the Marshall mix design method for asphalt (ASTM D-1559 and AASHTO T-245). An amount of hot, plastic mixture material sufficient to yield a sample approximately 2-1/2 inch (6.4 cm) high was spooned into the 4 inch (10.2 cm) diameter Marshall mold and compacted by 25 blows per side with a standard Marshall hammer. The sample was then allowed to cool before removal from the mold. When cool, the specimens were extruded from the mold.

b. Two-Inch (5.1 cm) Diameter Specimens

An appropriate amount of hot, plastic mixture was placed in a 2 inch (5.1 cm) inside diameter split steel mold to make a 1 inch (2.54 cm) high sample. The 1 inch high samples were compacted by 20 blows per side of a 2 pound (0.91 kg) hammer falling 12 inches (30.5 cm). The density achieved was approximately the same as that for the Marshall specimens.

A liquid silicon spray was used to facilitate removal of the specimens from the mold. After the specimen had cooled, the mold was taken apart and the specimen removed.

Solvent Resistance Specimens

For the solvent resistance testing, 4 inch (10.2 cm) diameter and 2.5 inch (6.4 cm) high Marshall specimens were made using the same procedure as outlined above.

Permeance Specimens

For the permeance testing which used the outflow meter, the abrasion resistance test specimens were used. Preparation of these specimens was described previously.

Texture Depth

The texture depth testing which utilized the sand patch method, was accomplished with the same specimens as used for abrasion resistance testing. Preparation of these specimens was described previously.

APPENDIX C
TELEPHOTOMETRIC METHOD FOR RETROREFLECTANCE EVALUATION

1.1 GENERAL

This appendix contains a description of the telephotometer equipment and laboratory method for evaluation of retroreflectance of the various delineator materials.

2.1 DESCRIPTION OF THE TELEPHOTOMETER

The telephotometer used in this study to evaluate retroreflective characteristics is the one developed and reported by Tooke and Hurst [5]. Basically, it is a fixed-focus fixed-position light transducer which is attached to and aligned with a spotlight. The telephotometer sensors are calcium sulfide photocells, Claire CL905, which are centered in the focal plane of a f/1.0, 50 mm lense. The light source is a sealed beam spotlight, 12 volt, 30 watts with the sealed beam unit rotated to align the major axis of the filaments vertically. In the laboratory conventional 110 volt line current was converted to a 12 volt DC to power the unit. For use of the telephotometer unit in the field, the 12 volt system of an automobile provided the power. Figure C.1 depicts a schematic diagram of the telephotometer--spotlight unit. Figure C.2 depicts a cross-section of the telephotometer and a schematic diagram of the retroreflectance recording system.

3.1 LABORATORY TESTING PROCEDURE

The step-by-step laboratory procedure used to evaluate the retroreflectance characteristics with the telephotometer-spotlight unit consisted of the following:

1. The surface of a stimsonite reflector (Type 88) was partially masked off in order to prepare a "standard" of similar retroreflectance to the 12 inch (30.5 cm) square and 10 inch (25.4 cm) diameter samples. This standard was used throughout the laboratory study.

2. The voltage meter connected to the output from the telephotometer was zeroed and with the spotlight-telephotometer unit centered on the standard, the grain was adjusted to give a reading of 8.3 on the meter scale which was linear between 0 and 10.0.

3. The sample to be monitored was placed in position 20 feet (6.1 meters) away from the telephotometer unit and 26 inches (66 cm) below it. With this geometry, as depicted in Figure C.3, an elevation angle of 6.4^{o} was obtained.

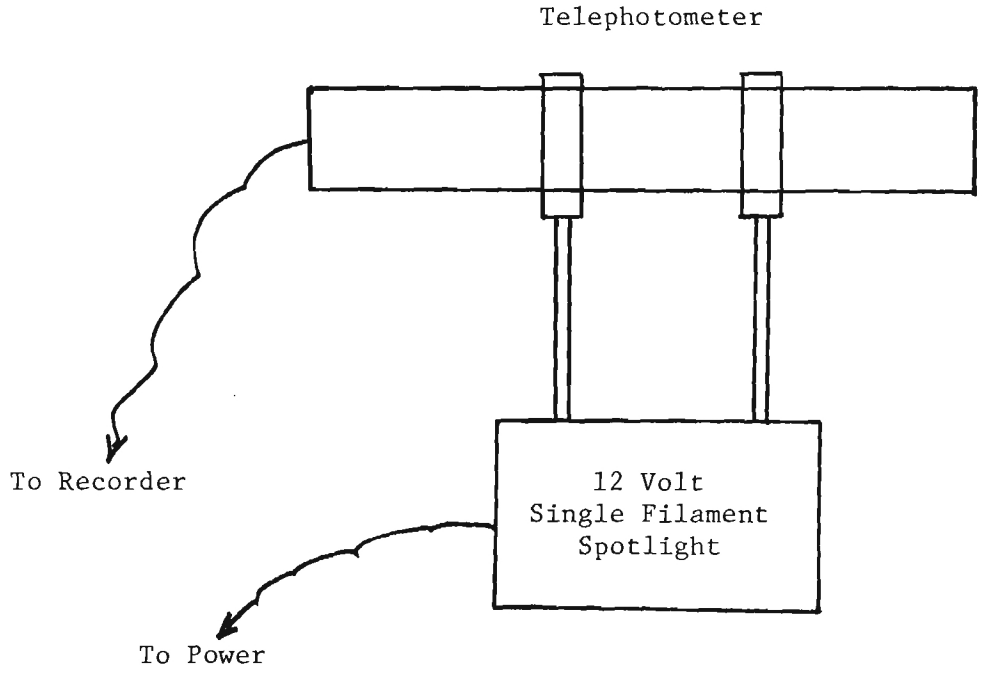
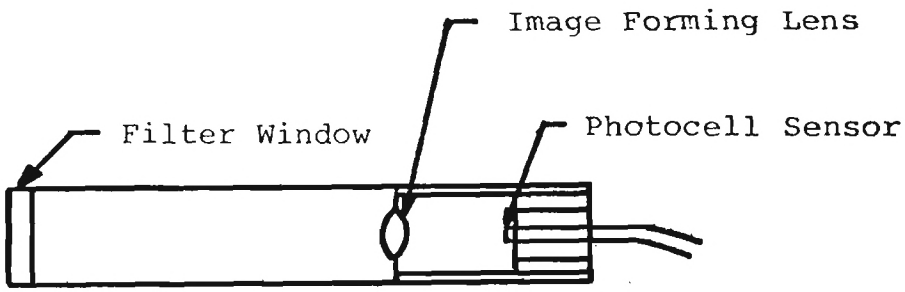
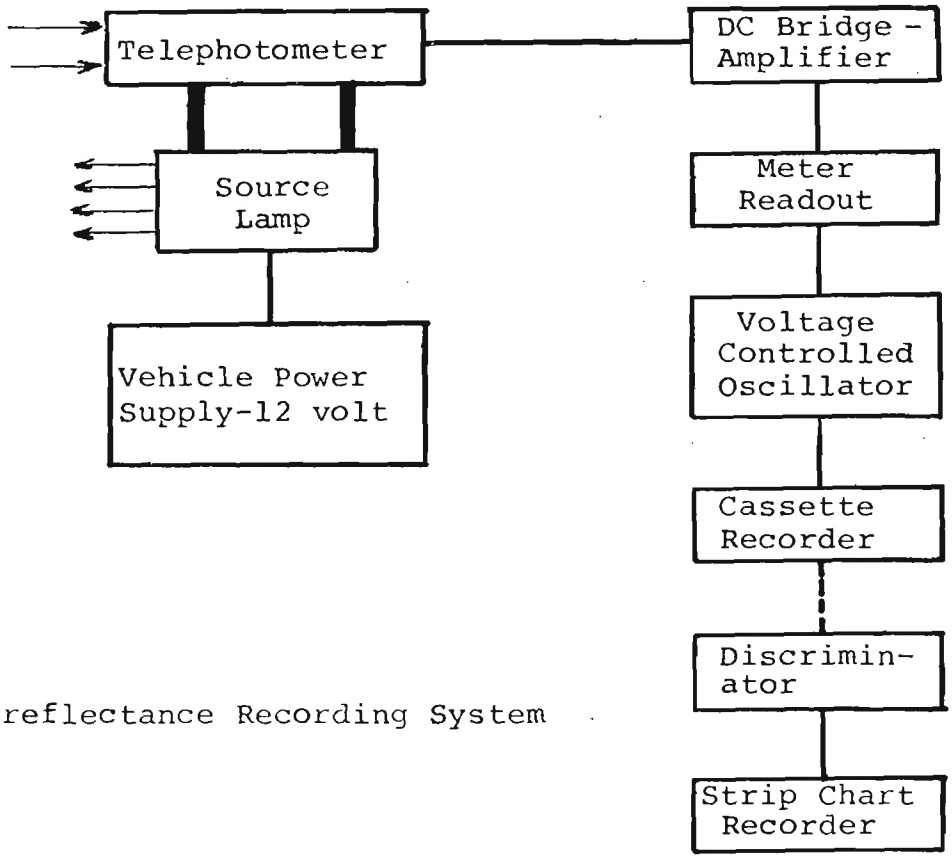


