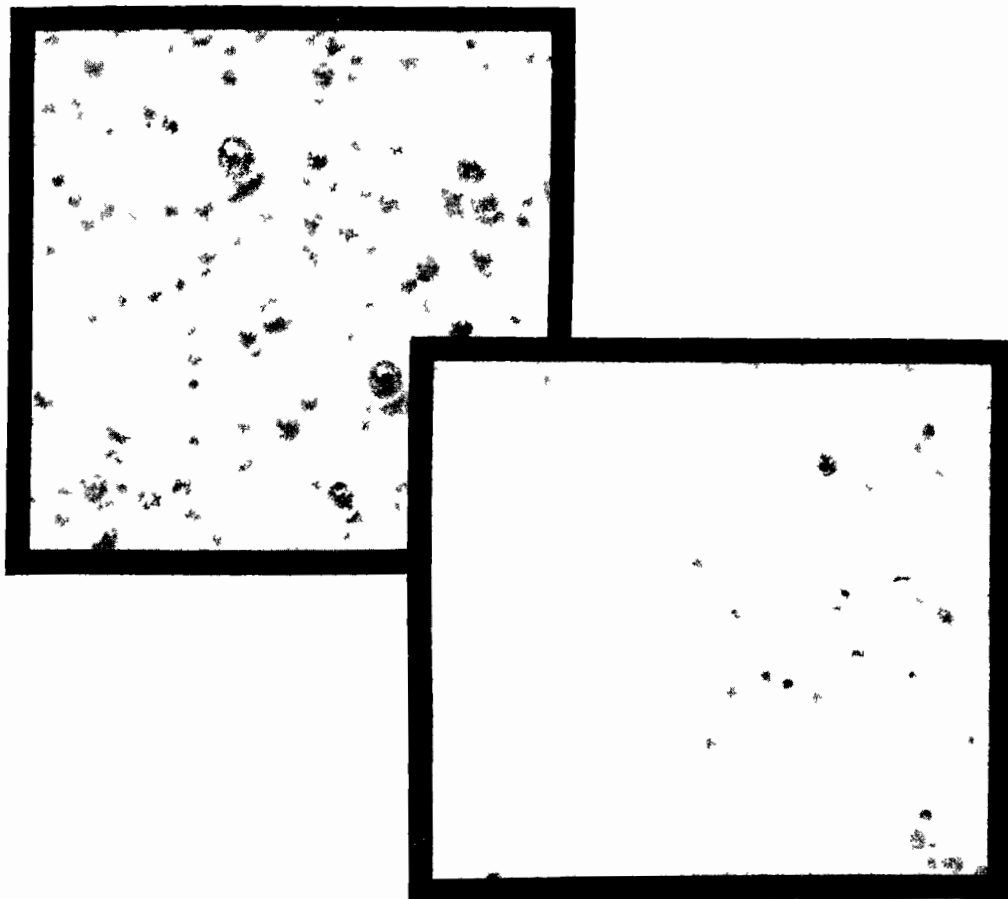


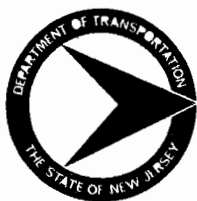
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FOLLOW-UP STUDY: FLOATING GLASS BEADS FOR TRAFFIC STRIPES



**A FINAL REPORT
MARCH 1977**

**The New Jersey Department of Transportation
Division of Research and Development
In Cooperation With
The U S Department of Transportation
Federal Highway Administration**



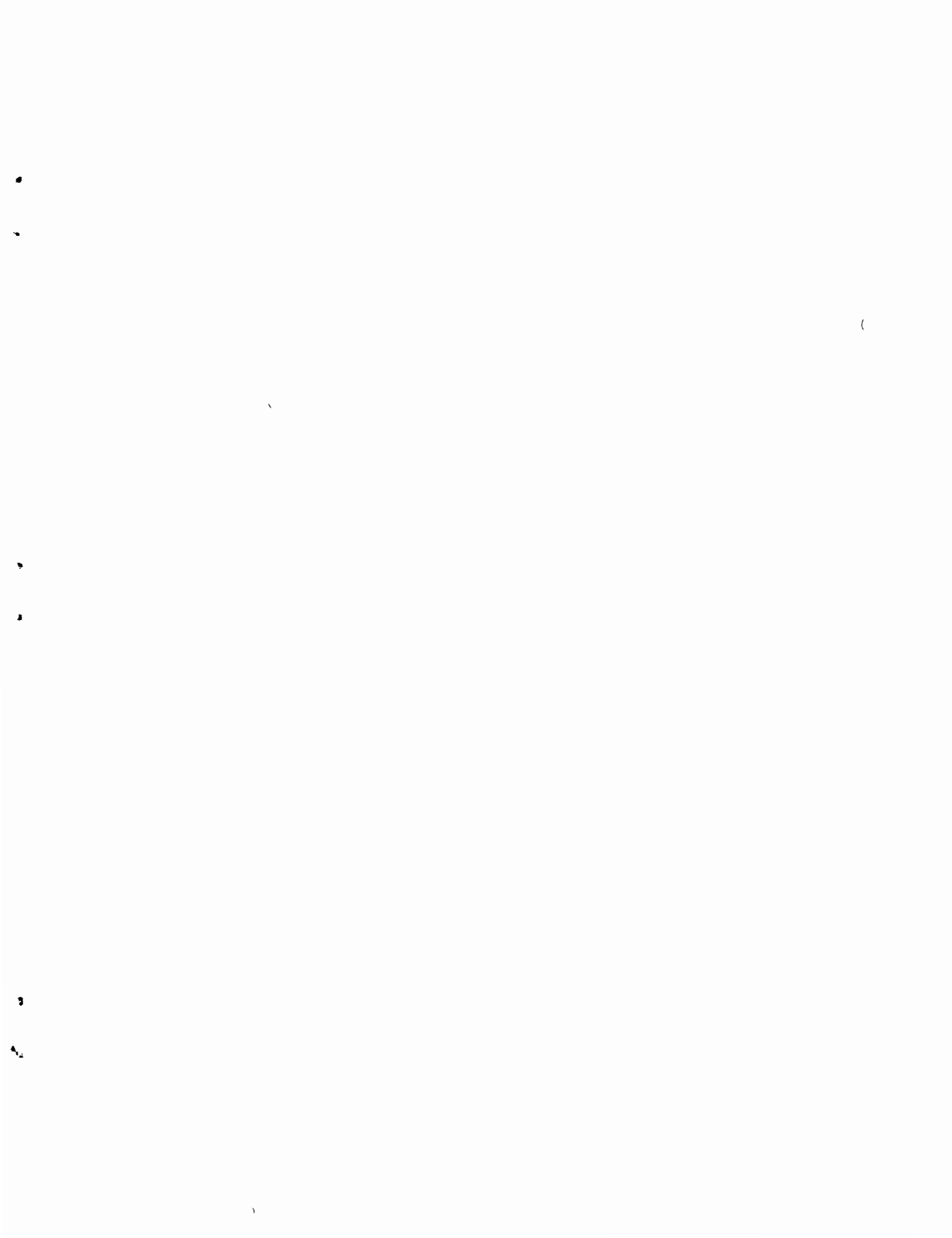


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<p>16 Abstract A previous New Jersey study indicated that a new type of specially graded, "flotation" coated reflective glass bead provided improved traffic stripe performance when applied by gravity feed to a conventional slow-drying paint. This report presents the results of a follow-up study undertaken to determine if the pneumatic pressure bead application technique required for the State's current fast-drying paint would negate the night visibility advantage previously observed for the special bead.</p> <p>The beads studied were of four types: the conventional wide-gradation beads with and without the flotation treatment and uniformly-graded floating and non-floating beads. The various beads were applied as lanelines and edgelines on both concrete and bituminous pavements. Night visibility measurements were made with a Colorado-type photometer. A series of special night visibility photographs were taken to complement these instrument measurements of stripe brightness. Conventional close-up photographs were made to assess the relative embedment of the beads.</p> <p>The collected night visibility data indicates that uniformly-graded, flotation coated glass beads applied using N.J.'s conventional (pneumatic pressure) equipment yield traffic stripes of greater brightness than those reflectorized with any of the other bead types studied. It is recommended that the state adopt the use of the special beads applied at 4 lbs/gallon on blacktop and 5 lbs/gallon on concrete. If adjusting bead application rate to the predominant pavement type is not deemed feasible by Maintenance, 4 lbs/gallon should be used on both pavement types.</p>			
17 Key Words Traffic Stripes, Pavement Marking, Glass Beads, Night Visibility, Roadway Delineation		18 Distribution Statement Copies available on request	
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Karl Brodtman, Principal Research Engineer, assisted in the collection of photocell data

Richard Weed, Principal Research Engineer, designed the night visibility photography apparatus

Mr Weed and Brian Margerum, Research Assistant, did the report photography

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PART ONE INTRODUCTION

1 1 RESEARCH OBJECTIVE

This report presents the results of a study undertaken to determine the suitability of using a pressure application technique to reflectorize traffic lines with glass beads having a special flotation coating

1 2 BACKGROUND

1 2 1 Earlier New Jersey Studies

A previous, two-year New Jersey research study (1) indicated that traffic stripes reflectorized with a new type of glass bead gave improved night visibility relative to that provided by our standard well-graded (i.e., mixed size) beads. The new beads differed from the standard in that they were of a relatively uniform, smaller size and were specially coated to prevent them from sinking in freshly applied paint. The visibility improvement observed for these uniformly-graded, floating beads was attributed to greater bead exposure caused by the flotation characteristic and improved bead retention due to bead sizing. The large beads in the conventional gradation were observed to dislodge at a relatively early stage of service, leaving only small beads of various degrees of embedment in the paint film available to provide reflectivity.

In the earlier study, the floating beads were applied by gravity feed to a paint binder having a specified maximum drying time of 15 minutes. Significantly, due in part to the reduced availability of a major ingredient of our then-current paint, New Jersey converted to the use of a paint formulation having a fast-drying* property (5 minutes maximum) soon after the bead study was completed. Such fast-dry paint (pre-heated to 90-125°F) reportedly requires a pressure rather than a drop-on application technique. Since the influence of a pressure application on the performance of the floating beads was not known, the recommended conversion to the use of the new beads was not implemented. The principal objective in undertaking this follow-up study was to determine if pneumatically-applied flotation beads will be forced into the paint film and lose their previously observed performance advantages.

Apart from investigating the influence of application technique on bead performance, a second reason for undertaking the present work was to determine the "optimum" application rate for floating glass beads applied to traffic lines on concrete pavement. That is, based on the findings of the earlier study, different application rates for flotation beads were recommended for use on New Jersey's bituminous and concrete pavements (4 and 6 pounds per gallon, respectively). While the 6 pound application rate for lines on concrete had a favorable benefit/cost ratio to justify its use, there were indications that a lesser rate might provide a satisfactory performance/economy compromise.

*Relative terms used to describe paint drying times are (reference 2)

instant dry	30 seconds or less
quick dry	30-120 seconds
fast dry	2-7 minutes
conventional	more than 7 minutes

1 2 2 Bead Studies and Usage by Other Agencies

The first state study of uniformly-graded, floating beads was by Colorado⁽³⁾ Due in part to the encouragement of the FHWA^(4,5), a considerable number of agencies have subsequently evaluated the performance and economy of various combinations of bead flotation, gradation, and application rate⁽⁶⁻¹⁵⁾

Currently, twelve states* reportedly satisfy all or part of their bead requirements using the small, flotation beads and two states** specify similarly sized, non-floating glass The great majority of states specify the conventional wide-gradation, non-floating beads

The uniformly-graded flotation beads are a premium priced product, reportedly costing about 2 to 3 cents per pound more than the (13 5 cents/pound) conventional beads This higher price results from the cost of imparting the flotation treatment and providing a restricted gradation. Bead sizing is a factor since the gradation specification for conventional beads largely coincides with the production gradation

A major factor commonly entering into the using state's decision to adopt the flotation beads is that the newer type beads provide equal or superior performance to the conventional beads even when applied at a reduced rate (e g , at 4 rather than the usual 6 pounds per gallon) This reduction in application rate in some

*Arkansas, Colorado, Illinois, Iowa, Missouri, Nebraska, New Hampshire, New Mexico, North Carolina, North Dakota, South Dakota, and Wyoming

**Delaware and Florida [source of information bead vendor]

instances results in a substantial net cost savings (\$50,000 per year in Colorado) In New Jersey -- where the standard beads are applied at 5 pounds per gallon rather than at the 6 pound rate of other states -- improved performance rather than cost savings would be the principal stimulus for any changeover in bead types

1 2 3 Traffic Paint and Glass Beads Usage in New Jersey

The striping of the approximately 2,200 miles of state highways in New Jersey is currently accomplished exclusively by State maintenance forces at a total cost of slightly more than one million dollars per year

In 1976, the striping program entailed purchase of some 685,000 pounds of reflective glass beads at 13-1/2 cents per pound and 137,000 gallons of traffic paint at about \$3.90 per gallon These materials purchases (approximately \$92,000 for beads and \$534,000 for paint) represent about 60 percent of the total cost of the striping program

Use of these marking materials is divided almost equally on the basis of interior markings (i e , center plus lane lines) versus edge markings A 60%/40% materials usage ratio prevails with respect to both white versus yellow markings and blacktop versus concrete striping

The center and lanelines in high traffic volume areas are generally repainted twice yearly, while interior markings subject to low traffic volumes and edgelines usually receive a single yearly painting

1 3 RESEARCH APPROACH AND PROBLEMS

1 3 1 Bead Applications Studied

For this study, fast-dry (skrip) lanelines were reflectorized with uniformly-graded floating (UGF) beads pneumatically applied at rates varying from 3 to 7 pounds per gallon. Test sections containing these beads were placed on both concrete and bituminous pavement, each test section being approximately one-half mile long. The performance controls for the test applications of the special bead consisted of

- equivalent applications of similarly graded, non-floating (UGNF) beads
- New Jersey's standard (5 pound) application of well-graded, non-floating (NJS) beads
- a 5 pound application of well-graded, floating (NJSF) beads
- short sections of unbeaded paint

The purpose of including uniformly-graded and well-graded beads, with and without the flotation coating, was to gain information regarding the relative contribution of bead sizing and flotation characteristics to stripe performance.

In addition to the laneline applications, short (500 foot) sections of outside edgeline were also installed for each of the described bead types and application rates. It was expected that by obtaining performance data for both types of line, a more complete analysis of the economics of the different bead types and application rates could be made.

1 3 2 Problems Encountered

It was originally planned that the performance of the variously beaded traffic stripes considered in this study would be based on night visibility and durability data obtained by a variety of techniques and over the full service life of the lines. The following unfortunate occurrences frustrated these intentions:

- the edgelines at the test sites were obscured about one month after application due to contractor shoulder surface-treatment operations
- due to a change in maintenance foremen, the test lanelines were inadvertently repainted about two months after their application

As a consequence, except for one subsequent evaluation of lanelines on the concrete pavement test site, the night visibility determinations of this study were limited to measurement of the initial brightness of the various stripes.

While this limited data collection is obviously fatal to certain of the purposes of this study (i.e., lane versus edgeline performance/economy comparisons), it is believed that evaluation of the as-applied reflectivity does permit resolution of the central question of the study: "Do pneumatically-applied floating beads in fact float and provide improved brightness?" Further, as discussed later in this report, our research confirms that a pressure application

can be expected to result in bead embedment at least equal to that of a gravity application. Thus, given that the retention of a particular bead type under the action of traffic is a function of bead embedment, the current research suggests that our previous rather extensive observations regarding the durability of gravity applied beads might be used to make some reasonable estimates of the durability of pneumatic applied beads.

PART TWO NATURE OF THE TEST INSTALLATIONS

2 1 LAYOUT OF THE TEST SITES

The test striping program consisted of installing a total of twenty sections of lines beaded at various rates with floating and non-floating glass spheres and two sections of plain (unbeaded) paint. The striping was conducted at two locations, the pavement at one site (U S 1) being asphaltic concrete and at the other (N J 68), portland cement concrete. The individual beaded test sections consisted of one-half mile of lanelines (about 66 fifteen-foot white skip lines) and approximately 500 feet of edgeline.

A listing of the experimental bead applications achieved and the pertinent physical and traffic characteristics of the test sites are given in Tables 1 and 2.

2 2 STRIPING EQUIPMENT AND PROCEDURES

The installation of test stripes was accomplished using a conventional high-production, truck mounted striper. As shown in Figure 1, a small pressurized bead storage pot was used in lieu of the large on-board storage tanks. This modification permitted rapid changeover in bead types and application rates.

Table 1 Description of Service Testing Sites

Test Site	Route N J 68	Route U S 1
Pavement Type	Concrete	Bituminous
Location	Mansfield Township, Burlington County SB Beginning at Clauser Buick	W Windsor Township, Mercer County, NB Beginning at Bakers Basin
Pavement Age And Condition	28+ years Fair	15+years Fair
Roadway Type	4 lane divided (11 foot lanes)	4 lane divided (12 foot lanes)
Two-way Traffic	8,200 vpd	28,400 vpd 17° trucks

Table 2 Bead Application Schedule

Bead Type*	Nominal Application Rate (lbs/gal)	Bituminous Site		Concrete Site	
		Actual Rate (lbs/gal)	Test Section(s)	Actual Rate (lbs/gal)	Test Section
UGF	3	3 3	1-4	---	---
	4	4 3	1-5	3 7	68-1
	5	5 0,4 8	1-2,1-3	4 0	68-4
	6	6 2	1-8	6 5	68-6
	7	---	---	7 3	68-5
UGNF	1	4 3	1-6	3 5	68-2
	5	4 6,4 0	1-1,1-7	4 0	68-3
	6	6 2	1-0	6 5	68-7
NJS	5	4 7	1-10	5 2	68-8
NJSF	5	4 7	1-11	5 2	68-0
Unheaded	0	0	1-12	0	68-10

*The following abbreviations are used throughout this report

- UGF = Uniform Gradation, Floating
- UGNF = Uniform Gradation, Non-Floating
- NJS = New Jersey Standard
- NJSF = New Jersey Standard, Floating

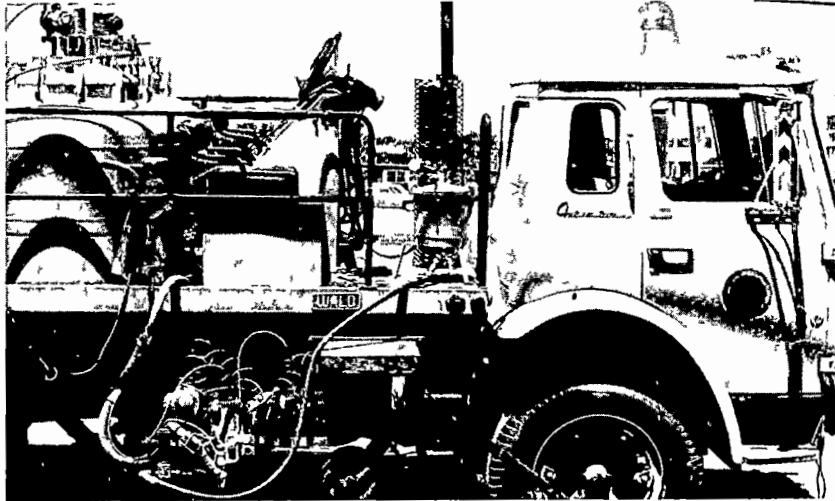


Figure 1 Test Stripper

Using this equipment, the rate at which beads are supplied to the paint depends upon the air pressure impressed on the system. Achieving the application rates desired in this work required use of air pressure ranging from 5 to 22 psi. The appropriate pressure setting for a particular bead type and application rate was determined from the results of a dry run. The actual application rate achieved on the lane line sections was calculated from the weight of beads used. Control of the quantity of beads supplied to the (variable length) companion edgeline sections was based on the pressure/weight calibration.

