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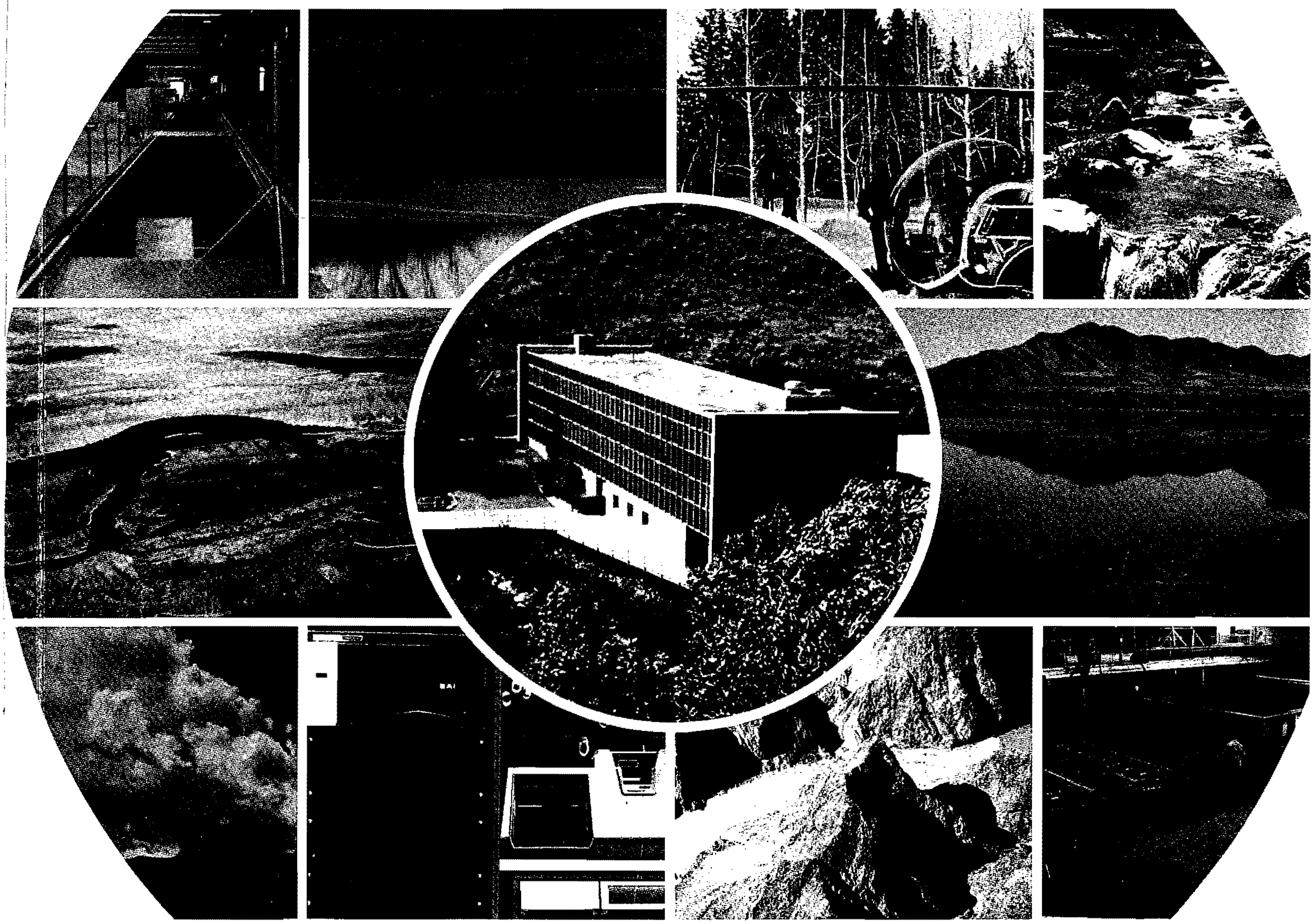