Figure C.1. Schematic of Telephotometer.

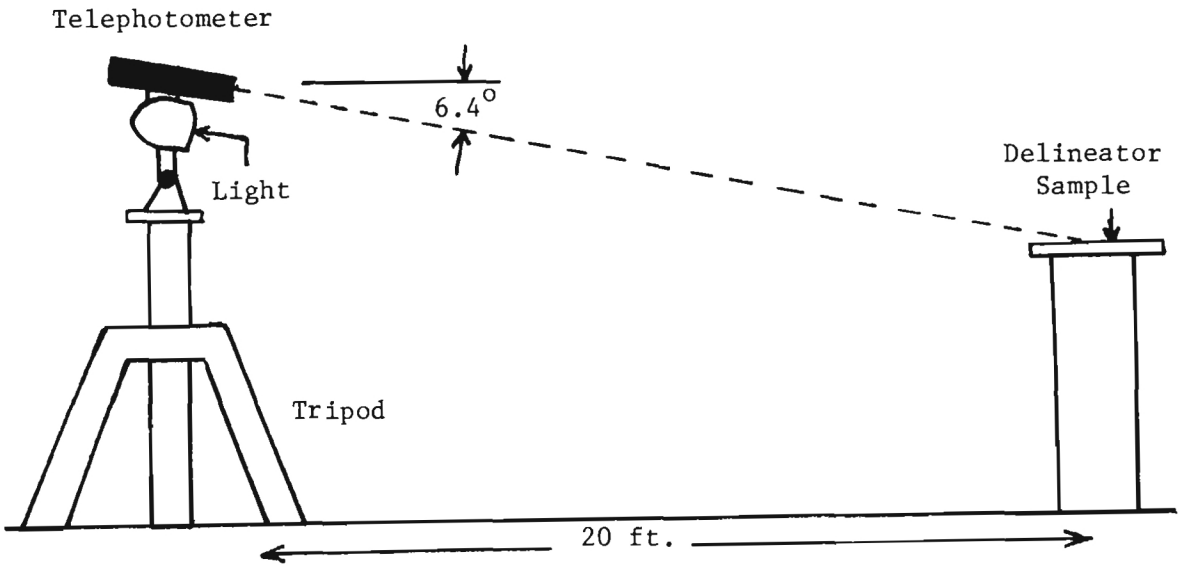


Telephotometer Unit
(section view)



Retroreflectance Recording System

Figure C.2. Section View of Telephotometer and Schematic of Retroreflectance Recording System.



NOTE: 1 meter = 3.28 ft.

Figure C.3. Schematic of Telephotometer-Sample Setup in Laboratory.

4. A black frame was placed over the sample so that a 4 inch (10.2 cm) wide strip oriented in the direction of the line drawn between the sample and the telephotometer was exposed.

5. The stimsonite standard was then placed in the center of this exposed area and the telephotometer unit alignment and elevation angle adjusted until a maximum reading was obtained on the output meter.

6. The standard was removed and a retroreflectance reading taken.

7. A fine water mist was then applied to the surface of the sample with a spray bottle in order to impart a maximum water film thickness on the sample.

8. Steps 4, 5 and 6 were repeated.

APPENDIX D
MATERIAL REQUIREMENTS AND SUGGESTED LABORATORY EVALUATION PROCEDURES

1.1 INTRODUCTION

Based on the results of research described in the main body of this report, the concept of using a porous delineation system in conjunction with OGAFC is attractive. It can improve the wet-night visibility of the delineation system compared to that of conventional beaded paint systems. This appendix describes in detail the material requirements for the special porous delineator systems, application guidelines and guidelines for field evaluation of in-service porous delineation systems.

2.1 REQUIREMENTS OF COMPONENT MATERIALS

The material requirements for the special porous delineator systems can be divided into two broad categories: (a) requirements of the individual components of the porous delineator and (b) requirements of the manufactured porous delineator system. Aggregate, binder, pigment, and glass beads comprise the four major components of the special porous delineator systems. Special requirements for each of these components are discussed below.