2.3 MATERIALS USED

The paint used was New Jersey Type IV (white) alkyd traffic paint having the composition limits shown in Table 3. Based on measurements of unbeaded paint applied to steel pick-up plates

placed in the path of the stripper, the paint was applied at the standard wet film thickness of 15 mils

A Paint Composition	
Pigment	48-50%
Vehicle	50-52%
B Pigment Composition	
Titanium Dioxide, Rutile	34-36%
Magnesium Silicate	30-32%
Calcium Carbonate	25-27%
Zinc Oxide	8-10%
C Vehicle Composition	
Alkyd Resin Solution	42%
Chlorinated Rubber	33%
Chlorinated Paraffin	25%
Volatiles (MEK)	49%(max)

The results of laboratory tests performed on the four types of beads studied are presented in Table 4. As indicated, the uniform gradation (40-80 mesh) flotation beads differ from their non-floating counterpart only with regard to the flotation property and a somewhat lower percentage of true spheres. The wide-gradation flotation (NJSF) beads contain a greater percentage of #50 sieve size (12+ mil) beads than the standard well-graded beads and a concomitant lesser percentage of the #100 sieve size (6+ mil)

Table 4 Glass Beads Laboratory Test Results

A Gradation Tests

Percent Retention on Current N J Specification Sieve Series						
	#16	#20	#30	#50	#100	Pan
	0*	0-2	5-28	35-65	15-40	0-5
NJS	0	0	13 8	58 1	26 2	1 9
NJSF	0	0 2	11 7	69 3	17 9	0 9

Percent Retention on Special Sieve Series				
	#30	#40	#80	Pan
UGNI	0	0 2	98 0	1 8
UGI	0 2	1 6	96 2	2 0

*Specification limits

B Other Tests

	Percent Flotation (Xylene) (1)	Percent Reflectance (2)	Percent Spheres (3)
NJS	--	53	73
NJSI	89	51	83
UGNI	--	56	92
UGI	92	58	80

(1) Special test method, beads floating in xylene are weighed Using states have required 90-95% Some also require 50% flotation in heptane

(2) ASTM E97, 55% minimum required

(3) ASTM D1155(B), 70% minimum required

PART THREE INSTRUMENTATION AND EVALUATION TECHNIQUES

3 1 PHOTOCELL DETERMINATIONS OF NIGHT VISIBILITY

3 1 1 Nature of the Equipment

The relative brightness or reflectivity of the variously beaded stripes was recorded using a photocell-based device similar to equipment developed by Colorado (3)

Various photocell measurement/panel rating comparisons performed in our earlier work indicated that the output of this device yields a valid measure of the relative visibility a traffic line provides to the highway user. Good agreement between visual night visibility ratings and the output of Colorado-type photometers has also been observed by other agencies, including (most recently) Kentucky (7) and New York (8)

The principal components of the night visibility apparatus are a sealed beam spotlight, recording electrometer, photocell and convex lens. The latter two components are housed in a metal tube in a telescope-like arrangement in which reflected light from the traffic stripes is admitted thru a front slot and focused on the photocell.

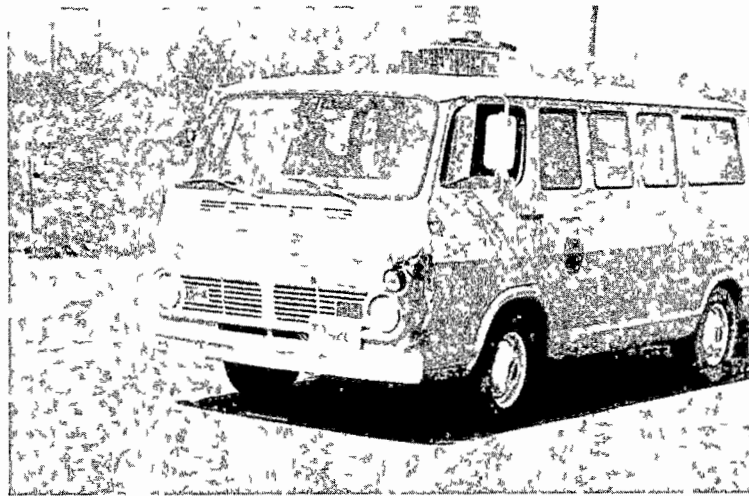


Figure 2· Photocell sensing tube and spotlight mounted on test van

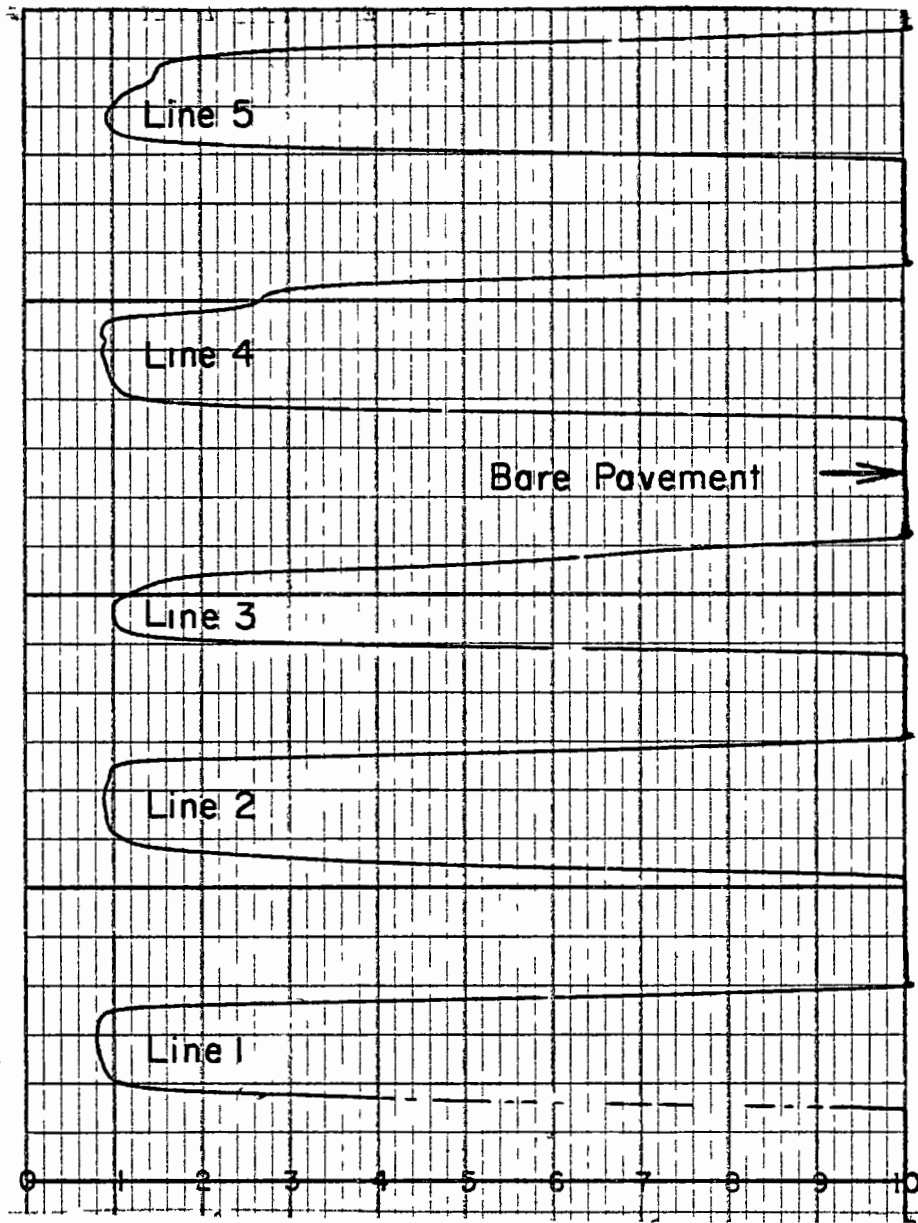
As shown in Figure 2, the sensing apparatus is mounted on a van at a height of about 3 feet above the pavement. The spotlight is focused on a point on the pavement about 10 feet in front of the van (approximate angle of incidence, 17°).

In collecting visibility data, the vehicle is driven over a test section at a speed of approximately five miles per hour with the spotlight centered over the stripes. Reflected light incident on the photocell is depicted on the electrometer strip chart recorder in terms of a resistance value, the indicated resistance being inversely proportional to stripe brightness.

3.1.2 Laneline Evaluation Procedure

A typical data record for freshly applied (skip) lanelines is shown in Figure 3. Each of the stripes shown are of approximately equal brightness.

Figure 3 Typical Record of Photocell Data for Skip lanelines



→ Increasing Resistance

← Increasing Brightness

To obtain a single brightness value representative of a given lane line test section, the resistance values of the individual lines comprising that section were averaged and transformed to a brightness unit using a conversion chart (a logarithmic curve) furnished by the photocell manufacturer. The brightness values ultimately assigned to the test sections were modified by the application of correction factors for temperature and instrument response. The latter correction consisted of relating test section measurements made on different dates to measurements made on a portable "Scotch-Lane" tape reference standard.

3 1 3 Edgeline Evaluation Procedure

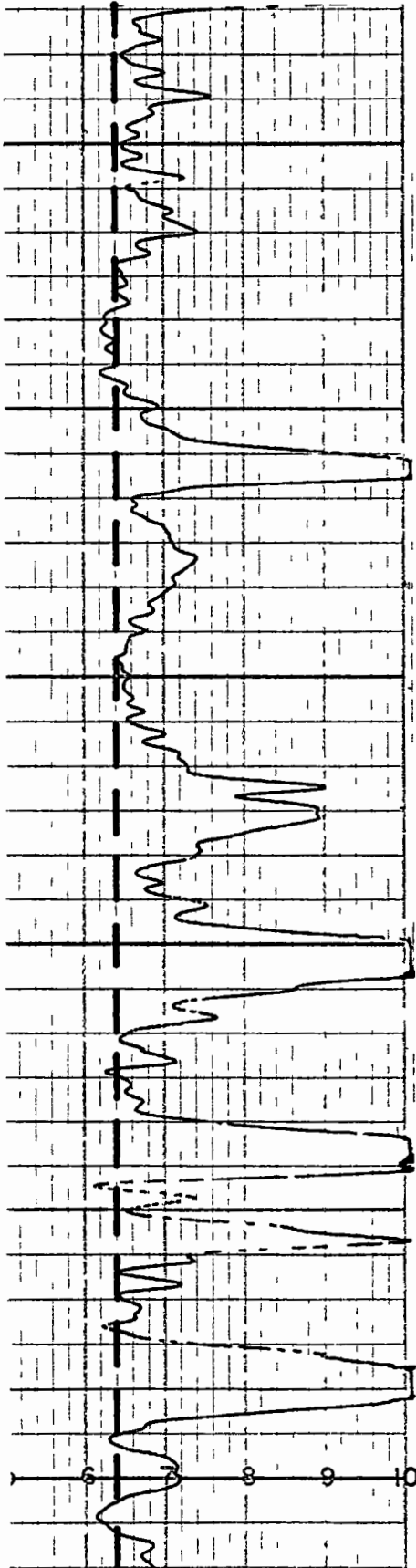
While the described determination of a representative brightness value for lane lines was quite straightforward, similar determinations for edgelines required somewhat different methods and an exercise of judgment. The necessity for interpretation resulted from two types of observed variation. First, differences in instrument response between lane and edgelines (i.e., differences in the way the photocell "sees" skip and continuous stripes) and second, and most importantly, differences in the consistency of brightness provided by certain bead types.

For example, Figures 4 and 5 show comparative photocell records for four newly applied edgeline test sections on concrete. Each chart represents measurements on about 225 feet of test line (i.e., 1" of record = 25' ± of test). The charts of Figure 4 are from test sections reflectorized with uniformly-graded, flotation beads applied at low and high rates (4 and 6 lbs/gallon), while Figure 5 presents

Figure 4 Photocell Data Records for Edgelines

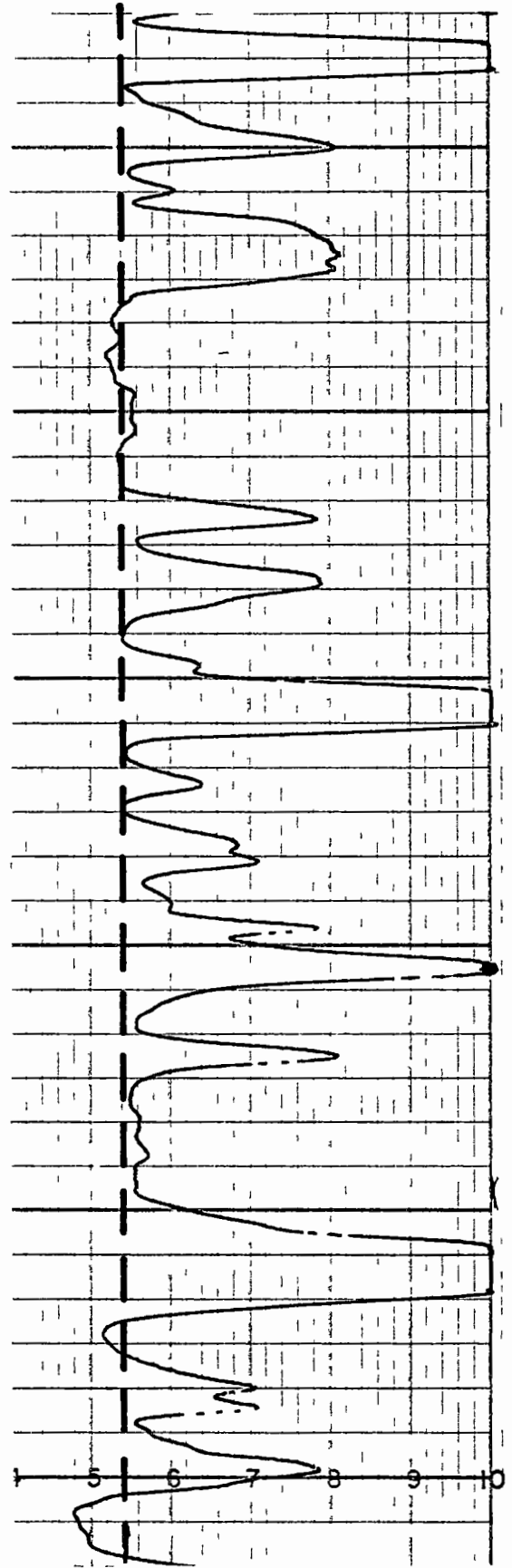
"A"

UGF @ 4 lb/gal
(Section 68-1)



"B"

UGF @ 6 lb/gal
(Section 68-6)



Scale

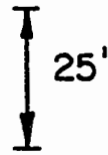
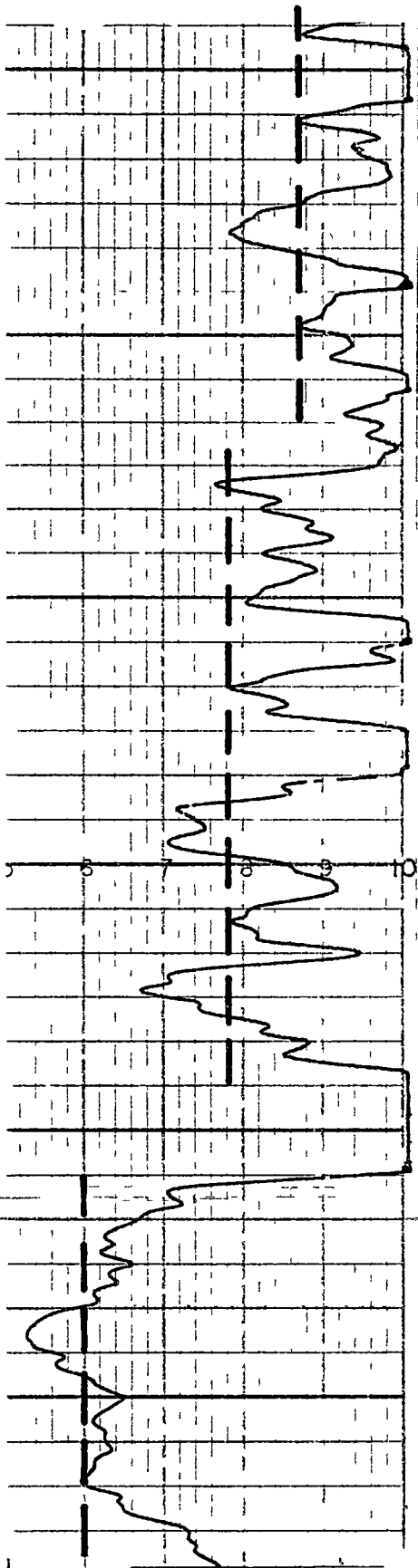


Figure 5 Photocell Data Records for Edgelines

"A"

UGNF @ 4 lb/gal

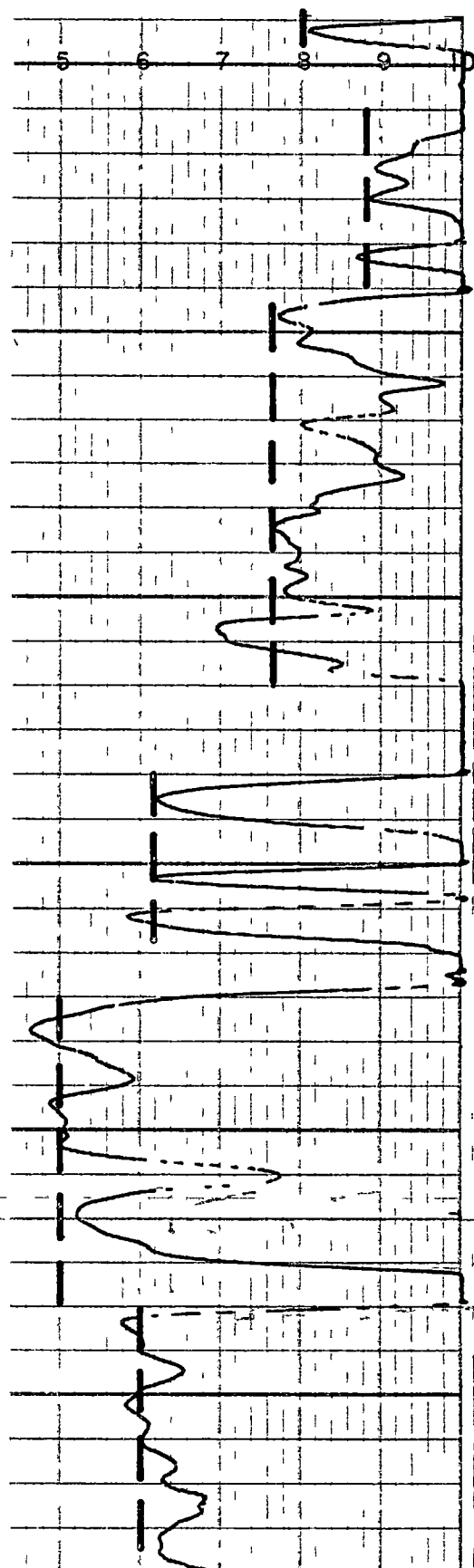
(Section 68-2)



"B"

UGNF @ 6 lb/gal

(Section 68-7)



Scale
↑
25'
↓

data records for similarly graded, non-floating beads applied at these same rates

Unlike the data for new skip lines -- where a single representative value is obtained for each stripe -- the continuous edgeline data of Figures 4 and 5 indicate brightness variations from place-to-place within the test section. Certainly to some extent, such variations are indicative of the natural variation of the application process. That is, in achieving a given average rate of application, it is to be expected that beads will be applied at higher and lower than average rates over particular (short) sections of line. It seems reasonable to assume that if such natural variation is within reasonable bounds, the resultant brightness differences would not be discerned by the motorist.