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# EVALUATION OF LEGIBILITY OF REFLECTORIZED LICENSE PLATES

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# ABSTRACT

The rainfall simulator at the Utah Water Research Laboratory, Utah State University, Logan, Utah, was utilized in evaluating various types of license plates. This unique facility enables the production of controlled uniform rainfall inside the laboratory. For this experiment, rainfall rates of 0" (dry), 1/2" and 2" per hour were used to compare reflective performance of reflective sheeting (RS), beads-on-paint (BOP), and new paint (NP) license plates under dark nighttime conditions. Both new and used license plates were evaluated. The three types of new plates were made and embossed at the Idaho State Prison using standard state manufacturing procedures. The used plates were from the current Idaho issue (RS) and from Missouri (BOP). The used plates averaged 1 year exposure for the BOP plates and over 3 years for the RS plates.

Reflectance of plates was measured under various wet and dry nighttime conditions using appropriate photometric equipment. Legibility of the plates under these same conditions as well as in daylight-dry conditions was determined by using selected trained human observers. Results of both the photometric and legibility parts of these tests indicate the superiority of RS plates over both the BOP and NP plates.

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# INTRODUCTION

Personnel from the Utah Water Research Laboratory (UWRL) and from the Safety and Security Systems Division/3M have collaborated previously on the testing of reflectorized materials for safety clothing and automobile license plates under the UWRL rainfall simulator. This unique facility enables the production of controlled uniform rainfall inside the laboratory over a wide range of rates, and is adaptable to a variety of research studies.

Under a research contract sponsored by 3M, UWRL personnel organized a research project designed to test the reflectivity of selected reflectorized materials presently marketed throughout the United States and world for use on automobile license plates. Evaluation of the effectiveness of the materials was to be made from data generated by a selected group of human observers as well as from those produced by appropriate photometric instruments. The rainfall simulator enables highly controlled tests to be made under typical rainfall conditions, tests not heretofore run on automobile license plates.

# DESCRIPTION OF TESTING FACILITY

## Rainfall Simulator

The rainfall simulator is a drip type device in which individual raindrops are formed by water emitting from the ends of small diameter brass tubes. The rate of flow is controlled by admitting water into a manifold chamber through fixed orifice plates under constant hydraulic pressure. Five separate inlet orifices are used in each chamber or simulator module. The ratios of the areas of the orifices are 1:2:4:8:16. By controlling the flow to the orifice with an electrically operated solenoid valve it is possible to vary flow in on-off increments with 31 steps. Outlet from the chambers or modules is through uniform equally spaced brass tubes. Each module is a 24 inch rectangular box about 1 inch deep and oriented so that the tubes or needles form a horizontal plane to let the water drip vertically toward the tilting flume. Each module has 672 needles spaced on a 1 inch triangular pattern. The simulator module is illustrated in Figure 1.

The rainstorm simulator consists of 100 modules spaced and supported to make a continuous unit 20 feet square. Each module has separate controls so that a spatially moving storm with time-changing intensities can be simulated. The 500 switches are controlled by a programmed computer or if desired can be manually operated.

Raindrop sizes and velocities of impact have been designed to represent the energy of typical high intensity storms. The spatial distribution of the rain is essentially uniform and the control of application rates is within the accuracy requirement of most experiments.