2.1.1 Aggregate

Material requirements for the aggregate should be the same as if the aggregate is to be used in OGAFC. Reference 2 is an excellent source of information and requirements for OGAFC. It is recommended that relatively pure carbonate aggregates or any aggregates known to polish be excluded from the coarse aggregate fraction. In addition, the coarse aggregate fraction should have at least 75% by weight of particles with at least two fractured faces and 90% with one or more fractured faces. The abrasion loss (AASHO T-96) should not exceed 40%.

The recommended gradation for the aggregate (exclusive of powdered pigment) to be used in the special porous delineation materials is as follows:

Sieve Size	Percent Passing
1/2"	100
3/8"	90-100
# 4	25 - 50
# 8	5 - 15
#200	2 - 5

2.1.2 Binder

Materials to be used as binders in Open-Graded Asphalt Friction Course Lane Marking composites shall consist of thermoplastic resins (although elsewhere in this report as pointed out, thermosetting resins should be given consideration) having physical properties closely approximating those of asphalt, except that such materials shall have no color which will interfere with or obscure white and yellow pigments to be incorporated in the composites. Physical properties, such as solvent resistance, freeze-thaw resistance, resistance to light and moisture, adhesion, penetration, etc., shall equal or exceed the corresponding properties of asphalt used for OGAFC binder. Resins such as acrylics, hot-melt glues and synthetic asphalt (Pavebrite) have been found satisfactory; however, other resins exhibiting properties within the limits of the following specifications may be used.

Specifications

1. Solvent Resistance (See Section 4.1.4d of Appendix D)

2. Freeze-Thaw Resistance

Method: Specimens are prepared as specified for the Adhesion test (Procedure 5 of this specification). Two sets of 6 specimens are required for each binder.

One set of specimens is subjected to the Adhesion Test as described in Procedure 5 of this specification.

The second set is cycled between $-30^{\circ}F$ and $140^{\circ}F$ ($-34^{\circ}C$ and $60^{\circ}C$), at 24 hours per cycle for 168 hours. Following freeze-thaw cycling, the second set is subjected to the Adhesion Test as above.

Requirement: Specimens not subjected to freeze-thaw cycling should exhibit pull test stress of not less than 90 $lb.in^2$. Following freeze-thaw cycling, the specimens should exhibit a loss of not more than 20% of adhesion strength.

3. Daylight Reflectance and Yellowness Index

Method: The Photovolt Reflectance Meter (ASTM E97) is used, with diffuse reflectance head No. 610Y and three tristimulus filters, amber (A), blue (B), and green (G). The method of ASTM E97 is followed. Report the G reading as "Daylight Reflectance", and compute "Yellowness Index" from the three readings, using the formula,

$$Y = \frac{A - B}{G} \qquad (D.1)$$

4. Color and Color Retention

Method: Test disks of the yellow resin formulation, but without aggregate, are prepared, and their colors are matched with chips on the FHWA Yellow Color Tolerance Chart to determine an initial reading. Separate samples are then exposed to (a) 100% relative humidity at room temperature for 24 hours, (b) immersion in kerosene for 24 hours, and (c) high intensity ultraviolet light for 200 hours. Following exposure, the test pieces are again matched with chips of the FHWA Yellow Color Tolerance Chart.

Requirement: Initial readings should be in the immediate range of "Central Color" on the chart. Exposure to 100% relative humidity for 24 hours should produce no change in this reading. Immersion in kerosene for 24 hours should produce no color change, although a portion of the resin might dissolve. Exposure to ultraviolet light for 200 hours should not darken the resin-pigment test disk by more than "Gray Limit C" or "Dark Limit V".

5. Adhesion

Method: AASHTO Method T250-6 (Bond Strength) is followed, except that the test pieces are prepared as follows to fit better into an Instron Testing Machine.

Concrete tablets 1 inch by 1 inch by 3.5 inches (2.54 by 2.54 by 8.9 cm) are sawn from solid concrete blocks (cap blocks). The resin binders are prepared with pigments, plasticizers, etc., but without aggregate. The hot plastic mix is used to cement two of the test blocks together with a 1 inch by 1 inch (2.54 cm by 2.54 cm) lap joint and allowed to stand overnight to achieve thermal equilibrium. A test jig is employed to apply the loading longitudinally on the lap joint at a loading rate of 200 lb/min. (90.7 kg/min.) at a sensitivity of 0.2 lb. (0.1 kg). The load at failure is recorded.

Requirements: Minimum acceptable load at failure is 90 lb./in.^{2} except that for a resin that complies with other physical requirements, a load of 70 lb./in.^{2} may be accepted.

6. Resistance to Moisture and Varying Temperature

Method: Test pieces are prepared as in Procedure 5 (Adhesion). These pieces are immersed in water at 75°F (23°C) for a period of one week. Once each day the pieces are removed and chilled to 0°F (-18°C), then returned to the water bath. At the end of the week they are tested for bond strength as in Procedure 5, Adhesion.

Requirements: Following the moisture and temperature conditioning, the specimens should exhibit a loss of not more than 20% of Adhesion strength.

7. Resistance to Light

Method: Ductility test pieces are prepared in accordance with ASTM D-113, and elongation to failure is determined by use of the Instron testing machine. Duplicate samples are exposed to a high intensity mercury arc tube lamp for 168 hours and similarly tested.

Requirement: Elongation will be determined as a standard for each material and may be as low as 15% to as high as 250%. Increase in elongation following ultraviolet exposure should not exceed 25%, however, 50% is allowable if other physical properties are within satisfactory range.

8. Ductility and Penetration

Method: Ductility test pieces are prepared in accordance with ASTM D-113, and elongation to failure is determined by use of the Instron testing machine.

Requirement: Elongation is determined as a standard for each material and may be as low as 15% to as high as 250%. Penetration should fall within the range of 0 to 4.0 mm.

9. Toxicity

Method: Binder formulations are reviewed to determine if any components are included in the list of TLV's (Threshold Limit Values) compiled by the American Conference of Governmental Industrial Hygienists. If so, the TLV's of said components are noted.

Requirements: No component shall be present in sufficient quantity that its TLV shall be exceeded in the atmosphere during processing, application, or service life of the binder in its OGAFC application.

10. Coefficient of Linear Thermal Expansion

Method: Bar specimens of the pigmented resins are prepared and tested in accordance with ASTM D-696-70.

Requirement: Coefficients of linear thermal expansion shall not be in excess of 10×10^{-4} in./in./^{o}F.

11. Flow Rate and Pot Life

Method: Flow rate is determined on the pigmented resin using the method of ASTM D-1238-70. Pot life is determined by (a) repeating the flow rate measurement after a 10-hour period at melt temperature and (b) determining the yellowness index before and after the 10-hour melt period.

Requirement: Flow rate is determined as a standard for each material. An acceptable range is 100 to 600 gm/10 min.