In the case of the flotation beaded lines of Figure 4, the measurement fluctuations indeed occur over a relatively short length and a single reasonably representative test value for each of the edgeline sections can be fairly chosen (the dotted line shown).

In contrast, there is no discernible single measured value which characterizes the data for the non-flotation beads edgelines of Figure 5. Consequently, to determine a representative measurement for edgeline sections containing this type bead, the test chart was divided into subsections as shown, and a weighted* average resistance calculated. This average resistance value was then converted to a brightness equivalent using the technique described earlier.

$$\text{*Average resistance} = \frac{\sum \text{Subsection length} \times \text{resistance}}{\sum \text{Subsection lengths}}$$

The obvious implication of these distinctly different data patterns for the flotation and non-flotation beads edgelines is that the markings reflectorized with the latter bead type display considerably more brightness variation along the length of the stripe. Close-up photos presented later in this report indicate that this variable reflectivity is a result of the small, non-floating beads sinking into the paint film.

When the edgeline data was being obtained, the writer thought that it would facilitate interpretation of the data records if the natural fluctuations shown in Figures 4 and 5 were damped out to some extent. Consequently, for the last few concrete pavement edgeline test sections and for all of the bituminous edgeline sections, a different (less sensitive) electrometer setting was used. Unfortunately, this apparently resulted in unreliable edgeline readings for the flexible pavement section. That is, the freshly applied edgeline test sections on the bituminous site were indicated to be of a generally uniform level of brightness, and substantially less bright than the corresponding new lanelines. As indicated in night visibility photographs presented later in this report, no such marked difference between these edge and laneline sections was apparent. In the writer's judgment then, the laneline reflectivity data is most representative of the actual brightness of both types of markings (lane and edge) for the bituminous site.

3 2 NIGHT VISIBILITY PHOTOGRAPHY

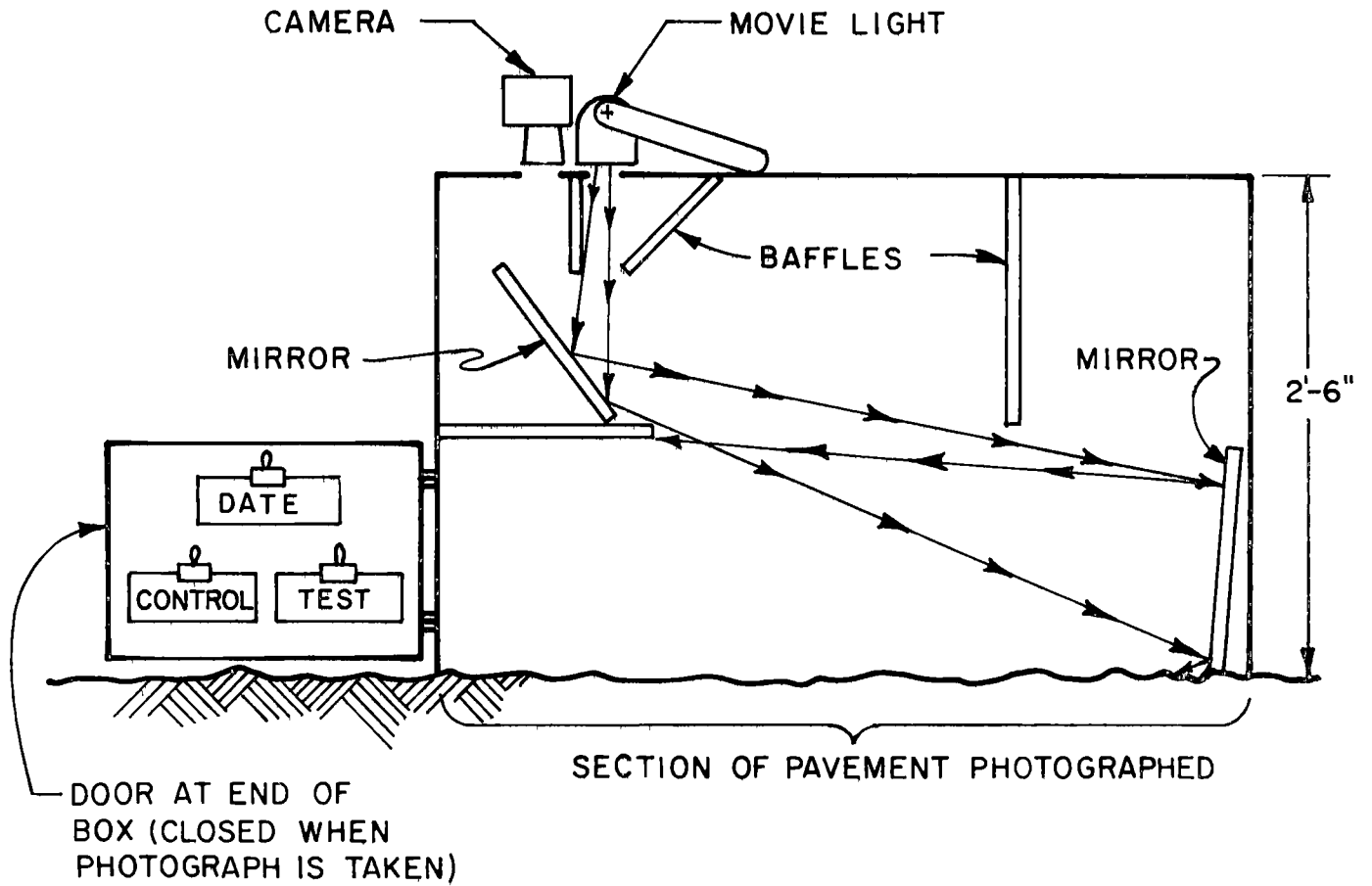
The described photometer determinations have an obvious disadvantage in a report context in that the reader unfamiliar with the photocell equipment may have little "feel" for the significance of the various relative brightness measurements. Consequently, to provide a complementary (visual) record of the appearance of the various stripes studied, an apparatus was devised which permitted the lines to be photographed during the day under simulated night viewing conditions.

As shown in the schematic of Figure 6, this homemade "black box" apparatus for photographing traffic lines consists of an open-bottomed wooden box fitted with various interior baffles and mirrors. The latter are positioned such that when the box is placed over a four-foot section of stripe, the camera views the line at an angle of approximately 5 degrees. A strip of "Scotch-lane" tape, permanently mounted in the bottom of the box, provides an adjacent brightness reference in the photo. Illumination is provided by a movie light powered by an inverter connected to a car battery (Figure 7).

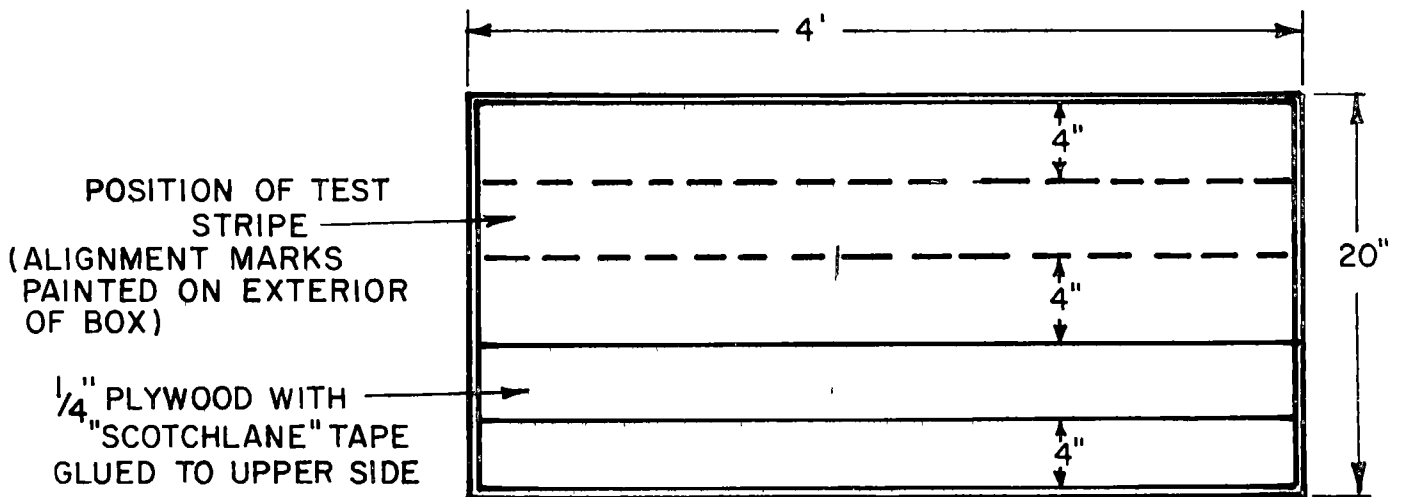
Example photographs made with the black box are shown in Figure 8. The particular stripes shown are two-month old lanelines on concrete pavement. Figure 8A shows a plain (unbeaded) paint stripe and Figure 8B is a stripe reflectorized with New Jersey's standard beads applied at the normal 5 pounds per gallon. Photocell measurements made two weeks prior to these photos indicated an average relative

Figure 6: "Black Box" for Evaluating Traffic Stripes

A. SECTIONAL VIEW



B. BOTTOM VIEW (PARTIAL)



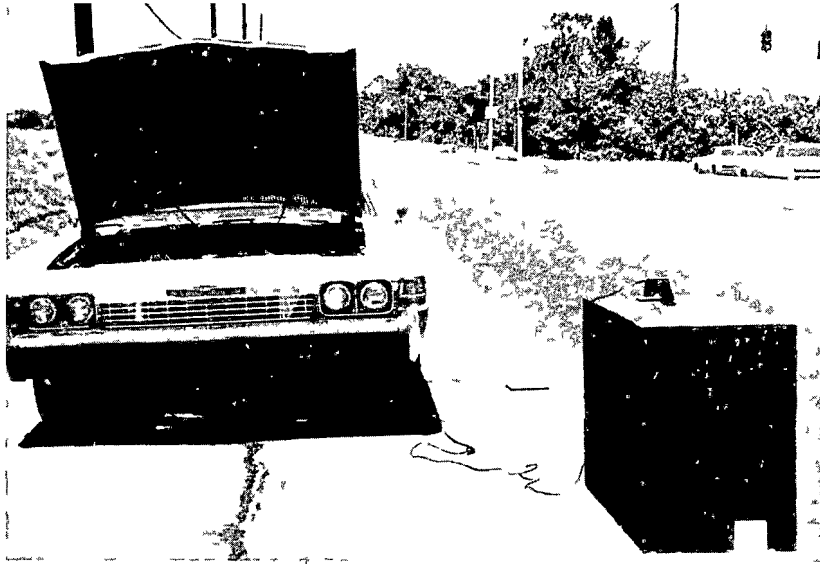


Figure 7 Apparatus for simulated night visibility photographs

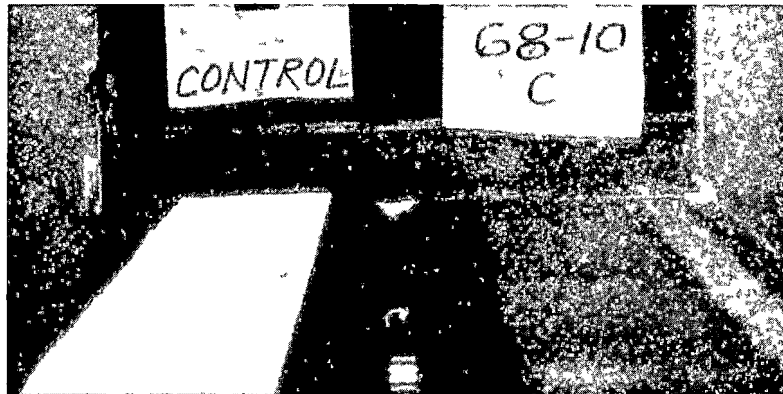


Figure 8A Appearance of unbeaded laneline after two months service

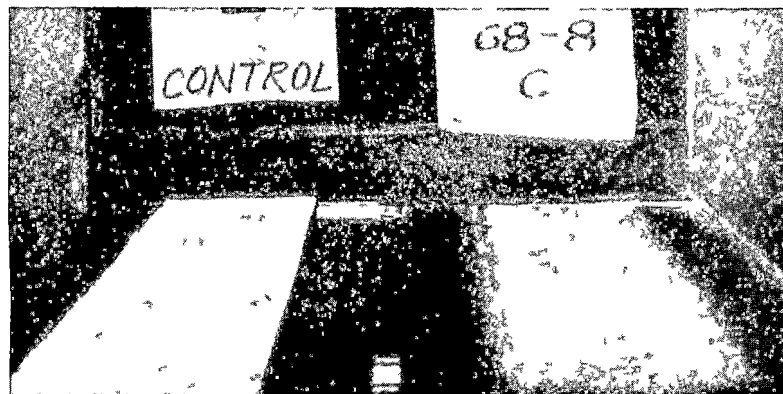


Figure 8B Appearance of standard beads laneline after two months service

brightness rating of 10 units for the "Scotch-lane" control, 2-1/2 units for the standard beads section, and 1 unit for the unbeaded stripes

In the present study, one laneline and one edgeline location per test section were randomly chosen for photography. As previously noted, photocell measurements indicate that considerable within-test section brightness variation can occur, at least in the case of edgelines. It thus would seem advisable that if black box photos were to be relied on as the predominant measure of line performance in a future study, the photos should be taken according to some type of formalized sampling plan.

3.3 BEAD EMBEDMENT PHOTOGRAPHY

Close-up photographs (approximately 8X magnification) were made in each of the lane and edgeline test sections to assist in assessing the relative embedment of the various flotation and non-flotation beads. These photos were taken at the time and place of the "black box" photography.

PART FOUR TEST RESULTS AND DISCUSSION

4 1 EVALUATION OF PHOTOMETER DATA

4 1 1 General

The photocell brightness data obtained in this work are tabulated in Table 5 and plotted in Figures 9 and 10.