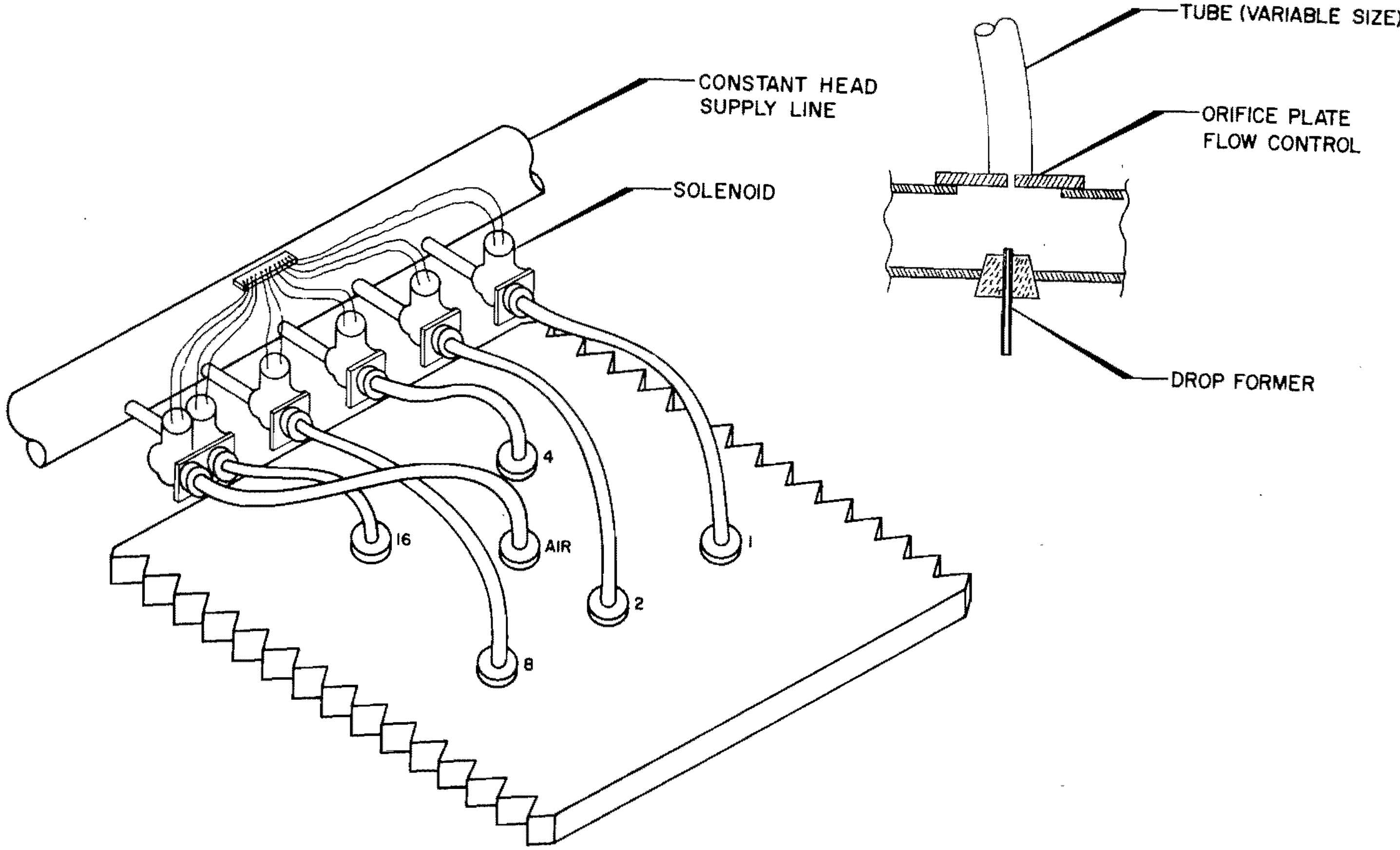


Figure 1. Typical rainstorm simulator module.

At rates greater than about 2 inches per hour, the simulator produces a uniform pattern of rainfall. At rates below this amount, the pattern is irregular due to the lack of sufficient water to fill all the needles which form the drops. For the present experiment, one of the modules was modified by replacing the existing needles with smaller ones, and increasing their triangular grid spacing from 1 inch to 2 inches. This enabled the production of uniform rainfall at rates less than 2 inches per hour. Throughout the ensuing tests the license plates were suspended beneath this modified module where the rainfall was controlled at either 1/2 inch or 2 inches per hour. During the tests the rest of the simulator was allowed to rain at a slightly higher rate. Figure 2 shows the simulator over a tilting flume, the latter not used in the present studies.