Pot Life: (a) Flow rate shall not change during the 10-hour melt period to a value lower than 90 nor higher than 660 gm/10 min., (b) Yellowness index shall not be adversely affected by the 10-hour melt period.

2.1.3 Pigment

A dry, powdered pigment shall be used. The pigment shall be chemically compatible with the other components of the porous delineator. The pigments should not contain calcium carbonate filler because of potential adverse reaction with certain types of binders. Specific requirements follow:

White Pigment Composition, % by weight

	maximum	minimum
Titanium Dioxide, ASTM: D476, Type II, Rutile	42	42
Diatomaceous Silicate, ASTM: D 604, Type B	29	29
Magnesium Silicate, ASTM: D 605	29	29

Yellow Pigment Composition, % by weight

	maximum	minimum
Chrome Yellow, ASTM: D 211, Type III Medium Chrome Yellow	44	45
Diatomaceous Silica, ASTM: D 604, Type B	26	25
Magnesium Silicate, ASTM: D 605	30	30

2.1.4 Glass Beads

General

Glass beads shall consist of clean, dry, transparent spheres manufactured from high-grade optical crown glass of a composition designed to be highly resistant to traffic wear and to the effects of weathering. In addition, the glass beads shall be of such character as to permit their embedment in pigmented binder leaving their upper surfaces exposed to light rays creating night visibility without altering day visibility of the traffic lines.

The glass beads shall not show any tendency toward

decomposition, including surface etching, when exposed to atmospheric conditions, moisture, or dilute acids.

The glass spheres shall be crystal in color and free from all surface film. They shall be corrected to prevent their imparting any noticeable daytime hue.

The glass beads shall be free of:

1. Angular particles, the quantity of which shall not exceed 1 percent.

2. Particles showing milkiness, scoring or scratching, the quantity of which shall not exceed 2 percent, and

3. Foreign matter, the quantity of which shall not exceed 1 percent.

Grading

The beads shall conform to the following grading when tested in accordance with ASTM: D 1214:

U.S. Standard Sieves		Requirements Minimum	Maximum
Passing No. 20	Retained No. 30	5	20
Passing No. 30	Retained No. 50	30	75
Passing No. 50	Retained No. 80	9	32
Passing No. 80		0	15
Passing No. 100		0	2.0

Shape

Not less than 70% of the beads, overall, and not less than 60% of the beads retained on any specified sieve shall be true spheres when tested in accordance with ASTM D-1155.

Index of Refraction

The glass beads when tested by the liquid immersion method at 25^{o}C shall show an index of refraction within the range of 1.50 to 1.65.

3.1 DETERMINATION OF MIXTURE PROPORTIONS

3.1.1 Binder Content

It is recommended that the amount of binder or binder content be estimated by using a method similar to that used for estimating the asphalt content of open-graded asphalt friction course mixtures. This method is based upon surface area. The binder content however may need to be adjusted based upon permeability, stability, and/or abrasion-raveling. The procedure for estimating binder content is described below:

The surface capacity of the aggregate fraction retained on a #4 sieve is determined in accordance with the following procedure:

A surface constant, K_c, is determined for the percent of SAE #10 oil retained, which represents the total effect of superficial area, the aggregate absorptive properties and surface roughness. The step-by-step procedure for determination of this constant is as follows:

1. Quarter out 105 grams representative of the aggregate passing the 3/8 inch (0.95 cm) size and retain on the #4 sieve.

2. Dry sample on hot plate or in 230 $\pm$ 9°F (110 $\pm$ 5°C) oven to constant weight and allow to cool.

3. Weigh out 100.0 grams and place in a metal funnel (top diameter 3-1/3 inch (8.9 cm) height and 4-1/2 inches (11.4 cm), orifice 1/2 inch (1.3 cm) with a piece of No. 10 screen soldered to the bottom of the opening).

4. Completely immerse aggregate sample in SAE #10 lubricating oil for 5 minutes.

5. Drain for 2 minutes.

6. Place funnel containing sample in oven at 140°F (60°C) for 15 minutes of additional draining.

7. Pour sample from funnel into tared pan; cool, and reweigh sample to nearest 1/10 gram. Subtract original weight and record difference as percent oil retained (based on 100 grams of dry aggregate).

8. Use chart shown in Figure D.1 for determination of "K_c". If specific gravity for the fraction is greater than 2.7 or less than 2.6, apply correction to oil retained, using formula at the bottom of chart in Figure D.1. Start at the bottom of chart in Figure D.1 with the corrected percent of oil retained; follow straightedge vertically upward to intersection with the diagonal line, hold point, and follow the straightedge horizontally to the left. The value obtained will be the surface constant for the retained fraction and is known as "K_c".

Determine the required binder content, which is based on the weight of aggregate, from the following relationship:

$$\text{Percent Binder (By wt. of Aggregate)} = 2.0\ (K_c) + 6.0 \qquad (D.2)$$

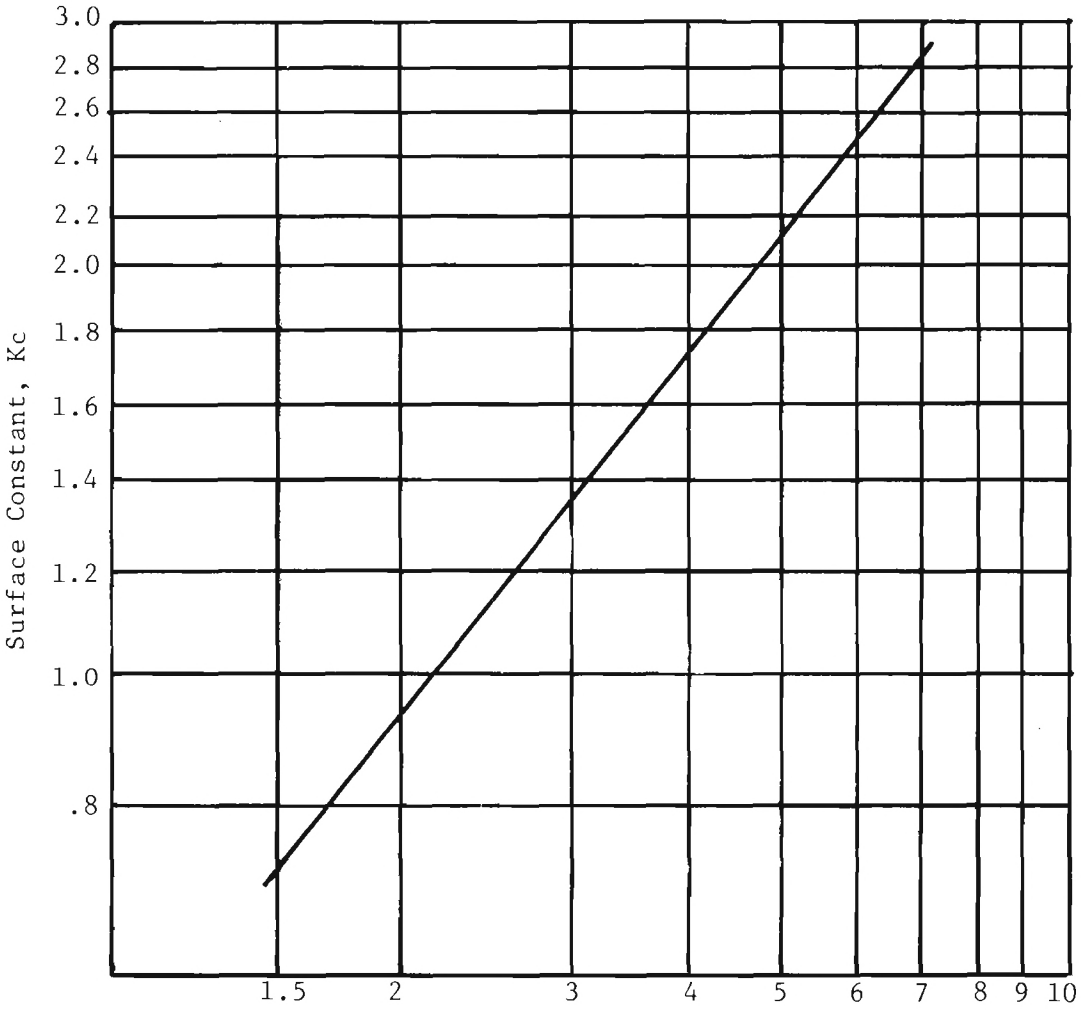
A correction may need to be applied to this quantity based upon the amount of pigment needed and the relative permeability, stability and raveling of the resulting mixture. The laboratory part of this project indicated a range from 8 to 10 percent was satisfactory. Insufficient binder may produce high strength but very brittle mixes. Excessive binder will adversely affect porosity.

3.1.2 Pigment Content

Proper color is the major consideration in determining the amount of pigment to be used in the total mixture. Depending upon the nature of the binder, more or less pigment may have to be used in order to obtain either the desired white color or yellow color. Less pigment is required to develop proper yellow than white. The FHWA Color Tolerance Chart can be used to aid in judging the color adequacy of the yellow mixes. Typically the pigment content for yellow mixes is about 2% by wt. of the aggregate. For white pigment, quantities normally range from about 3 to 4% by weight of the aggregate.

3.1.3 Quantity of Glass Beads

The glass beads are placed on the surface of the hot binder and allowed to partially settle into the binder. Slightly less than 50% imbedment seems to be ideal in terms of retroreflectance [7]. The quantity of glass beads to be used is approximately 50 grams per square foot of delineator surface area.



$$\text{Oil Retained Corrected (\%)} = \text{Oil Retained (\%)} \times \frac{\text{"apparent" sp. gr. of Coarse Aggregate}}{2.65}$$

Figure D.1. Chart for Determining Surface Capacity of Coarse Aggregate (from Reference 2).

4.1 SUGGESTED PROCEDURES FOR LABORATORY EVALUATION OF SPECIAL POROUS DELINEATOR SYSTEMS

4.1.1 General

Prior to field application of a proposed new porous delineator system, certain laboratory tests should be conducted on the porous materials. The results from these laboratory tests should aid in ascertaining the overall potential of the special PDS for field application.

The first step in laboratory evaluation is to select the appropriate aggregate, binder, pigment and glass bead. Each of these materials should meet the requirements previously outlined. The second step is to establish the mixture proportions, i.e., the relative quantity of each component to be used in the total mixture. This can be done using the previously outlined guidelines. The third step is to conduct various laboratory tests on the resulting mixture. The suggested tests to be used for overall mixture evaluation are as follows:

1. Snowplow Resistance
2. Tire Scuffing Resistance
3. Solvent Resistance
4. Night Retroreflectance
5. Permeance
6. Stability or Strength

4.1.2 Types of Test Specimens

For each of the above tests, certain types of specimens must be made. However, some of the specimens can be used for more than one test. The following is a summary of the type, dimensions, and number of various specimens needed:

1. Two rectangular specimens, 12 inches (30.5 cm) square and the same thickness as the OGAFC layer in which the PDS is to be installed. This latter dimension normally ranges 0.5 to 0.75 inches (1.3 to 1.9 cm) although other OGAFC overlay thicknesses have been used. These two rectangular specimens should have glass beads applied to their surfaces at a rate of 50 gms per ft^2.

2. Nine cylindrical specimens, 4 inches (10.2 cm) diameter and about 2.5 (6.4 cm) in. high. Six of these specimens shall be made of the special porous delineator mix with no glass beads applied to the surface. The other 3 specimens shall be made from an OGAFC mixture with the same or similar aggregate type and gradation and asphalt type and quantity as the OGAFC system into which the PDS is to be installed.

4.1.3 Specimen Preparation Techniques

The rectangular specimens shall be prepared using the following procedure:

1. Prepare porous delineator mixture. This entails heating materials to appropriate temperature if a thermoplastic binder is used, adding the correct proportion of ingredients, and thoroughly mixing in the plastic state.

2. Place the hot, plastic mixture in a properly dimensioned, preheated steel mold. The mix is then evenly distributed and smoothed with a small steel trowel.

3. Fifty grams of glass beads are then evenly sprinkled on the surface.

4. The specimen is then compacted by placing a rigid 2 inch (5.1 cm) thick steel plate on the surface of the loose mix. A downward force of 20,000 lbs. (9,000 kg) is applied to the center of the plate and left for 5 minutes.