For the test stripes on concrete pavement, the data comprises an evaluation of the reflectivity of freshly-applied lane and edgelines and of lanelines after 1-1/2 months service. The photocell data for the bituminous test site consists of a determination of the initial brightness of the variously beaded lanelines

As indicated in Table 5, the observed relative brightness values range from a high of ten brightness units for the "Scotch-lane" reference tape to lows of about one unit for plain (unbeaded) paint and one-tenth unit for (bare) bituminous pavement. The average initial brightness of the individual test sections ranged from about one-third to two-thirds that of the "Scotch-lane" reference or, in other words, from about 3 to 7 units on the 10 unit brightness scale

On an overall (entire test site) basis, the stripes on both pavement types displayed similar levels of brightness (i.e., the simple average of all test section measurements is about 4 units). These similar average photometric readings do not mean, however, that the stripes were generally equally as visible to the human eye on the two pavement types. That is, given that traffic lines are apparently visually distinguished by contrast*, it follows that a stripe of a

*brightness contrast may be defined as

$$C = \frac{B_L - B_p}{B_p} \quad \text{where } B_L = \text{Traffic Stripe Brightness}$$
$$B_p = \text{Pavement Brightness}$$

Table 5

Data Summary Photocell Evaluation of Night Visibility

A Traffic Stripes on BITUMINOUS Pavement

Bead Type	Nominal Application Rate (lbs/gallon)	Test Section(s)	Relative Brightness*	
			7 Days Service Lanelines	
UGF	3	1-4	3 0	
	4	1-5	6 8	
	5	1-2,1-3	5 2,5 1	
	6	1-8	3 9	
UGNF	4	1-6	6 5	
	5	1-1,1-7	3 8,4 1	
	6	1-9	3 3	
NJSF	5	1-11	3 0	
NJS	5	1-10	2 7	
Unbeaded	0	1-12	1 0	
Pavement Background			0 13	

*Units foot-lamberts

B Traffic Stripes on CONCRETE Pavement

Bead Type	Nominal Application Rate (lbs/gallon)	Test Section	Relative Brightness		
			7 Days Service		49 Days Service Lanelines
			Lanelines	Edgelines	
UGF	4	68-1	4 0	3 8	4 2
	5	68-4	5 3	6 0	5 3
	6	68-6	4 5	4 5	4 7
	7	68-5	6 5	5 2	6 7
UGNF	4	68-2	3 3	3 5	3 1
	5	68-3	3 4	3 8	3 1
	6	68-7	3 6	3 6	2 8
NJSF	5	68-9	4 7	4 4*	3 9
NJS	5	68-8	3 3	4 2*	2 4
Unbeaded	0	68-10	1 3	1 5*	1 3
Pavement Background			0 48		0 43
"Scotchlane" Reference			10 0		10 0

*Obtained using different recorder setting

Figure 9 Relative Brightness of Traffic Stripes on Bituminous Pavement
(one-week old lanelines)

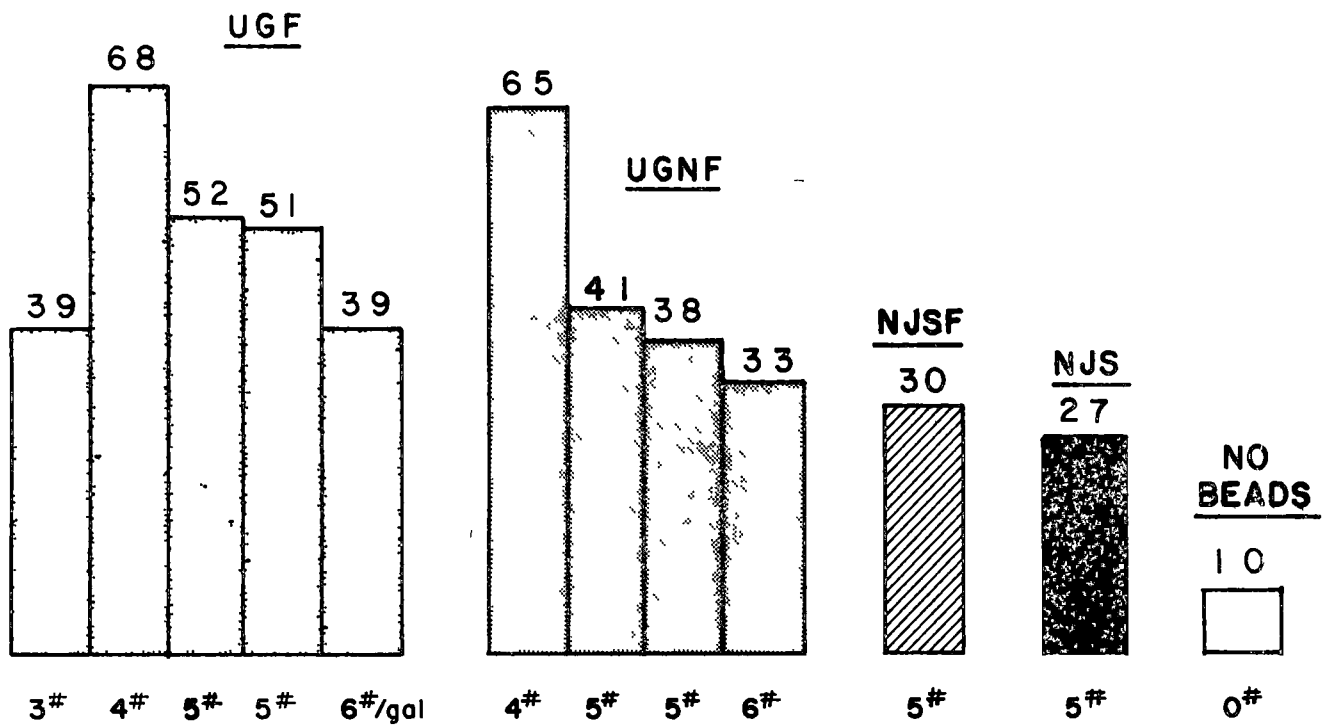
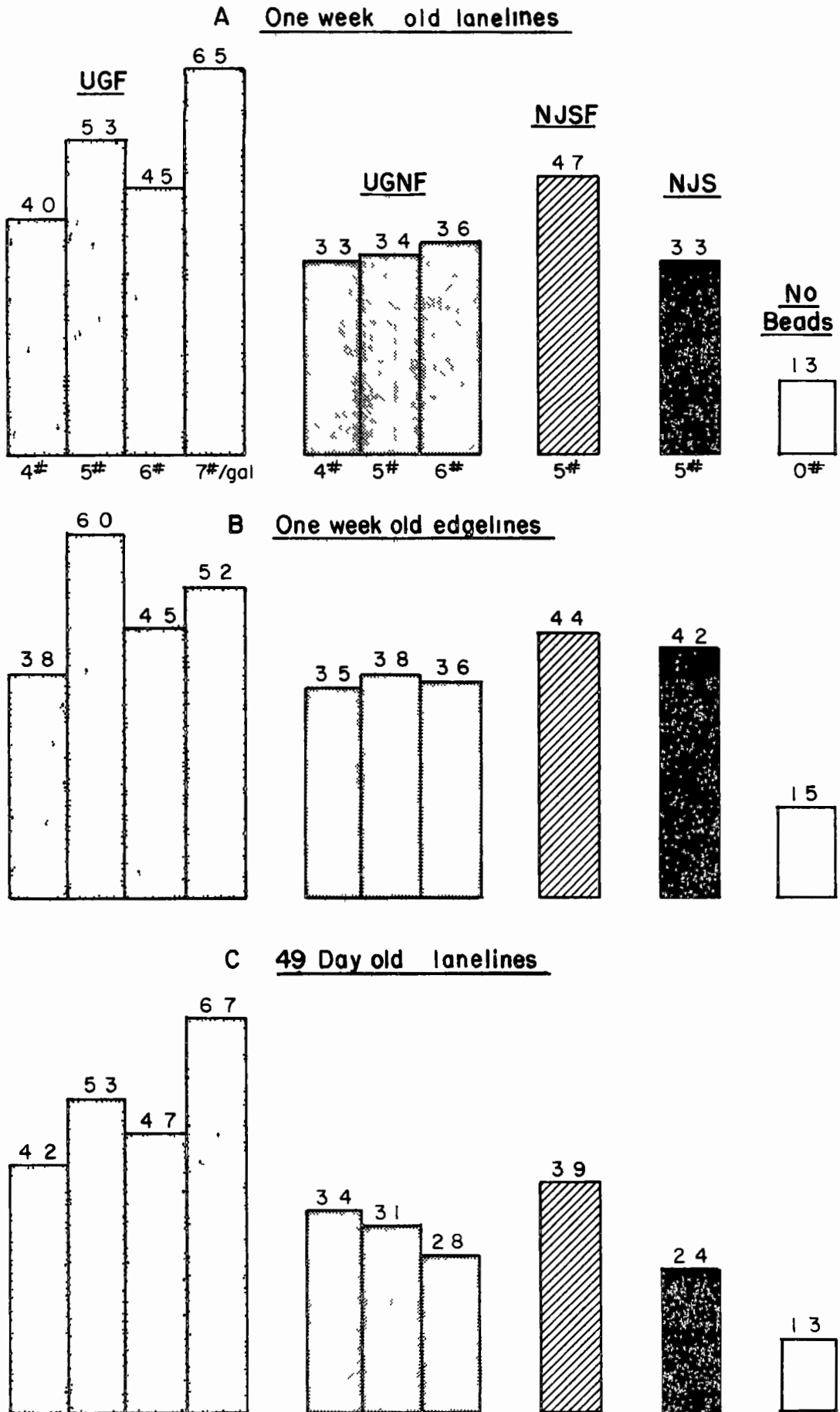


FIGURE 10 Relative Brightness of Traffic Stripes on Concrete Pavement



particular measured brightness level on concrete would be less visible than a line of similar brightness on bituminous pavement. Similarly, and more importantly in the context of this report, a given brightness difference between bead types or application rates will generally be less discernible for stripes on concrete pavement. In our earlier study, for example, while surprisingly small differences in measured brightness for stripes on bituminous pavement were visually distinguishable by field rating panels (i.e., photocell differences on the order of 10-15%), at least twice as great a relative difference in measured brightness (i.e., 30-35%) was generally required for these same observers to differentiate between lines on concrete pavement*

4 1 2 Performance of Standard Beads (NJS)

The test sections reflectorized with New Jersey's presently specified beads generally provided a lower level of initial night visibility than sections beaded with the other three types of glass spheres, particularly on bituminous pavement.

As indicated in Figure 9, when applied to stripes on blacktop, the standard (NJS) beads and similarly-sized, flotation coated (NJSF) beads provided nearly the same average brightness of about 3 units

*While this historical data serves as a useful guide as to what constitutes a "significant" difference in photometer data, the extent to which particular lines are in fact visually distinguishable will depend on a number of factors (e.g., the general level of visibility provided). For example, the greater disparity between photometric and user ratings for lines on concrete pavement observed in our earlier work was due in part to the uniformly low order of visibility provided by many of these stripes in the later stages of service.

This average value for wide-gradation beads is about one to four units lower than that indicated for equivalent or lighter applications of either type of the uniformly-graded beads (i.e., floating and non-floating)

On the concrete pavement site (Figure 10), the standard bead test sections were indicated to be initially of equal or slightly greater brightness than the various applications of the small size, non-floating (UGNF) beads and about the same as the mixed-size, floating (NJSF) beads edgelines. However, the standard beads lane and edge markings displayed about two units less brightness than an equivalent (5 pound) application of the uniformly-graded floating beads.

After about 1-1/2 months service on the relatively lightly travelled* concrete pavement test site, the reflectivity of the standard bead lanelines decreased by about 25% [from 3.3 to 2.4 units], providing the lowest measured level of reflectivity of any of the beaded lines.

4.1.3 Performance of N.J. Standard Gradation Beads with Flotation Property (NJSF)

As indicated in Figures 9 and 10, the initial reflectivity provided by flotation beads sized similar to the standard beads generally differed with pavement type.

As noted in the preceding report section, on the bituminous test site, photocell data indicates that the addition of a flotation

*AADT 8,200 vpd versus New Jersey's "average" of more than 17,000 vpd

treatment to the standard size beads provided little overall increase (0.3 units) in initial visibility. The standard beads with and without flotation displayed about the same (low) average measured brightness.

On concrete pavement, the wide-gradation floating beads provided lanes with one of the higher brightness levels (4.7 units), about 1-1/2 units (50%) greater than their non-floating gradation counterpart. In the case of concrete pavement edgelines, however, only a small difference in measured brightness is indicated for these two bead types (4.4 vs 4.2 units).

While the writer can offer no explanation for the observed difference in initial visibility for this NJSF bead type between concrete and bituminous pavement lanes, it is interesting to note that similar -- indeed, more pronounced -- differences were observed in our previous tests of a similar bead. Specifically, earlier applications of well-graded, floating beads to traffic stripes on concrete pavement yielded one of the better performances throughout the period of study, displaying as much as 2/3 greater brightness than the standard beads at certain stages. On bituminous pavement, however, lanes reflectorized with these beads provided the poorest visibility, being only half as bright as the standard beads after three months service.

Close-up photographs of these earlier-studied, mixed-size floating beads indicated that the marked differences in performance were initially due to associated substantial differences in bead embedment. That is, for some reason -- possibly related to pavement

surface texture differences -- these beads were relatively well-exposed when applied to stripes on concrete, but were generally submerged in the paint film when applied to the more open or porous surface of bituminous pavement

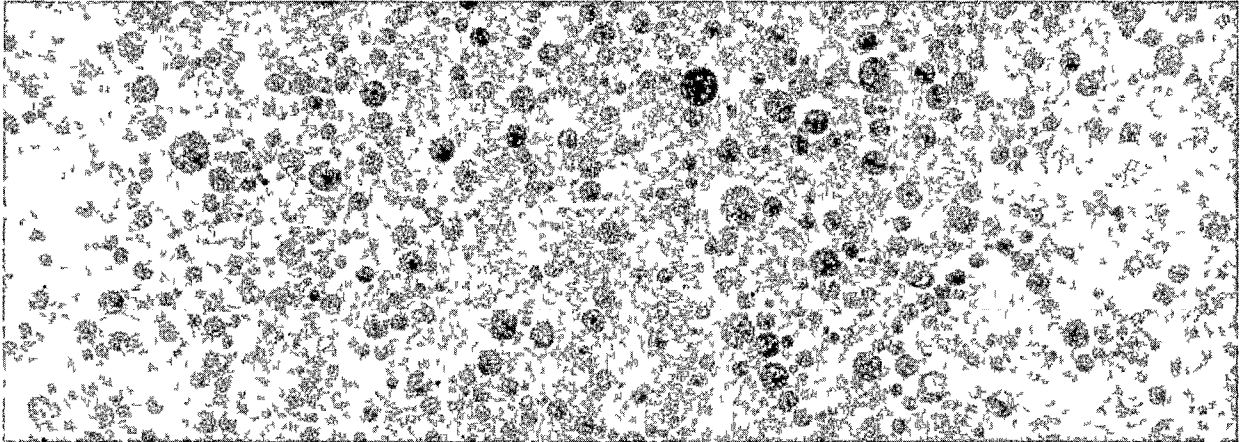
As suggested earlier, however, similar close-ups of the NJSF beads studied in the present research do not indicate these substantial differences in bead exposure between stripes on concrete and bituminous pavement. As shown in Figure 11, the only obvious difference among the photos of the mixed-size flotation beads is that at the place photographed on the bituminous edgeline (representing about 1-1/2 square inches of stripe), relatively few of the finer bead fraction are apparent.

4 1 4 Performance of Uniformly-Graded, Floating Beads (UGF)

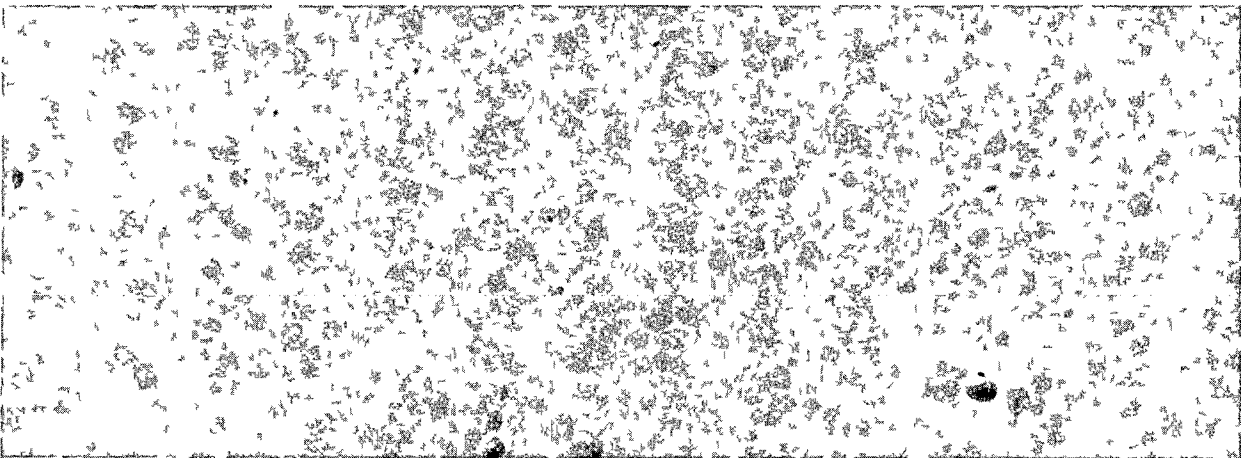
As in our earlier tests of gravity-applied beads, the highest level of initial night visibility and most consistent brightness advantage compared to New Jersey's standard beads is indicated for test sections reflectorized with uniformly-graded, floating (UGF) beads.

The most significant improvement for these newer type beads was observed on bituminous pavement. As indicated in Figure 9, UGF beads applied at each of the studied rates -- 3 thru 6 pounds per gallon -- provided greater initial brightness than the standard beads. The greatest improvement for the UGF beads -- 4 units higher brightness than the standard beads -- was provided by the intermediate application

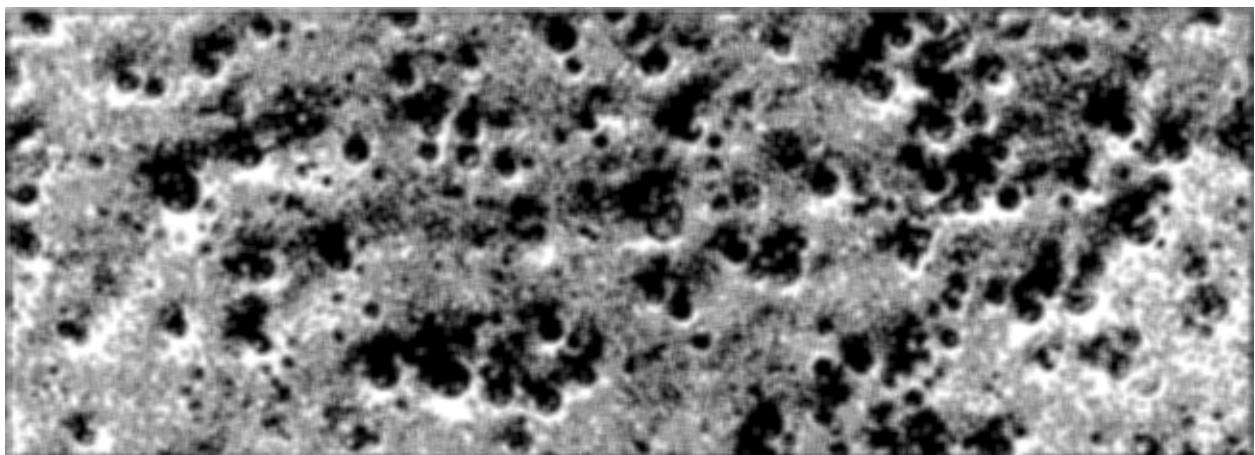
Figure II Appearance of Standard Gradation
Flotation-Treated Beads



A. Laneline on Concrete



B Laneline on Blacktop



C Edgeline on Blacktop

rate of 4 pounds per gallon. Increases in the rate of application of UGF beads above this optimum 4 pound rate resulted in successive decreases in measured brightness.

As shown in Figure 10, a different relationship between initial brightness and application rate is indicated for the UGF beads when applied to stripes on concrete. On rigid pavement, measured reflectivity increases for application rates above 4 pounds per gallon. Based on the initial visibility data of Figures 10A and 10B, the application rate of choice for pneumatically applied UGF beads on concrete is 5 pounds per gallon, since this rate yielded greater brightness than either the 4 or the 6 pound applications and nearly the same as a more costly 7 pound application. In comparison to an equivalent (5 pound) application of the standard beads, the small floating beads displayed about 2 units (50%) greater initial brightness.