## Photometric Equipment

The standard L-S-300 type photometric procedure was used for all measurements. Equipment included the following and was arranged as shown in Figure 3:

1. One - KODAK 600K projector modified by removing the infrared filter and wiring the bulb and fan motor separately (to allow for voltage control of the bulb). A DAH bulb was used at the proper voltage to maintain a 2856°K output. A mask was used in the slide holder to control the lighted area.
2. One - EG&G Model 550-1 Radiometer/Photometer with matching photocells color corrected to the photopic standard observer.
3. One - 0 to 140 volt A.C. Output Variac.
4. One - 117 volt A.C. Output Stabilizing Transformer.

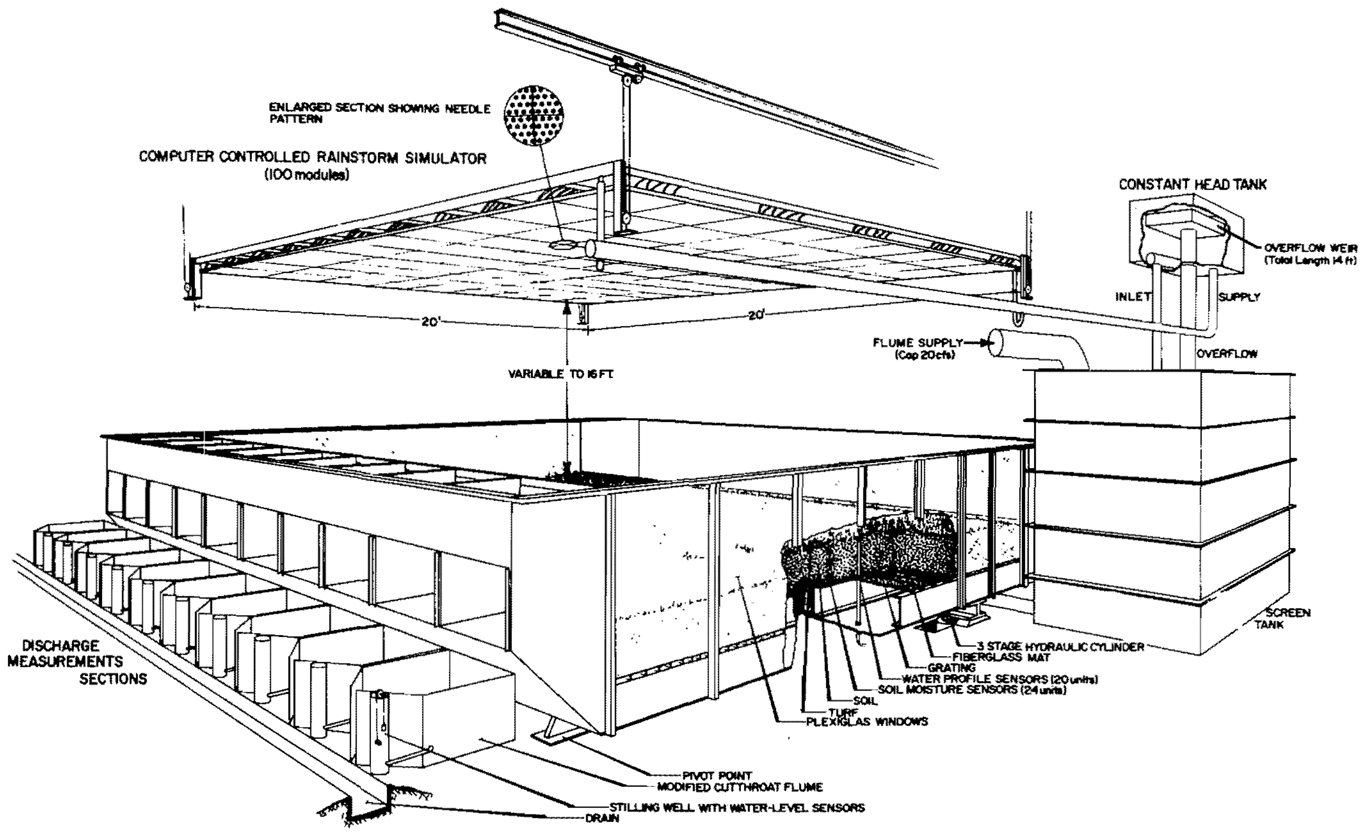


Figure 2. Rainstorm simulator with tilting flume.

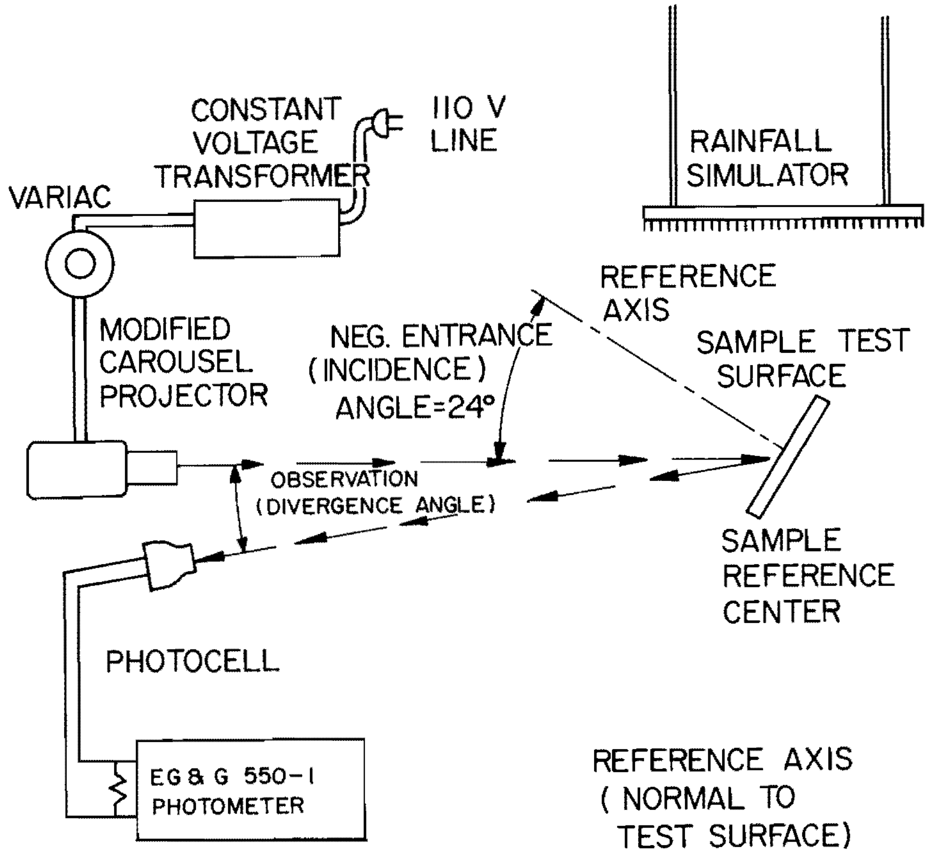


Figure 3. Equipment used for reflectance tests.

The height of the projector and license plate was the same and the light was essentially parallel with the floor. Therefore, the plate angle of 24 degrees was also the incidence angle.

In addition to measurements made at 0.2° and 1.0° observation angles at a nominal 50 ft. distance (56.5 ft.) the equipment was used for measurements at the driver's eye position at 60, 90, 120, and 150 feet.