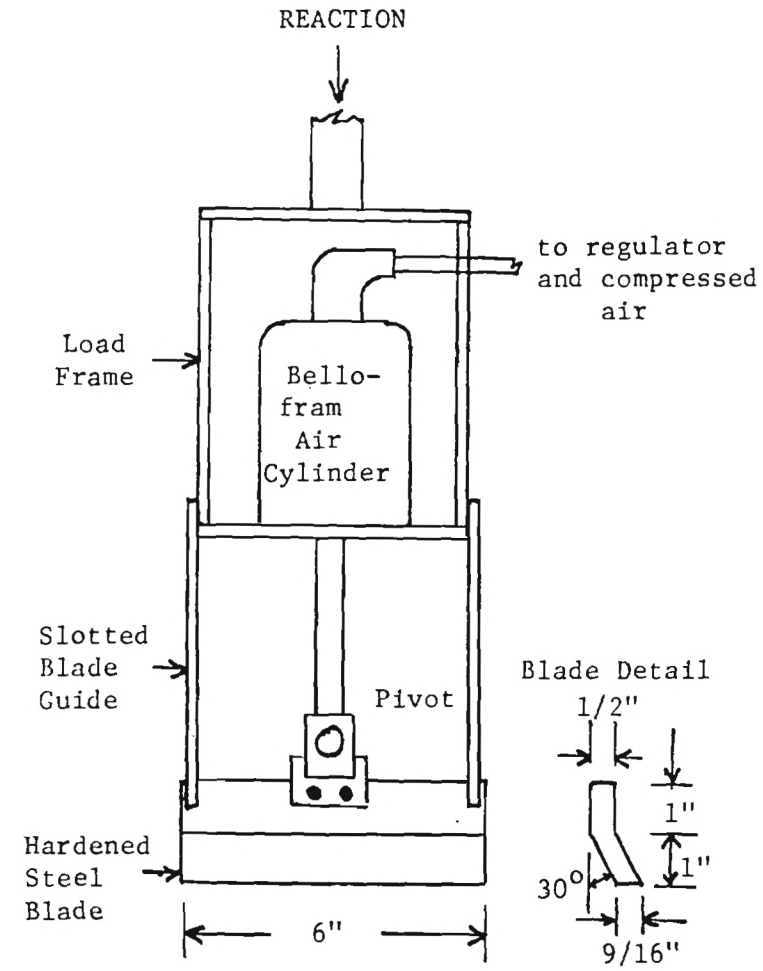
5. After allowing the specimen to cool, remove it from the mold and carefully store for later testing. Particular attention should be given to protection of the upper beaded surface.

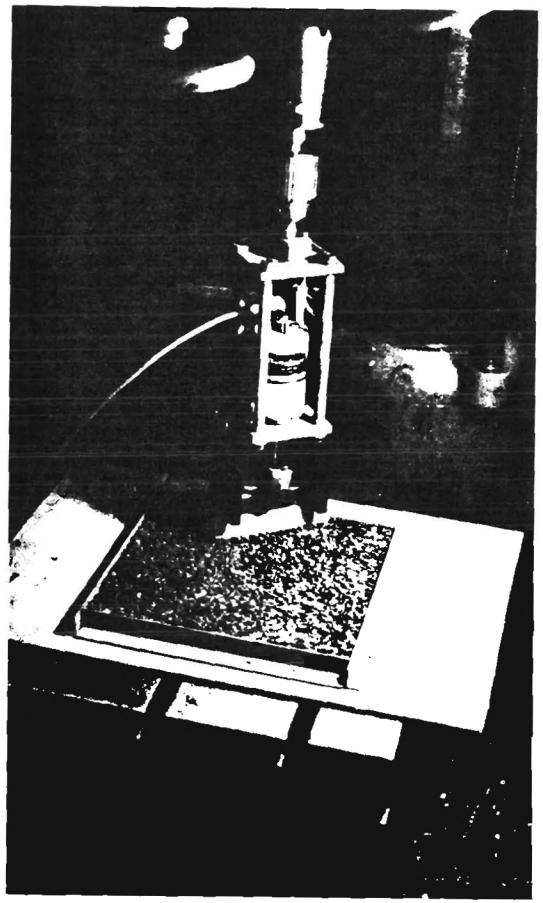
The cylindrical Specimens shall be prepared as per ASTM Procedure D 1559. Mixture preparation is the same as above. Twenty-five blows per side should be used for compaction. Six of the cylindrical specimens should be prepared from the special porous delineator mix and three from the OGAFC mix.

4.1.4 Testing Procedures

a. Snowplow Resistance and Night Reflectance

The abrasion resistance of the PDS is evaluated using a model snowplow. The model snowplow is depicted in Figure D.2. Retro-reflectance readings are first taken for one of the 12 inch by 12 inch (30.5 cm by 30.5 cm) square specimens. The procedure outlined in Appendix C is used. For comparison, a piece of plywood 12 inches (30.5 cm) should be prepared with standard traffic paint and glass beads. This specimen is evaluated for retroreflectance as per Appendix C. The model snowplow blade is placed on the surface of the 12 inch (30.5 cm) square sample and the blade positioned to make a 60^{o} angle with the direction of blade movement. A downward load of about 30 pounds per linear inch (5.4 kg/in.) of blade is applied using compressed air and the Bellofram air cylinder. The blade is then moved back and forth across the surface of the specimen for 100 passes. A pass is defined as one complete back and forth cycle. Test temperature should be about $65^{o}F - 75^{o}C$ ($18^{o}C - 24^{o}C$). Following snowplowing, the specimen is visually examined for damage.





NOTE: 1 inch = 2.54 cm

Figure D.2. Schematic and Picture of Model Snowplow.

It is suggested that the following rating scale be applied:

Degree of Snowplow Damage	Description
none	only gray to black surface coating left by wearing away of steel snowplow.
moderate	about 25% of aggregate surface has beads and pigmented binder removal. Only a few aggregate are dislodged.
severe	greater than 50% of aggregate at surface has beads and pigmented binder removed; also numerous aggregate may be dislodged.

b. Permeance Using Outflow Meter

The other 12 inch by 12 inch (30.5 cm by 30.5 cm) specimen is used to evaluate the relative open-graded nature of the PDS. Later this specimen is used for the scuffing action test.

The procedure for determining relative permeance of the porous delineator materials consist of the following:

1. Place the 12 inch (30.5 cm) square specimen on a relatively soft impermeable rubber pad. A piece of soft rubber gasket material about 0.75 inch (1.9 cm) thick works well for this. Figure D.3 depicts this setup.

2. Place the outflow meter shown schematically in Figure D.4 in the center of the upper surface of the specimen.

3. Fill the outflow meter using a bucket of water. Record the time required for the water to drop from a position 10 inches (25.4 cm) above the specimen to 6 inches (15.2 cm) above the surface. Elapsed time is determined by observation and hand-held stop watch. The outflow value is recorded as elapsed time in seconds.