It is to be noted that our earlier study also indicated that the effect of increasing the rate of application of uniformly-graded floating beads above a nominal four pounds per gallon is not the same on both pavement types. This differing behavior was additionally exhibited by the uniformly-graded non-floating glass. Indeed, the finding that the 40-80 mesh beads provided better overall performance when applied at 6 rather than 4 pounds on concrete and at 4 rather than 6 pounds on blacktop was the basis for recommending use of different application rates for UGF beads on the two pavement types.

In the previous New Jersey study, these differences in performance in the later stages of service were ascribed to the distinctly different traffic stripe failure modes on the two pavement types (i.e., better bead retention in the chipping failure on concrete compared to the abrasion failure on blacktop). While the reasons for the difference in initial brightness between low and high application rates on concrete and blacktop are not known, another state(16) which has observed similar (albeit less pronounced) trends has suggested that an optical interference ("shadowing") effect(17) may take place when high rates of application of the small, essentially single-size beads are attempted. However, while such bead "shadowing" may take place, the fact that the effect is different for concrete and blacktop clearly suggests that other factors (again, possibly surface texture*) must contribute to the result.

To return to the findings of the current research, Figure 10C depicts the reflectance levels of UGF beads after about 1-1/2 months service on rigid pavement. As shown, the reflectivity of the various concrete pavement lane line sections reflectorized with UGF beads remained essentially unchanged from their initial values, while the brightness of the standard bead section decreased by nearly one unit. Consequently, at this stage of service, each of the UGF test sections displayed an even greater brightness advantage compared to the standard beads, this difference amounting to about 3 units (a reading of 5.3

*In addition to any inherent pavement textural differences, a related factor is that the actual substrate for new lines on concrete is often (as in this study) a relatively substantial remnant of an existing stripe, whereas stripes on blacktop are usually placed on a more heavily abraded stripe or bare pavement.

versus 2 4) in the particular case of the 5 pound application

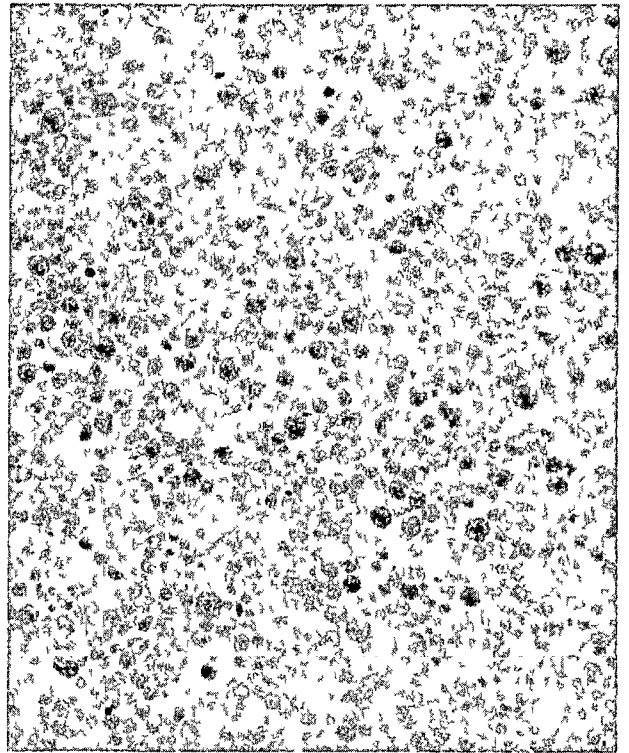
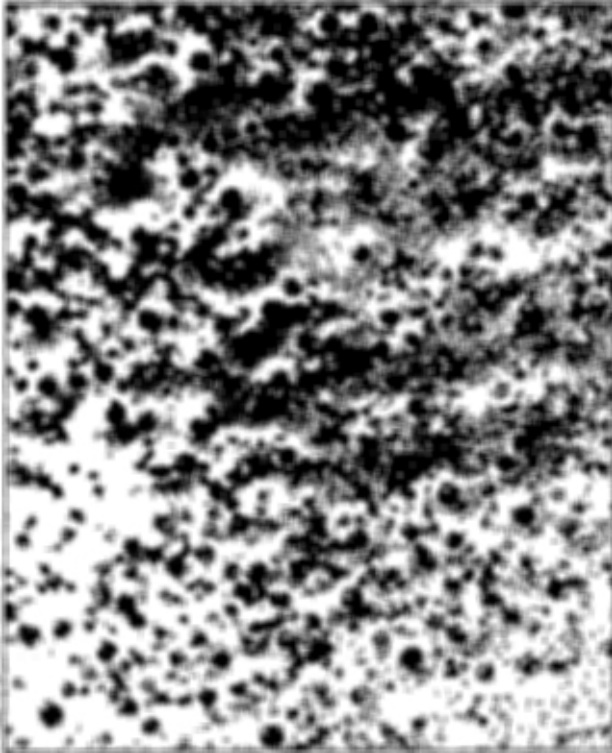
While the initial reflectivity results suggest an answer to the research question "Do pressure applied UGF beads in fact float?", a specific indication in this regard can be obtained from examination of Figures 12 and 13. These figures present close-up photos (8x magnification) of the uniformly-graded beads with and without the flotation treatment applied at low and high rates on both pavement types.

Although the degree of embedment of individual beads is obviously difficult to gauge in the photographs, it is evident that on both pavement types, the flotation-treated bead sections generally display greater overall bead exposure and reflective surface area than that of their non-floating counterpart.

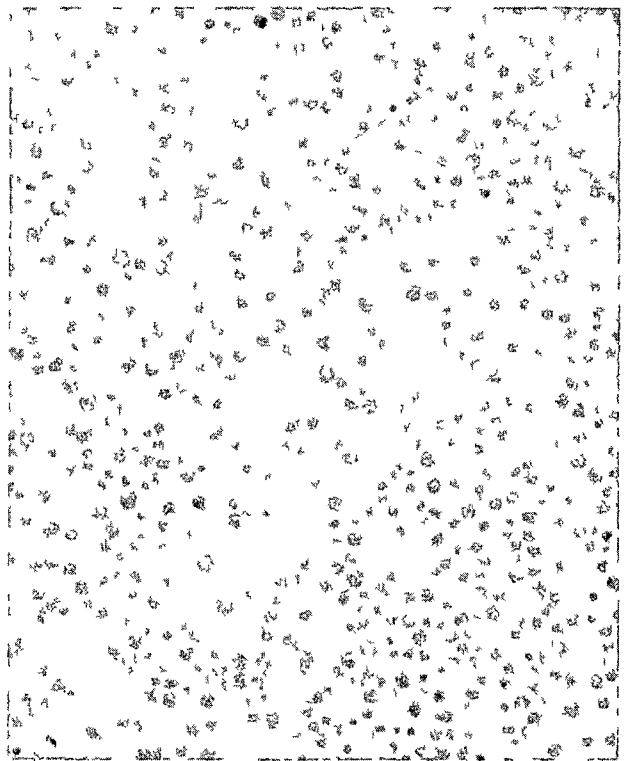
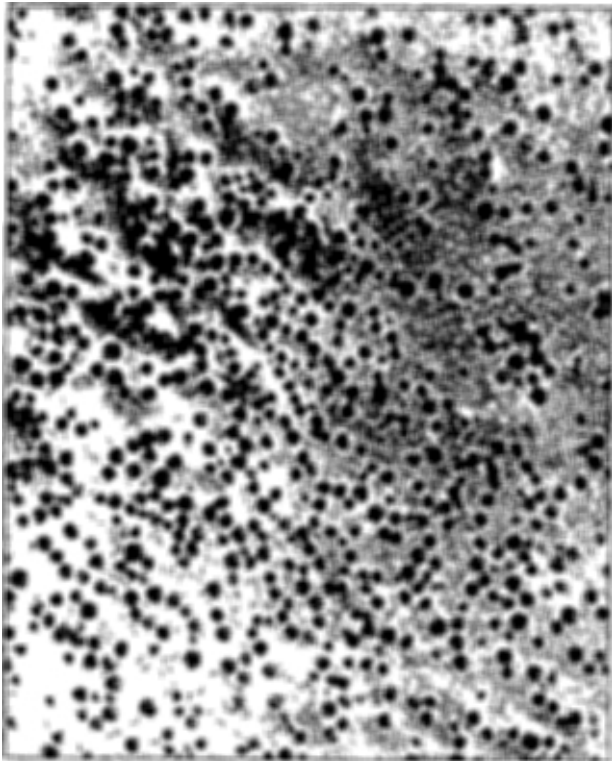
In both sets of photographs, and particularly in the case of those made on the concrete test site, a relatively higher fraction of the UGF beads appear larger (more highly exposed) in the photos made on the sections beaded at 6 pounds in comparison to the 4 pound UGF sections. This is a somewhat surprising result since the sections beaded at 6 pounds were applied at more than twice the pneumatic pressure used for the 4 pound sections. Consequently, any difference in exposure between the flotation beads sections would have been expected to be in favor of the lower application rate.

Figure 12 Appearance of Uniformly - Graded Beads Applied to Stripes on Bituminous Pavement

A Floating Beads



B Non - Floating Beads

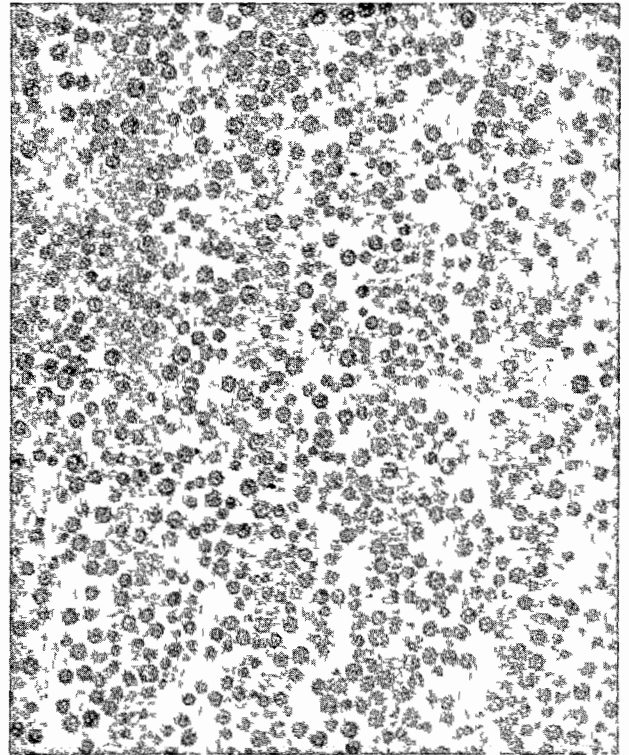
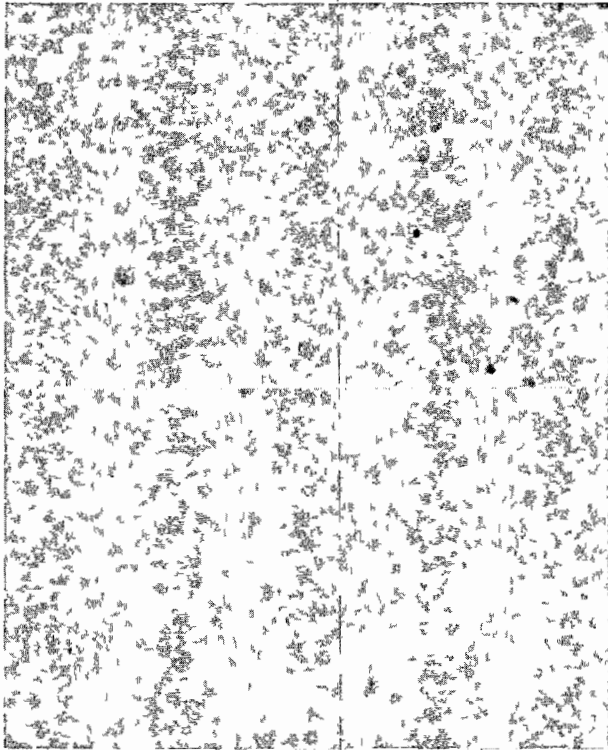


4 lb /gal

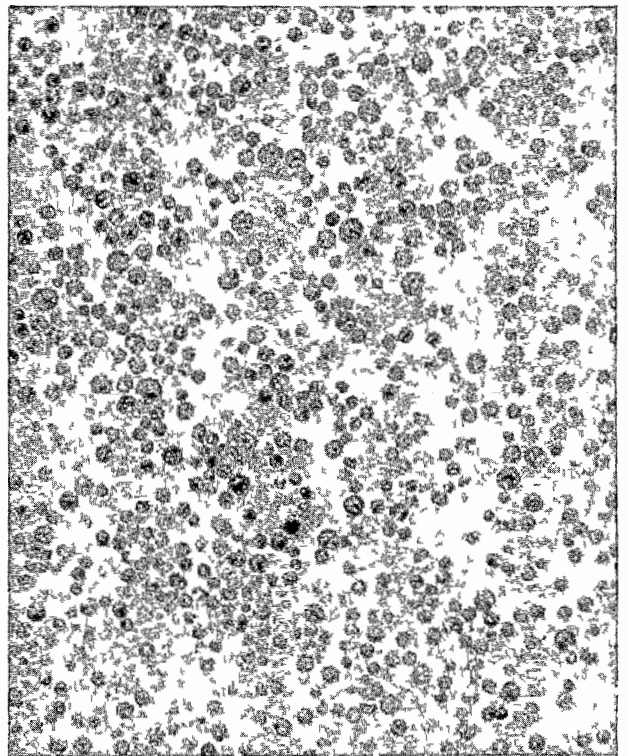
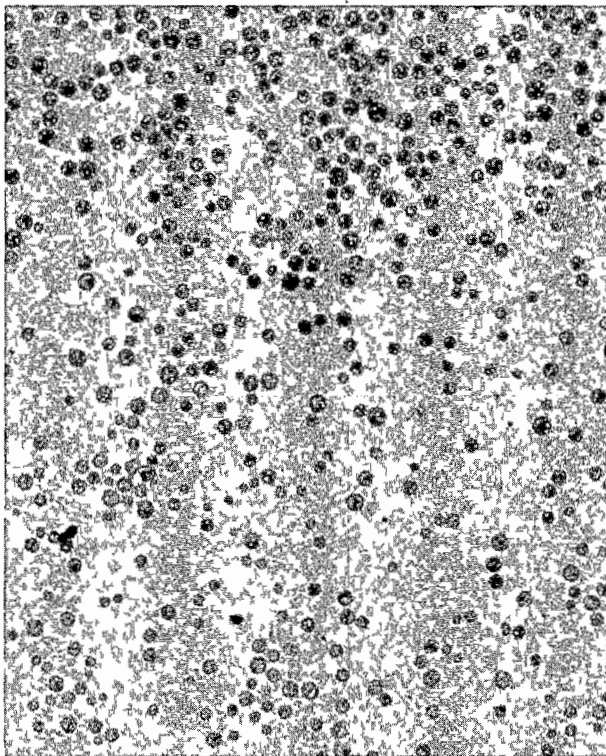
6 lb /gal.

Figure 13 Appearance of Uniformly - Graded Beads Applied to Stripes on Concrete Pavement

A Floating Beads



B Non-Floating Beads



4 lb /gal

6 lb /gal.

4 1.5 Performance of Uniformly-Graded, Non-Floating Beads(UGNF)

New Jersey's previous tests of uniformly-graded non-floating (UGNF) beads applied by gravity feed to transverse and lane line stripes yielded mixed visibility results. The overall performance of these beads was extremely inconsistent, varying from substantially less than that of the Department's standard beads to approximately the same as that of the best-performing floating beads.

The pressure applications of UGNF beads studied in the present research yielded a similar "mixed bag" of results.

On the bituminous pavement test site, the uniformly-graded non-floating beads displayed the same general application rate/brightness trend observed for the similarly-graded floating beads. Substantially greater initial reflectivity for low rather than high rates of application. Applied at 4 pounds per gallon, the UGNF beads provided about the same high brightness as a comparable application of the UGF beads, and about one-half to one unit less than the flotation coated beads when applied at higher rates. Each of these UGNF test sections displayed a brightness advantage compared to the standard beads, the advantage for particular applications ranging from "some" to "substantial" (i.e., from about 1/2 to 4 brightness units). Thus, on flexible pavement, UGNF beads provided one of the better performances.

In contrast, on the concrete pavement test site, the UGNF bead class generally displayed the lowest level of initial brightness.

On rigid pavement, UGNF beads applied at each of the studied rates displayed a relatively uniform level of average brightness, about equal to that of the standard bead lanelines and slightly less than the standard edgelines

One of the reasons advanced for employing the small-size non-floating beads is that under the action of traffic, the initially submerged beads will eventually become exposed, resulting in a brightness recovery in the later stages of service. Our experience with the UGNF beads indicates that the occurrence and desired degree of brightness recovery may not be realized since it will depend on such factors as traffic volume and pavement type. * For example, in the chipping failure generally exhibited by stripes on concrete (i.e., detachment of entire sections of the paint film), the initially submerged beads may be lost before becoming exposed.

In the 1-1/2 month evaluation made on concrete pavement in the present study (Figure 10C), the brightness of two of the three UGNF bead laneline sections remained unchanged from their initial levels, while the third section decreased by the same amount as the standard bead section.