## Test Vehicle

A small off-the-road vehicle shown in Figure 4 was modified for use on these tests. Its gasoline engine drive was disconnected and replaced

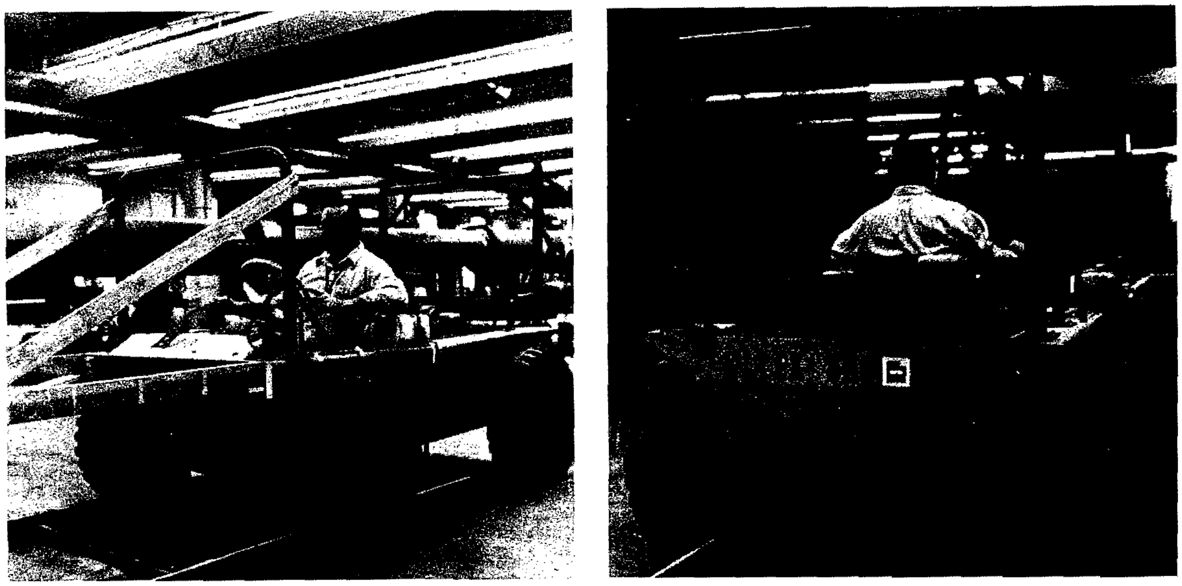

Figure 4. Observation vehicle used in tests.

with an electric motor and gear reductor to provide a constant speed of the vehicle of 13 inches per second, both forward and reverse. A 170 foot track was constructed and anchored to a concrete floor in line with the rainfall simulator such that an unobstructed view was provided over the entire length of the track of license plates suspended beneath the simulator. The track held the test vehicle in straight-line travel without steering. Electrical power (110 VAC) was provided to the vehicle from an overhead cord suspended on a cable.

The vehicle was equipped with low-beam headlights of the kind used on a 1978 Plymouth Fury III, which is one of the vehicles currently used by the Utah Highway Patrol. Headlight spacing, aiming, distance above the road, and distance from the driver's eye position were all carefully simulated. The average seat height of a Plymouth Fury is 22 inches, and on the test vehicle 24 inches, because vehicle configuration would not allow it to be placed lower. However, differences in heights of observers make this small difference in seat height on the test vehicle insignificant.

A new battery was placed in the test vehicle to provide 14.7 constant DC voltage to the headlights, and this in turn was connected to a heavy-duty battery charger throughout the tests to assure constant brightness of the lights.

A short lever operated by the observer controlled the forward and backward movement of the test vehicle, and no other controls were necessary.

## License Plate Mount

A long pivoting steel arm supported by a cable held the license plate mount. It was positioned so that it could be loaded from an outside position, then swung into place beneath the rainfall simulator to the desired location. The arm and mount were painted black to eliminate glare to the observer from the headlights. The plate was positioned normal to the track, 20 inches above ground level, with the face of the plate tilted backwards 24 degrees from vertical.