4. It is suggested that Step 3 be repeated and an average of the two outflow times be used.

c. Tire Scuffing Action Test

This test is used to evaluate the scuffing action from slow-speed directional maneuvers of vehicles. This test is conducted with the front tire of an automobile being placed on the same 12 inch (30.5 cm) square specimen as used in the Permeance Test. The specimen is anchored to the surface of a flat concrete pavement using an angle

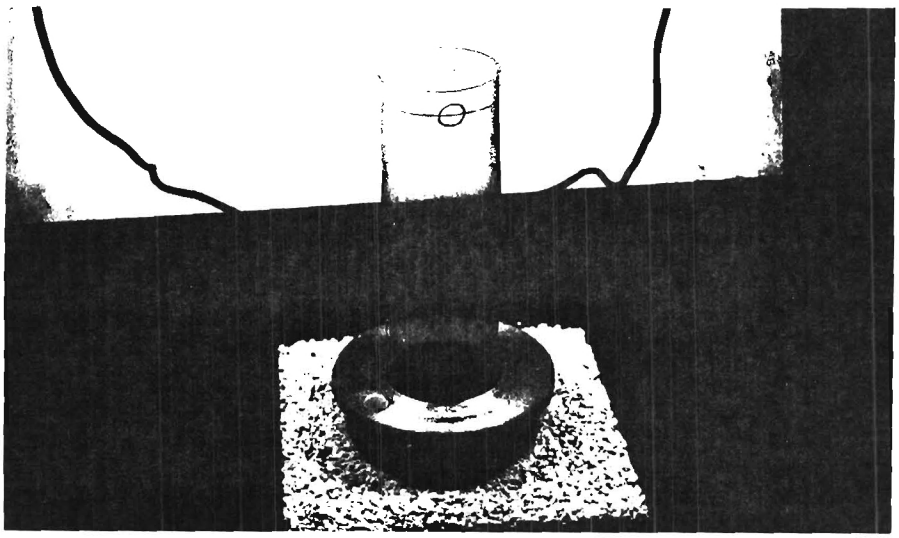


Figure D.3. Picture of Outflow Meter - Specimen Test Set-up.

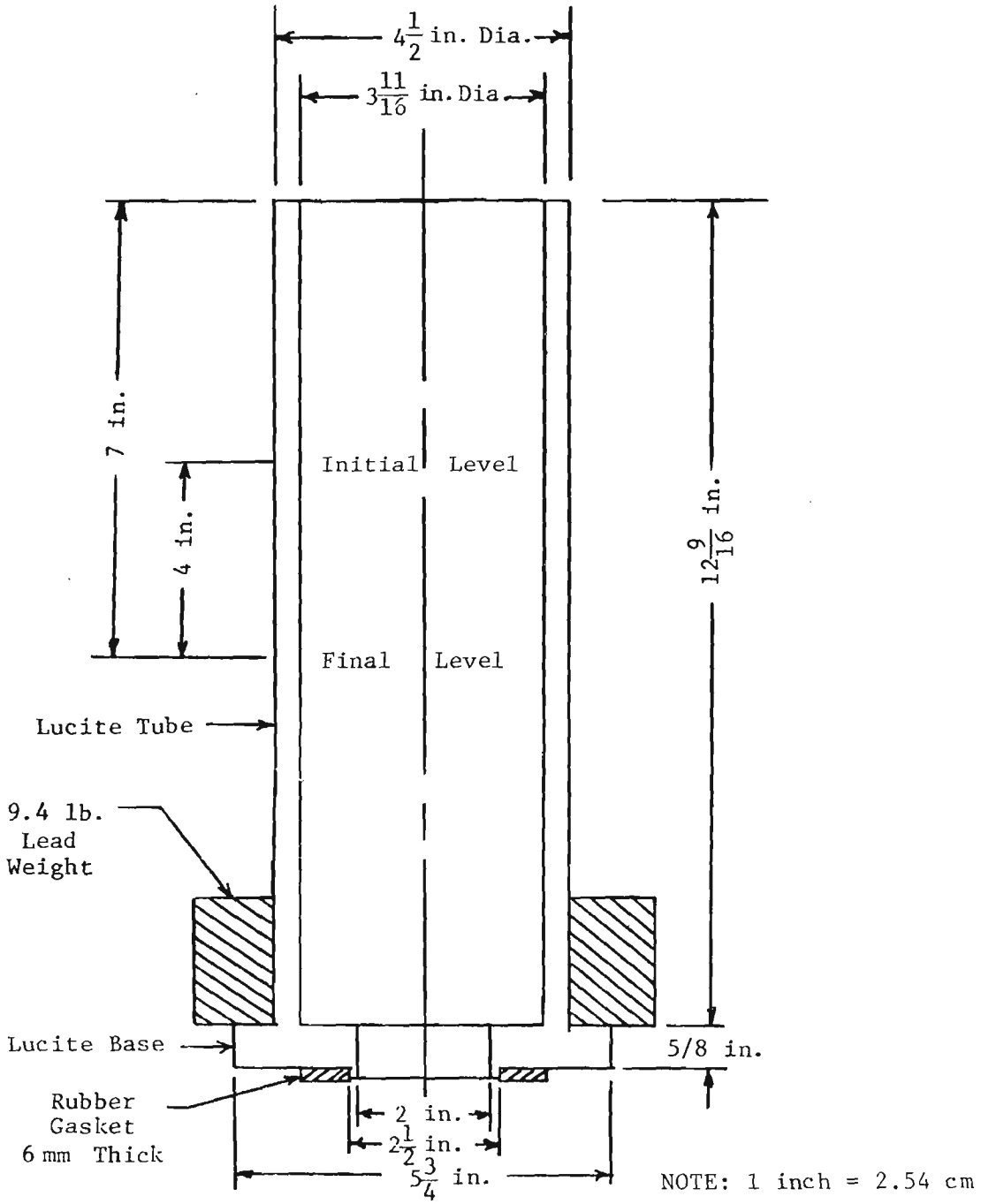


Figure D.4. Schematic Diagram of Outflow Meter.

iron frame as shown in Figure D.5 . The front tire of an automobile (inflation pressure = 30 psi) is placed on the center of the specimen. The steering wheel is slowly cranked from the left stop to the right stop a total of three times. It is recommended that the test temperature be in the range of 70^{o} - 80^{o}F (21^{o} - 27^{o}C). However, it may be desirable to examine the scuffing action at higher temperatures more representative of maximum pavement temperatures.

The automobile is backed off of the specimen and a visual examination made of any damage. It is suggested that the following rating scale be applied:

Degree of Scuffing	Description
none	no obvious dislodging of aggregate
slight	a few aggregate dislodged
moderate	about 25 to 50% or area under tire has dislodged aggregate
severe	all of area under tire has dislodged aggregate

d. Solvent Resistance

The solvent resistance of the PDS is evaluated by subjecting three of the 4 inch (10.2 cm) diameter by 2.5 inch (5.4 cm) high Marshall specimens to 25 hours of complete immersion in kerosene. Following the immersion period, Marshall stability and flow (ASTM D-1559 and AASHTO T-245) are determined at a testing temperature of 140^{o}F (60^{o}C).

e. Marshall Stability and Flow

The three OGAFC and three remaining PDS specimens, each 4 inch (10.2 cm) diameter by 2.5 inches (5.4 cm) high are subjected to Marshall stability and flow tests as per ASTM D-1559 or AASHTO T-245 except that the test temperature is 140^{o}F (60^{o}C).