4.2 EVALUATION OF NIGHT VISIBILITY PHOTOGRAPHS

Test stripe photographs made under simulated night viewing conditions using the "black box" apparatus described earlier in this

*It seems reasonable to assume that the extent to which such beads are uncovered may also vary as between edge and lane markings

report are presented as an appendix at page 54 Appendix Figures A1 thru A4 show the newly applied stripes, while Figure A5 presents (somewhat underexposed) photos of two-month old lanelines on concrete

A determination of the relative effectiveness of various bead types and application rates from these night visibility photographs is clearly a matter of individual judgment. However, it is of obvious interest to know in general the extent to which photocell measurements of traffic stripe reflectivity are reproduced and detectable in the photographs made with the "black box" apparatus For this reason, a correlation study was performed in which the brightness measurements obtained on each of the individual test sections studied in this research were compared to panel ratings of "black box" photos made on these same sections

In performing the photocell/photograph correlation, a panel of ten engineers were asked to independently rate the individual photos of the newly applied lines on a scale of 0 to 10. Except for the "Scotchlane" reference (which the raters were told was to be defined as a "10" rating), the panel members were unaware of the nature of the test lines The resulting individual panel ratings for the edge and laneline markings for a particular test section were combined and averaged, yielding a single numerical rating representative of the particular test section (i e , bead type and application rate) This visual rating was then compared to the combined average of the edge and laneline photocell data for that test section

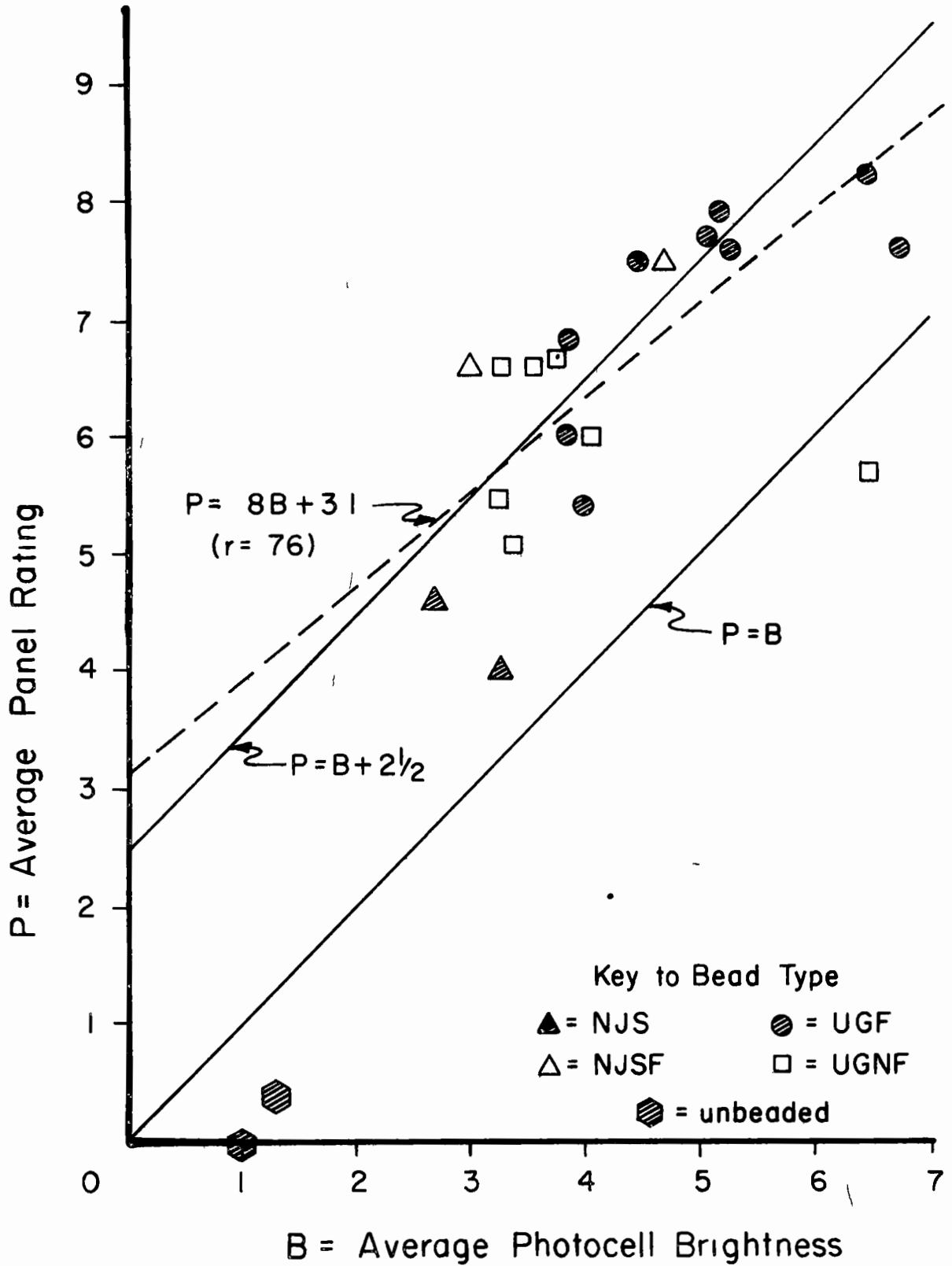
The results of the correlation analysis are presented as a regression plot in Figure 14. Application of conventional statistical standards to the best-fit line for 19 of the 22 points (the dashed line shown) indicates that there is a good relationship between the average field brightness measurements and the associated photographic brightness ratings.

As indicated in Figure 14, the actual best-fit line can reasonably be approximated by a line parallel to, but about 2-1/2 brightness units higher than, a 45 degree line passing thru the origin (i.e., 2-1/2 units higher than a line indicating equivalency between panel and photocell ratings). In essence, what this means is that the panelists ranked the brightness of the different test sections in generally the same order as that indicated by the photocell data, but on the average, assigned individual test sections a brightness value about 2-1/2 units higher than the actual field measurement. For example, in this set of photos, a test section displaying 4 brightness units might be expected to be assigned a panel rating on the order of 6-1/2 units.

One obvious distinction between the correlation technique presented here and the usual field photometric/user opinion comparisons, and one which might be expected to have an adverse effect on the extent of the observed agreement, is that the "office" visual ratings are based on a very limited sample (i.e., one photo for each edgeline and laneline section). Considering this limited sampling then, the observed good general agreement between the photocell and photographic estimates of visibility is a pleasant surprise.

Figure 14

Comparison of Field Brightness Measurements and Panel Ratings of Simulated Night Visibility Photographs



As previously alluded to, three test sections departed from the correlation pattern observed for the majority of the stripes. Two of these sections were the unbeaded stripes, which the panelists almost unanimously rated as having zero brightness (rather than about 1 to 1-1/2 units of brightness as indicated by the photocell). The one reflectorized test section which markedly departed from the best-fit pattern was the 4 pound application of uniformly-graded, non-floating beads on bituminous pavement. This particular application -- which displayed the highest measured level of brightness for the UGNF bead class -- received high photographic ratings as lane lines, but very low ratings as edgelines (Figure A4).

As a final comment on the correlation analysis, it is interesting to note that the sample photographs of sections reflectorized with New Jersey's standard beads were by consensus rated as displaying the least brightness of all the various beaded lines on either pavement type. [The data for these standard bead sections are shown as the solid triangles in Figure 14.]

PART FIVE CONCLUSIONS

5 1 INITIAL NIGHT VISIBILITY

The night visibility measurements obtained in this follow-up study indicate that uniformly-graded, flotation-coated (UGF) glass beads applied using New Jersey's conventional (pneumatic pressure) technique yield traffic stripes of greater brightness than those reflectorized with our standard beads. The magnitude of the achievable improvement varies with application rate and pavement type. The optimum rate of application for these special UGF beads is 4 pounds per gallon for stripes on bituminous pavement and 5 pounds per gallon for markings on concrete pavement. Applied at these rates, the initial brightness of the UGF beads was about 2-1/2 times that of our current standard beads on blacktop, and 1-1/2 times greater for stripes on concrete. While such photometric data is only an indicator of the response of the human eye, a series of night visibility photographs taken to complement these instrument measurements confirm that the observed substantial differences in measured brightness are indeed visually significant.

Both the flotation feature and the restricted gradation contribute to the improved brightness of the UGF type bead. The influence of the flotation feature is evidenced by the fact that while uniformly-graded beads without the flotation treatment provided

reflectance approaching that of the UGF beads when applied to stripes on blacktop, these non-floating beads generally displayed the lowest level of brightness when applied to stripes on concrete pavement. Similarly, while the addition of a flotation treatment to New Jersey's standard wide-gradation beads provided lanelines with one of the higher brightness levels on concrete pavement, the brightness of lanelines on blacktop and edgelines on concrete reflectorized with these wide-gradation flotation beads differed little from that provided by the standard beads.

5.2 ESTIMATES OF OVERALL VISIBILITY PERFORMANCE

As noted at the outset of this report, a number of unfortunate circumstances (e.g., the inadvertent early restriping of the test sections) precluded the planned collection of visibility and durability data over the full service life of the test markings. Except for a 1-1/2 month evaluation of concrete pavement lanelines, the collected data was limited to a determination of initial stripe visibility.

It is apparent that the present limited data sample of itself would be insufficient to characterize the overall performance of the studied stripes. However, it is believed that due to the nature of the experiment undertaken, our previous rather extensive observations of the overall performance of the same bead types applied by the "drop-on" (gravity) method may be used to make some valid judgments regarding the service life of the present pressurized applications.

That is, the basic objective of the present research was to determine whether application of UGF beads under pneumatic pressure would result in overembedment of the beads, negating their previously observed performance advantages. While such excessive embedment did not generally occur -- each of the variously graded and flotation-treated bead types demonstrating initial visibility results similar to those observed in previous tests -- a pressurized application of UGF beads will certainly result in embedment at least equal to a gravity application. The important point here is that since the retention of a given bead type under the abrasive action of traffic is a function of the depth of embedment, it seems reasonable to assume that the durability of pressure applications of UGF beads will be at least equal to that previously observed for gravity applications. In the writer's opinion then, the combined data from the past and present studies provides a reasonable basis for making an informed choice between competing bead types.

Our previous observations of the in-service behavior of traffic stripes comprised night visibility and durability examinations of lanelines conducted in two test series at a total of four locations. In both test series, the lines were subjected to winter conditions for about the last three months of their (5 to 7) month evaluation. The test site traffic volumes ranged from about 10 to 48 thousand vehicles per day. This exposure to winter conditions, when combined with the highest traffic volumes, had a pronounced effect on bead

retention In one test series, all of the variously beaded lanelines studied reached a terminal visibility level after only about 4-1/2 months service* (1-1/2 months less than the minimum stripe "design" life)

In summary, while certain of the gravity-applied flotation bead sections maintained a brightness advantage over the standard lines throughout the period of study, in cases of relatively severe exposure, the brightness of the UGF beads was about the same as that of the standard after three months service Thus, while the restricted gradation flotation beads may provide a long-lasting brightness advantage when subjected to less severe conditions, it more conservatively appears that what New Jersey would be buying by conversion to UGF beads applied at the indicated optimum rates of application is a definite brightness improvement over about the first half to two thirds of the effective service life of the stripes.

5.3 ECONOMICS

As noted at the outset of this report, improved performance rather than cost savings would be the principal stimulus for New Jersey's conversion from conventional well-graded beads to the uniform-graded, floating beads

*Such occurrences are apparently not unique to New Jersey or to the drop-on application technique A recent report(8) describing a New York study of various types of pressure-applied beads indicated "substantial failure" of traffic stripes after three months service including winter exposure

Achieving the described maximum visibility improvement relative to the presently specified beads would naturally entail applying the special beads at the indicated (different) optimum application rates of 4 pounds per gallon on blacktop and 5 pounds per gallon on concrete. At the probable 3 cent per pound premium for the special beads, this practice would result in an increase of about \$7,000 per year in materials costs.

Any such use of different application rates clearly would not envision changing bead dispenser (pressure) settings for every change in pavement type. Rather, a 5 pound rate would be contemplated only where the predominant pavement type over a substantial length (say at least 2 miles) was concrete.

If adjusting bead application rate to the predominant pavement type is not deemed feasible by Maintenance, the application rate of choice for the special bead is 4 pounds per gallon for both pavement types. Such applications would be expected to result in a significant brightness improvement for stripes on bituminous pavement and no sacrifice from present visibility levels for stripes on concrete (actually, the results of this study indicate a 4 pound application of the special bead to be substantially brighter than the present beads after 1-1/2 months service on concrete). Use of this 4 pound application rate would result in a slight (\$2,000/year) net decrease in annual marking materials costs.

PART SIX RECOMMENDATIONS

6.1 SPECIFICATIONS

It is recommended that the specifications for the glass beads used to reflectorize New Jersey traffic paint be modified by the following

- A Change bead sizing from the present large-to-small gradation to that of a small, essentially single size bead, meeting the following requirements when tested in accordance with ASTM D-1214

<u>Sieve No</u>	<u>Total Percent Passing</u>
30	100
40	90-100
80	0-10

- B In a new Specification Article, require the provision of the following bead flotation property "A minimum of 90% by weight of the glass beads shall float on xylol when tested as follows A sample of approximately one gram of the beads shall be spread in a single layer on a clean, inverted pint friction-type can lid Xylol shall be slowly introduced with a syringe or dropper at the edge of the lid until it overflows The amount of beads remaining submerged shall be determined quantitatively "

6 2 STRIPING PRACTICES

If the recommended change in bead type is implemented, it is recommended that the State's present striping practice be changed by adopting one of the following alternates

OPTION A

Instead of applying beads at a uniform 5 pounds per gallon, a 4 pound application rate should be used when the predominant pavement type in an area to be marked is bituminous concrete, the new beads should be applied at 5 pounds per gallon when portland cement concrete predominates.

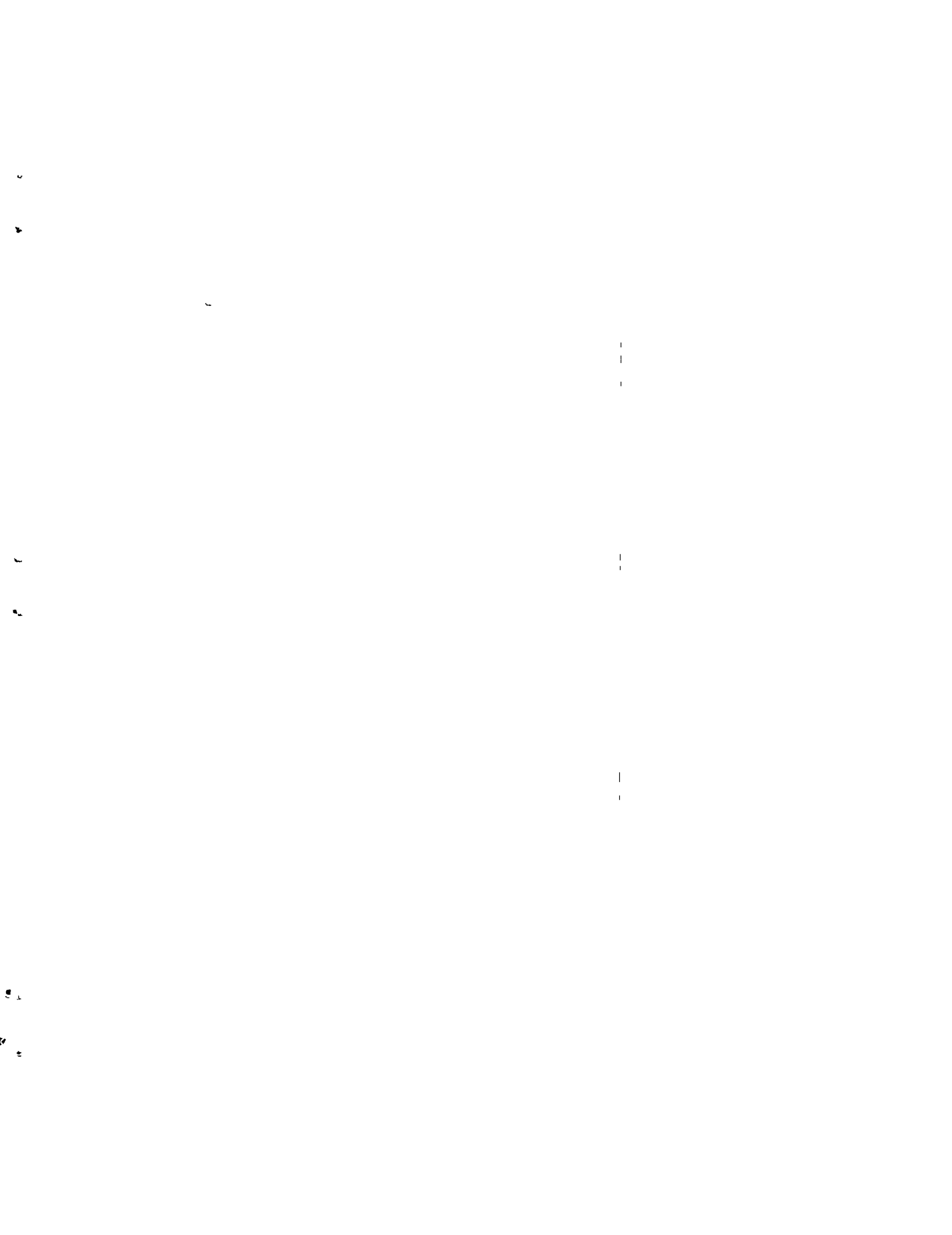
OPTION B

If the above option is not deemed feasible by Maintenance, a 4 pound application rate should be used on both pavement types

SELECTED REFERENCES

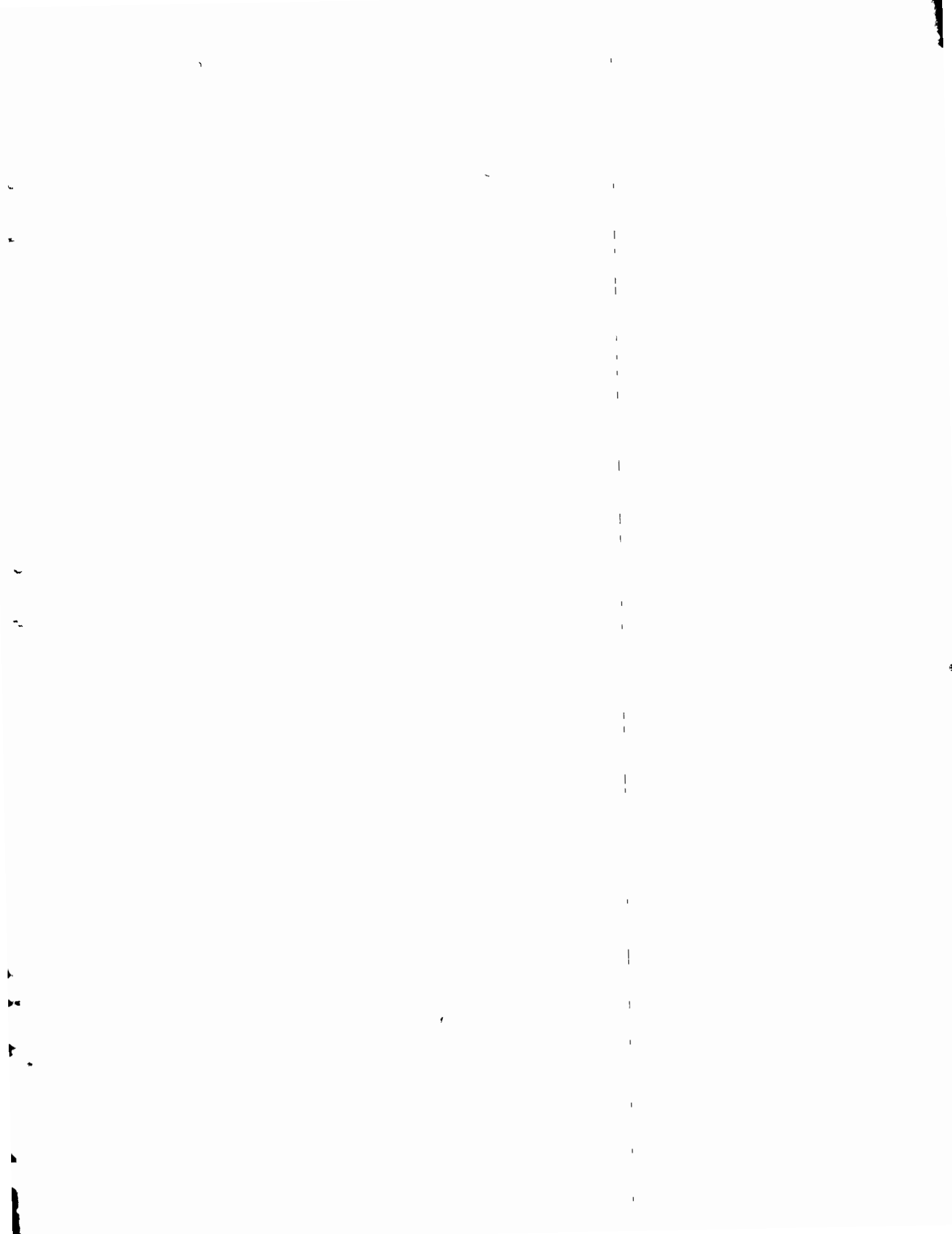
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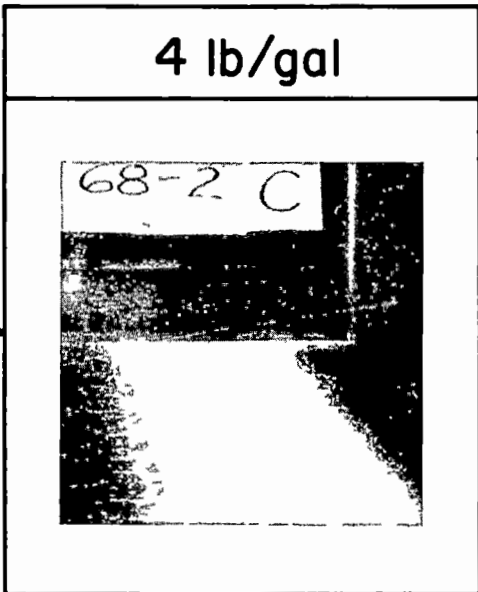


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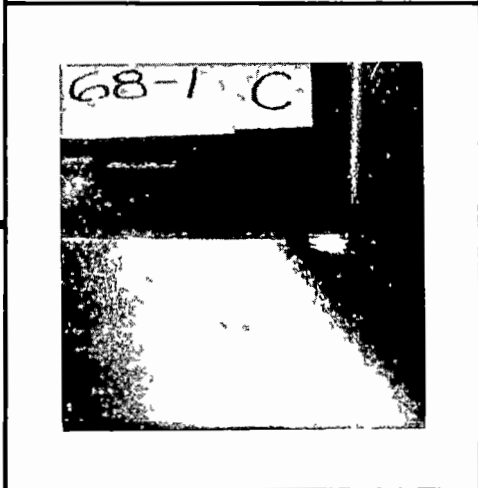


UGNF →



lb/gal

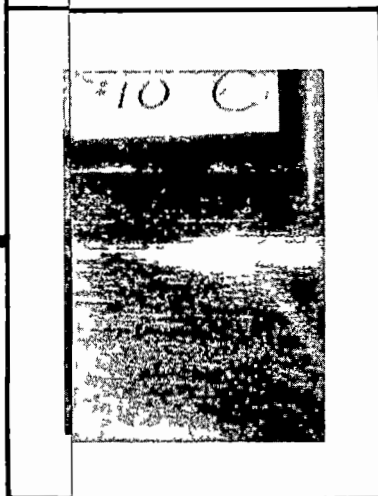
UGF →

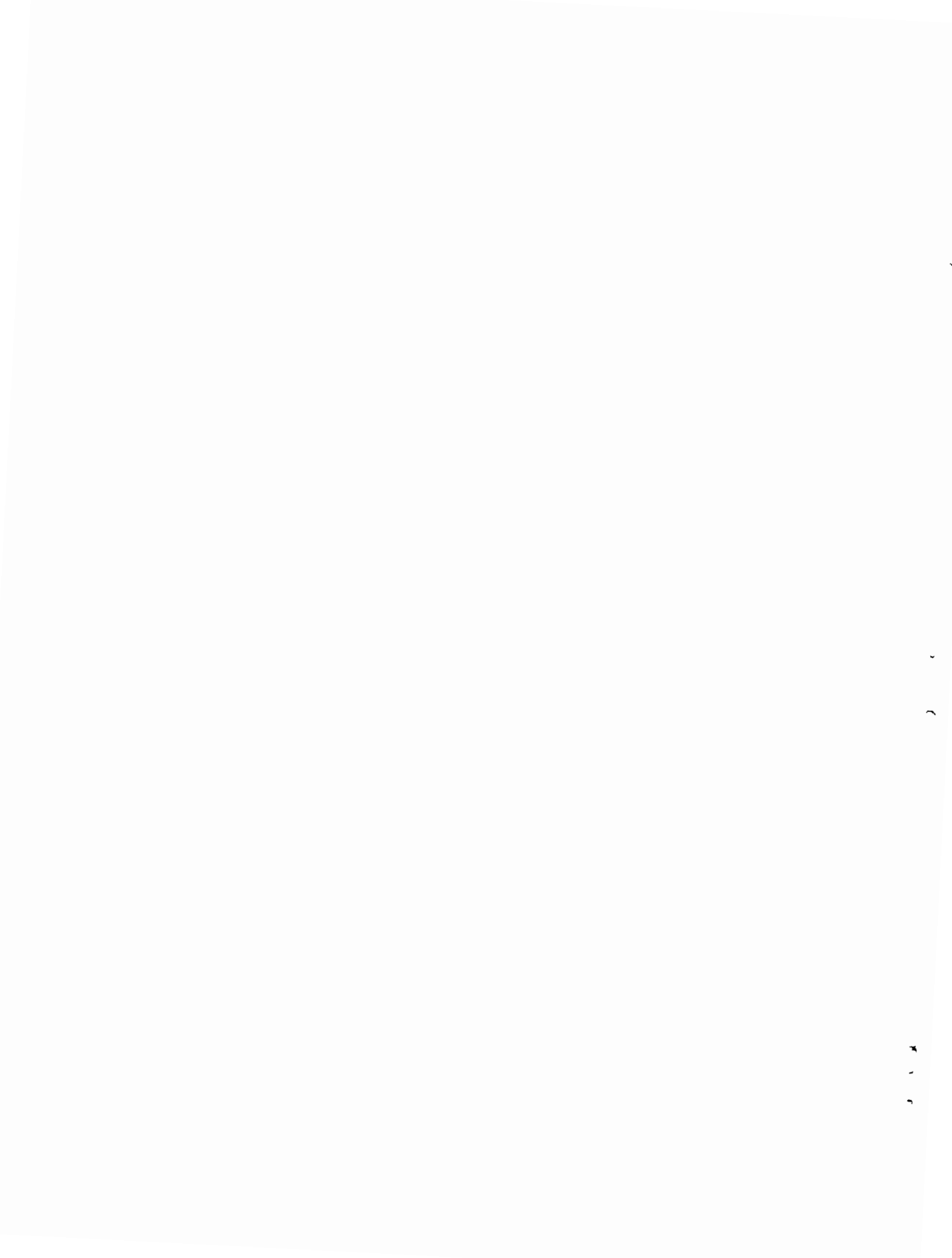


NJS →

nelines
ment

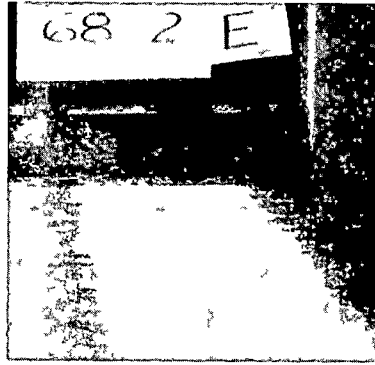
NJSF →





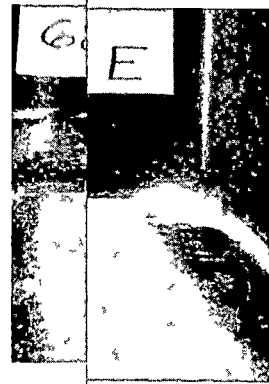
4 lb gal

UGNF



gal

UGF



NJS

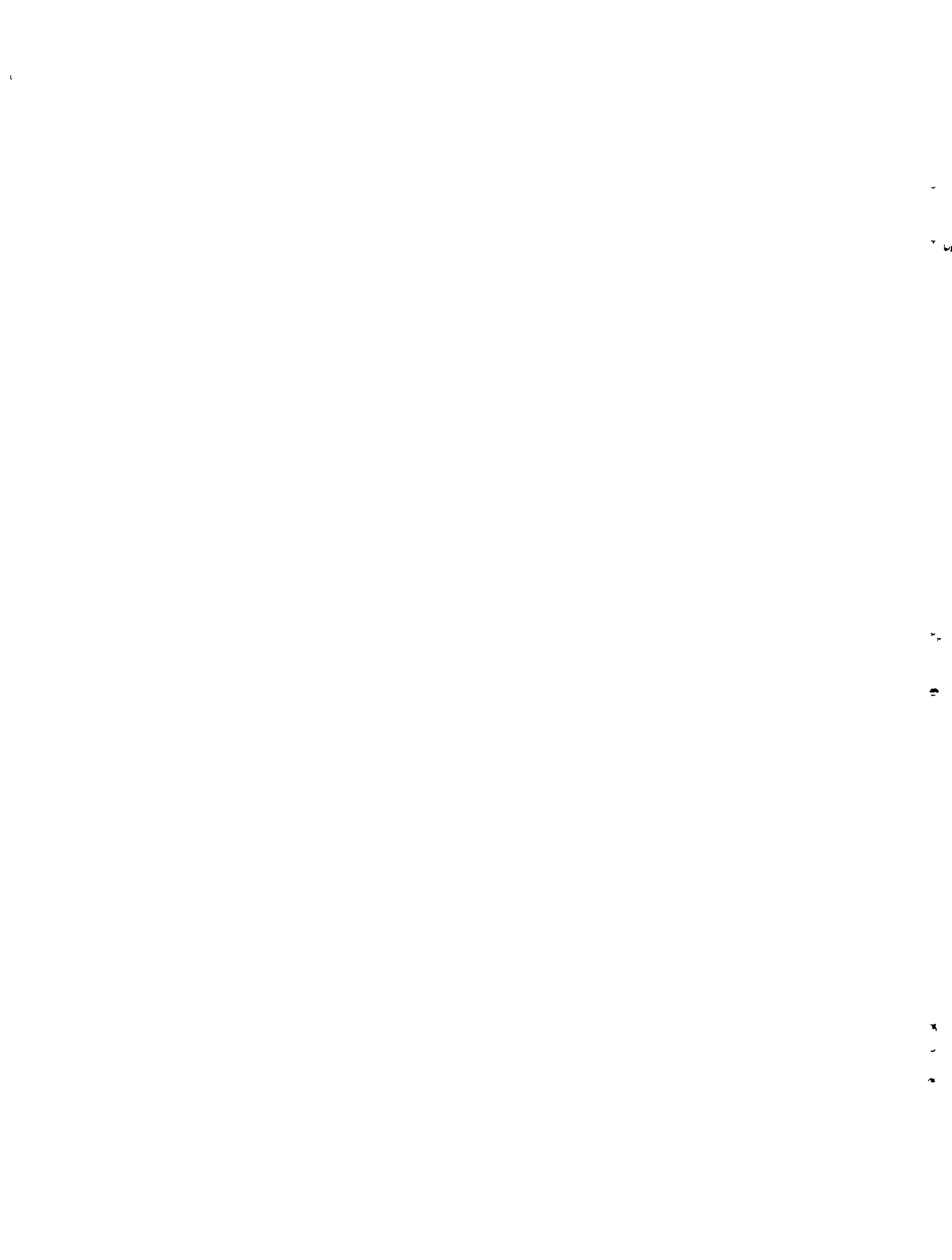


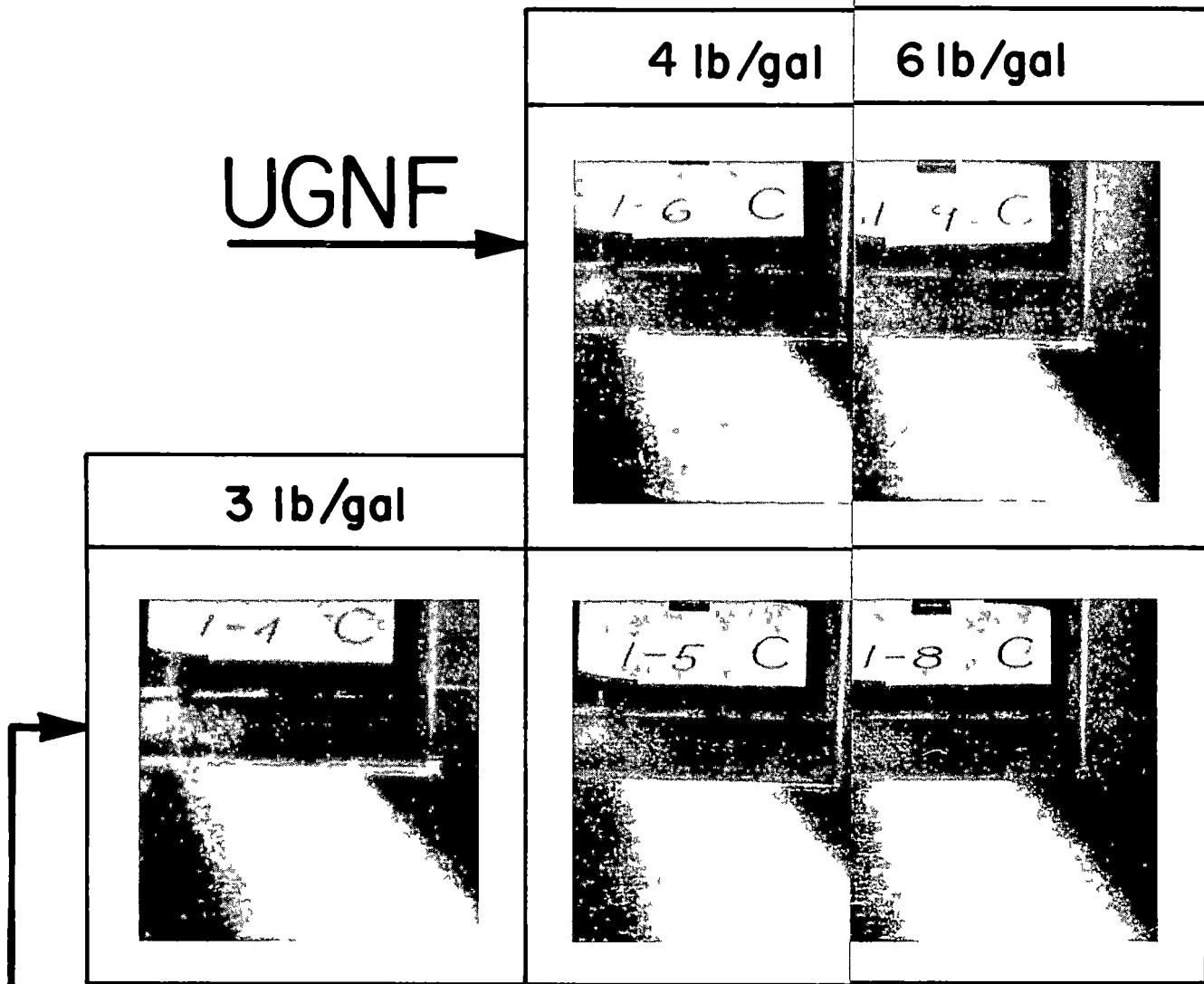
elines

ment

NJSF







UGF

unbeaded

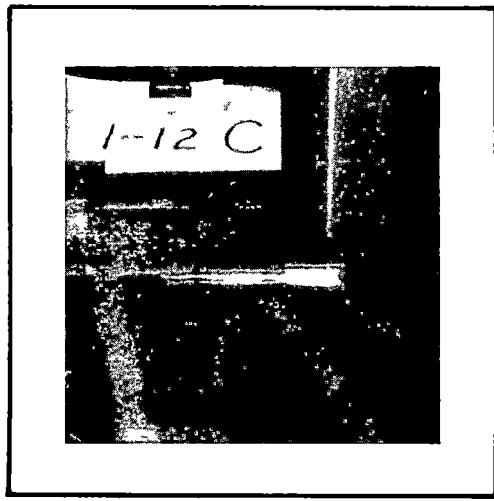
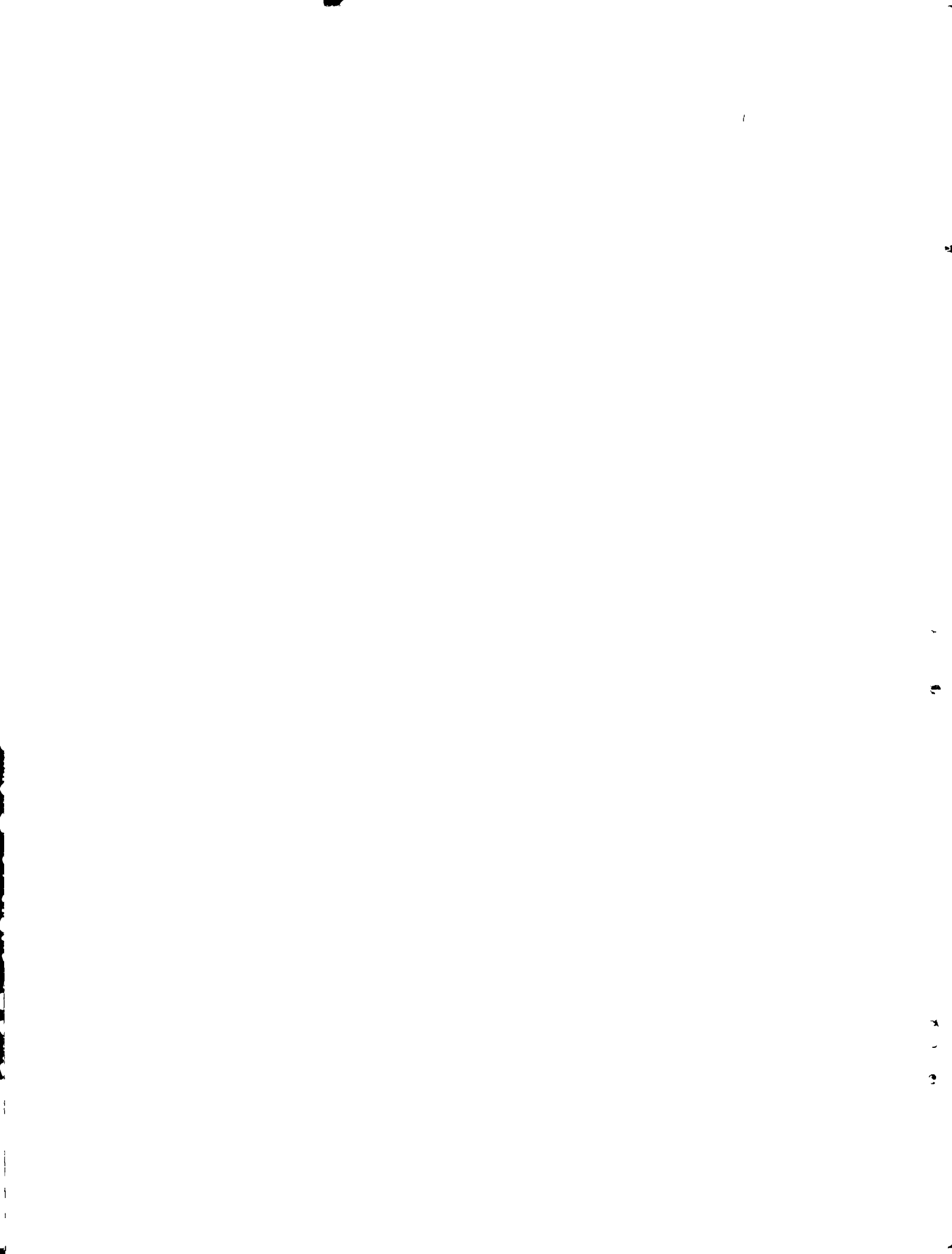