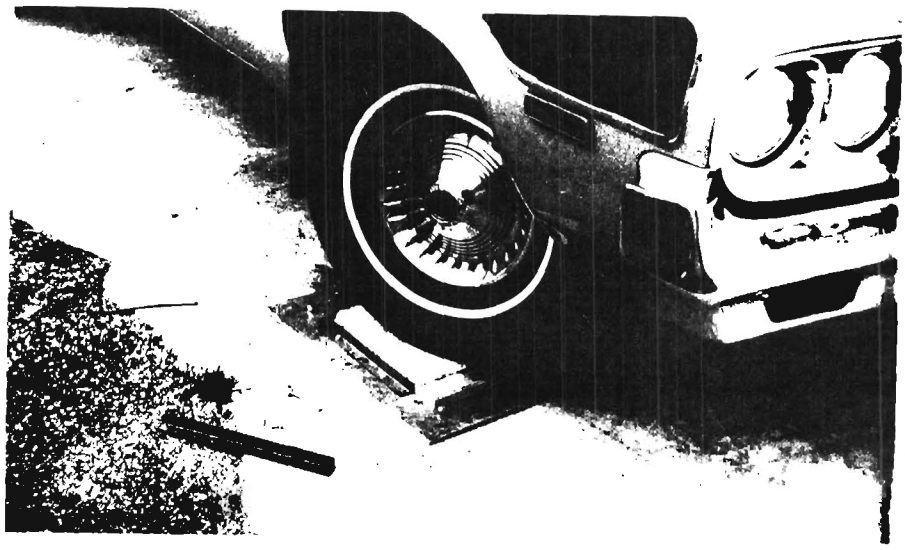


Figure D.5. Picture of Scuffing Test Set-up.

5.1 INTERPRETATION OF RESULTS FROM LABORATORY EVALUATION

5.1.1 General

The primary purpose of the laboratory evaluation of the candidate porous delineator system is that of trying to determine if the system will provide satisfactory in-service performance. The results from the previously described laboratory tests along with the tentative guidelines subsequently presented should aid in determining the potential for field performance.

5.1.2 Retroreflectance

The dry condition retroreflectance readings (taken with the telephotometer) for the PDS should be as good as the readings taken on the beaded traffic paint specimen. If the PDS retroreflectance readings are lower, the density of glass beads on the surface of the PDS should be examined. A high density is desired. Also, the amount of bead imbedment should be examined. Slightly less than 50% imbedment is ideal. By changing the size of glass beads, the depth of imbedment (for a given binder-pigment coating thickness) can be controlled. Greater retroreflectance can also be attained by using higher refractive index glass beads.

The wet condition retroreflectance readings should be substantially better for the PDS than the beaded paint specimen. If lower readings result for the PDS, possible remedies include: (a) more glass beads, (b) larger glass beads, and/or (c) improved porosity or permeability for the PDS by redesign of the mixture.

5.1.3 Snowplow Damage

If moderate or severe snowplow damage occurs, the PDS system is unacceptable. A likely modification is that a stronger or more viscous binder is required although redesign of mixture proportions may also be desirable.

5.1.4 Permeance

The outflow time which inversely relates to the porosity and permeability of the PDS should be less than 10 to 20 seconds and in no case should the outflow time be greater for the PDS than for the OGAFC pavement. If the outflow time is excessive either the binder-pigment contents needs to be reduced and/or the aggregate gradation needs to be adjusted to make a more porous system.

5.1.5 Tire Scuffing Action

If moderate or severe scuffing action occurs then the PDS is unacceptable. Possible remedial action would include a stronger or more viscous binder-pigment system or a redesign of the mixture proportions.

5.1.6 Marshall Stability

The Marshall stability at 140°F (60°C) of the PDS and OGAFC specimens should be compared. The average stability for the PDS specimens should be greater than the stability for the OGAFC. If the stability for the PDS specimens is lower, a stronger or more viscous binder should be used. A redesign of mixture proportions and aggregate gradation should also be considered.

5.1.7 Solvent Resistance

The Marshall stability of the PDS at 140°F (60°C) after 24 hours immersion in kerosene will be substantially lower than the unsoaked PDS. Acceptable values of stability range upward from about 100 lbs. If a greater loss is stability occurs, a change in binder formulation or binder type should be considered.

APPENDIX E
APPLICATION GUIDELINES

1.1 INTRODUCTION

Special porous delineator systems can provide improved wet-night visibility when used with OGAFC. The PDS either can be placed in existing OGAFC or can be placed simultaneously with a new OGAFC. Special application techniques markedly different from conventional lane striping operations must be used. Although numerous viable application techniques probably exist, the techniques which are described subsequently have been used successfully.

2.1 APPLICATION IN EXISTING OGAFC

The use of PDS with existing OGAFC in general requires that a groove be cut in the OGAFC layer. A series of diamond saws spaced about 1/8 inch (0.3 cm) apart mounted on a pavement surface grinder has been used successfully to cut the groove. The groove is normally cut to the full depth of the existing OGAFC layer. Whatever equipment is used, special care must be taken to cut a groove of proper dimensions (length, width, and depth). The groove must be cleaned and dried. An adhesive material is used at the bottom of the groove to insure bond between the substrate and the PDS. Various asphalt products including AC-20 paving grade asphalt cement and RC-250, rapid curing liquid asphalt have been used successfully as the adhesive. Whatever adhesive is used, it is important that it properly bonds to both the substrate and the PDS.

Small blocks of PDS can be prefabricated off site and transported to the site for installation in the groove. This technique was used successfully in this project. However, there appears to be another reasonable application technique. This technique consists of preparing either at the job site or at some central site, a hot, plastic PDS mixture. This mixture would then be placed and compacted in the groove. This latter approach is quite similar in concept to pavement patching using hot mix asphalt concrete. It is envisioned that due to the unique characteristics of PDS, some special equipment would need to be developed. Also, a technique for placing the glass beads on the PDS would have to be developed. It does appear that this latter method might be must less labor-intensive if appropriate equipment and application techniques could be developed.

Whichever method is used for placement of the PDS in the precut groove, it is desirable from the standpoint of snowplow resistance to insure that the PDS does not protrude above the surface of the existing OGAFC.

3.1 APPLICATION WITH NEW OGAFC

There appears to be two general techniques for applying PDS with a new OGAFC overlay. One technique is to preplace the PDS stripes and then place the pavement around the stripes. This technique was used successfully in this project. The other technique is to place the new OGAFC overlay and then groove and place the PDS as described previously.

If the PDS stripes are preplaced, then the technique described in Section 5.3 of this report would be appropriate. The step-by-step procedure would be as follows:

1. place adhesive at proper stripe location
2. place prefabricated blocks of PDS
3. place protective layer of tape on top of PDS stripe
4. place OGAFC overlay
5. remove protective layer from top of PDS stripe.