Figure A-3:
Applied
lines on
Continuous Pavement

M



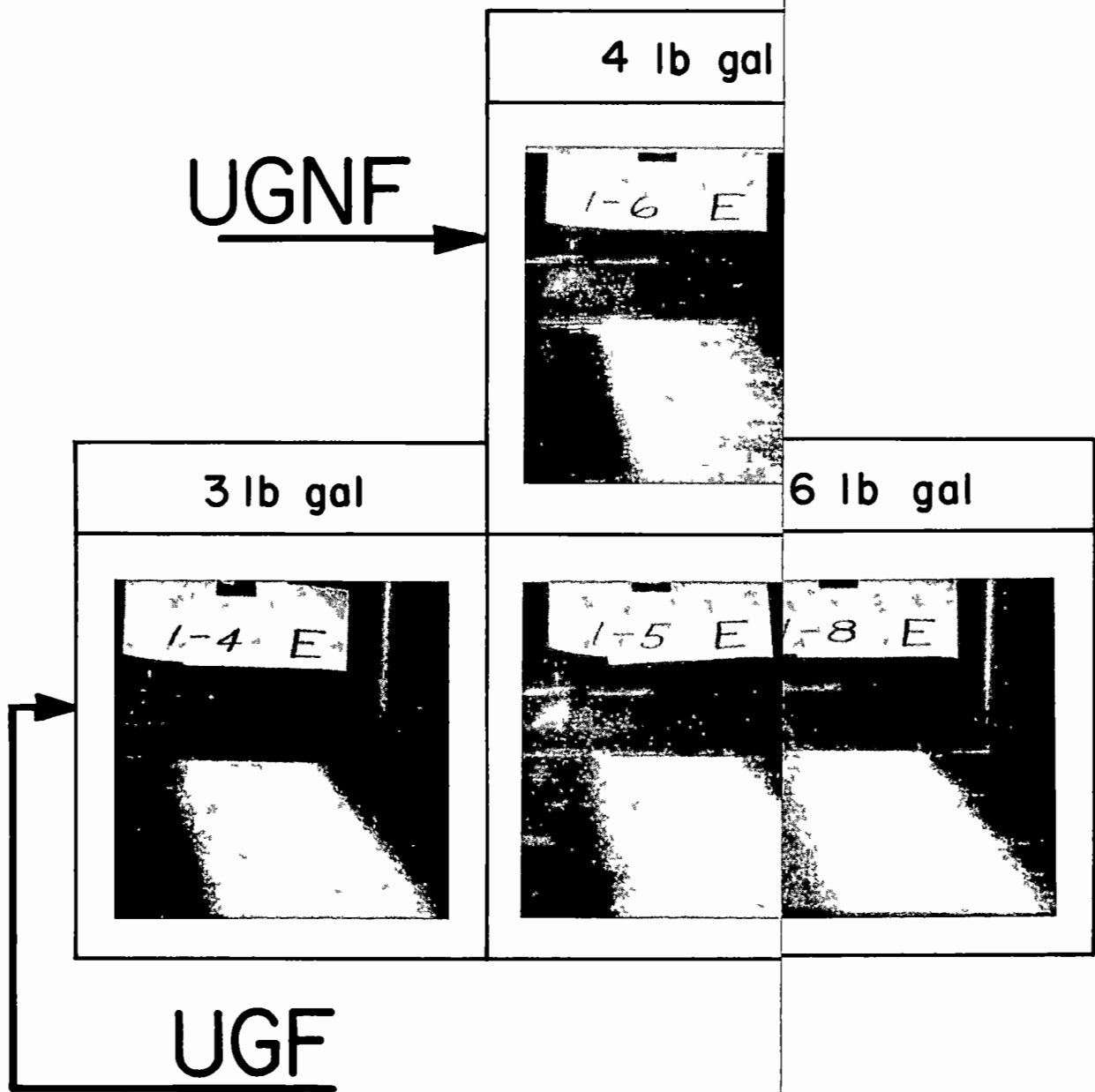
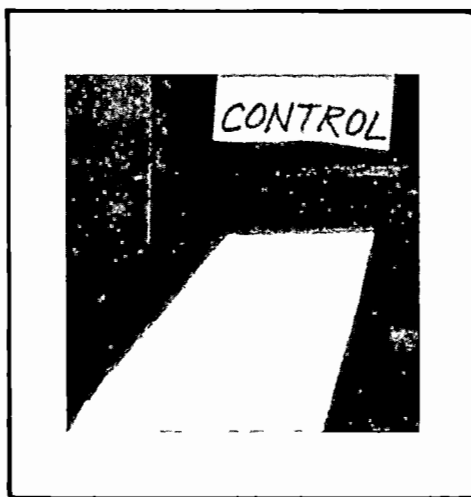


Figure A-4:

Applied
es on
ous Pavement

"Scotch Lane"



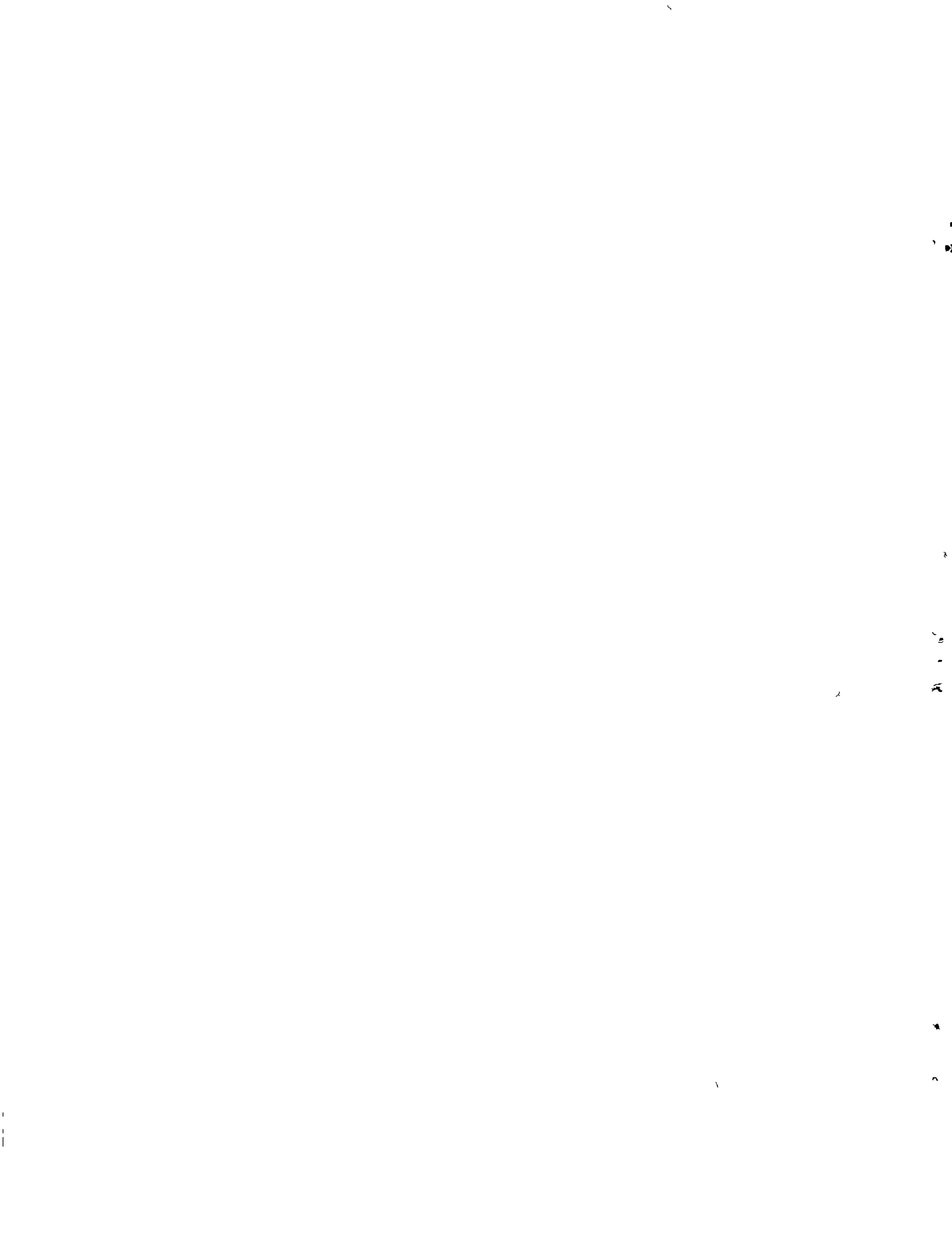
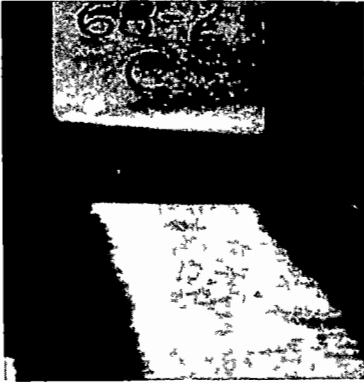
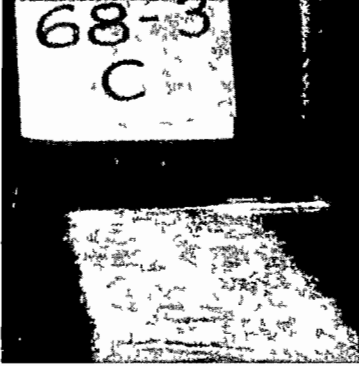
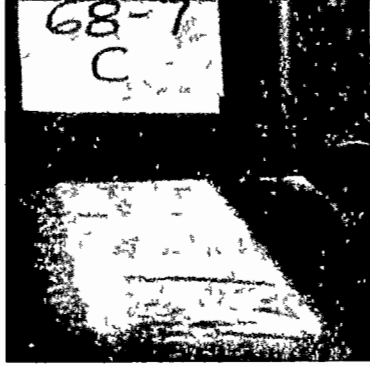
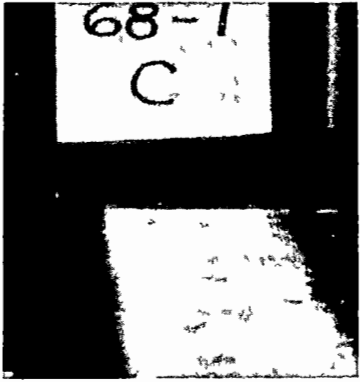
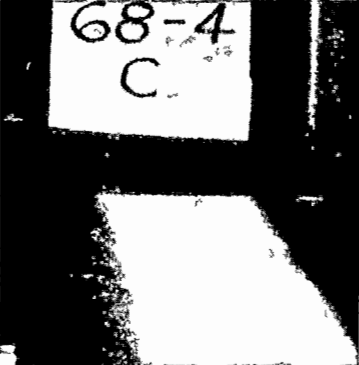
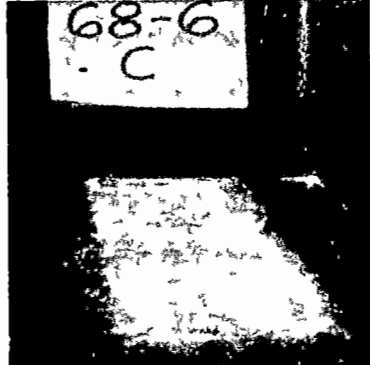
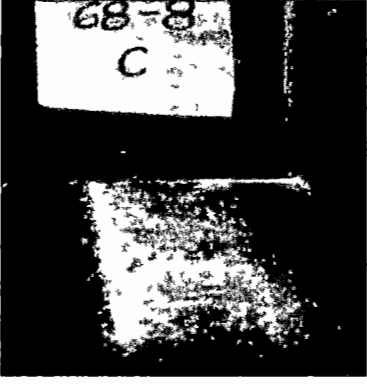
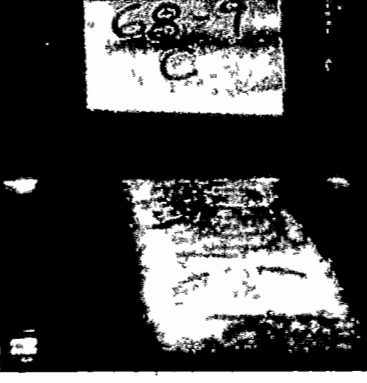


FIGURE A-5 TWO MONTH OLD LANELINES ON CONCRETE PAVEMENT

UGNF

UGF

	4 lb/gal	5 lb/gal	6 lb/gal
UGNF			
UGF			
			NJS NJSF
			

2

4

,

8

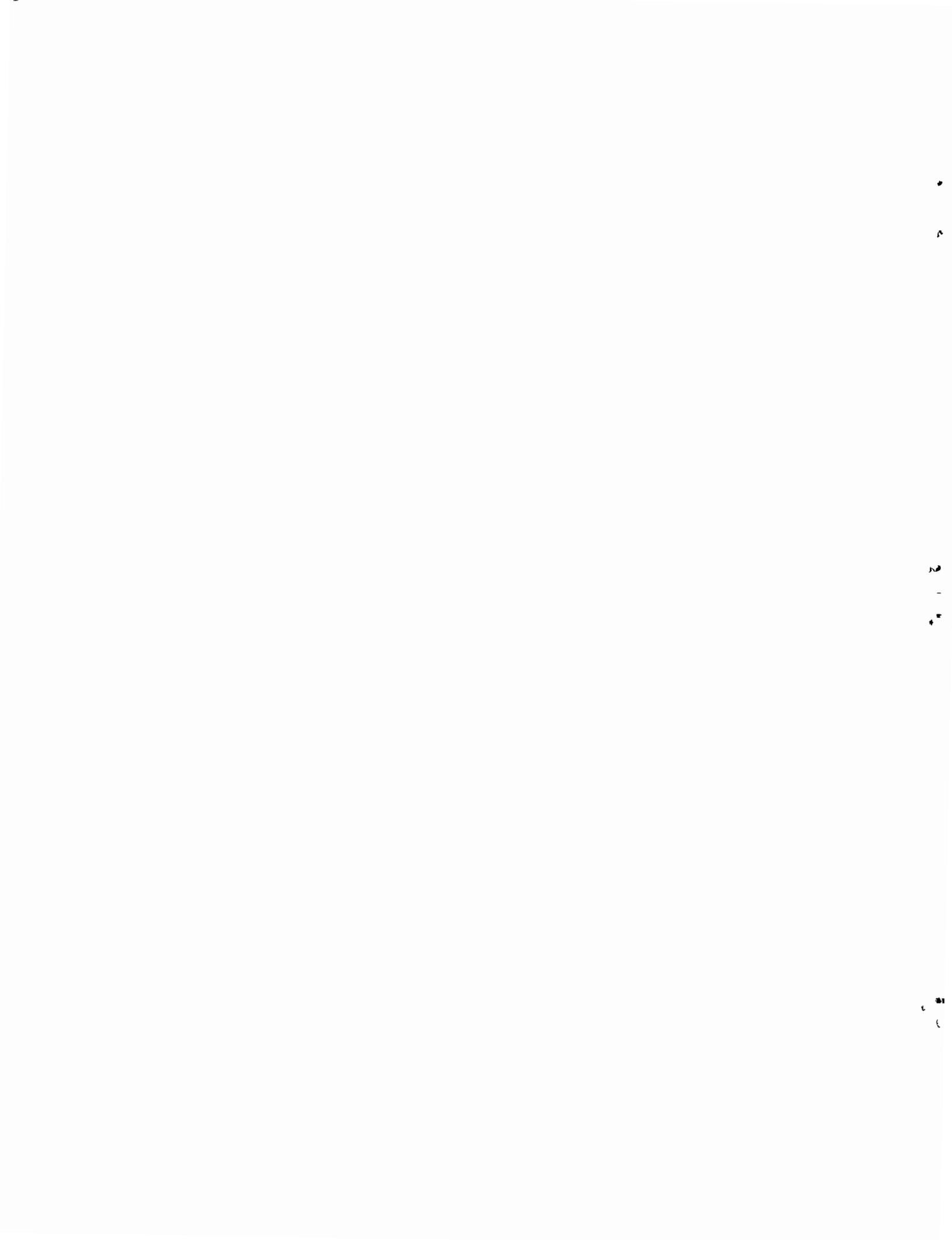
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