# PLATES INCLUDED IN TESTS

Five different categories of license plates were provided by 3M for use in the tests, and there were 10 plates in each category. Table 1 lists the various plate categories together with their numbers and reflectivities.

All three of the new sets of plates were prepared especially for these tests, and each set of ten has the same alpha numerics. The easiest and most difficult to read letters and numbers have been omitted from these 30 plates. The new sets were all embossed at the Idaho State Prison using the state's standard procedures. They were made into each type, reflective sheeting (RS), beads-on-paint (BOP), and new paint (NP), using typical manufacturing procedures and materials. The used plates were selected for, among other things, their range of ages, position on car, and uniformity of letter size and density. The used RS plates were selected from the current Idaho issue, and had an average time of use (exposure) of 3 years. Used BOP plates were from Missouri and had an average exposure time of 1 year.

Table 1. License plates used in tests.

| NEW License Plates | Candlepower Per Foot Candle** | Color | USED License Plates | Candlepower Per Foot Candle** | Color | Age (Years) | Location on Car (Front or Rear) |
|---|---|---|---|---|---|---|---|
| Reflective Sheeting | | | Reflective Sheeting | | | | |
| CNP 426 | 19.6 | Green on White | 24767* | 16.49 | Green on White | 2-3 | F |
| CYE 265 | 20.2 | | YB 545 | 16.41 | | 4-5 | R |
| ENC 562 | 21.5 | | 70146* | 15.36 | | 2-3 | F |
| EPY 650 | 21.5 | | 22085 | 14.76 | | 3-4 | - |
| NCY 405 | 21.2 | | 11966* | 16.23 | | 3-4 | R |
| NPE 064 | - | | 16863* | 12.50 | | 3-4 | F |
| PNE 240 | 21.6 | | 95508 | 12.33 | | 4-5 | R |
| PYC 504 | 20.1 | | G9875 | 13.80 | | 4-5 | R |
| YNC 025 | 20.7 | | 87987* | 10.07 | | 4-5 | R |
| YPE 642 | - | | JY 973 | 14.58 | | 3-4 | R |
| Beads-On-Paint | | | Beads-On-Paint | | | | |
| CNP 426 | 2.14 | White on Black | M8863 | 1.16 | White on Dark Color | 1 | R |
| CYE 265 | 1.94 | | 74978 | 1.28 | | 1 | F |
| ENC 562 | 2.03 | | F7355 | 0.93 | | 2 | R |
| EPY 650 | 2.17 | | JN746 | 1.41 | | 1 | F |
| NCY 405 | 2.15 | | B2548 | 0.85 | | - | R |
| NPE 064 | 2.22 | | B2537* | 1.11 | | 1 | - |
| PNE 240 | 2.13 | | Z1801* | 1.04 | | 1 | F |
| PYC 504 | 2.08 | | A0849* | 1.21 | | 1 | R |
| YNC 025 | 2.12 | | M2970* | 1.28 | | 1 | R |
| YPE 642 | 2.05 | | J4634* | 1.22 | | 1 | F |
| Painted Plates | | | | | | | |
| All (same ten numbers) | 0.12 to 0.16 | Black on White | (No used painted plates) | | | | |

*These plates were used on all tests.

**Determined in 3M laboratory.

# TEST DESCRIPTION AND PROCEDURES

## Human Observations

Plate Selection. Prior to beginning the tests a selection was made of the used plates to be included. There were ten used beads-on-paint plates and ten used reflective sheeting ones, and five of each were selected for the tests as indicated in Table 1. Considerations in making the selections were:

1. All ages of plates should be represented.
2. Eliminate those plates that are noticeably different and can be remembered by different letter size or grouping, background figures, or other identifying characteristics.
3. Include plates in approximately equal numbers from front and rear mountings.

A computer program was written for randomly selecting the plates to be shown to each observer, and 70 different sets of 25 plates each were selected. The same 10 used plates were included in each set, but not necessarily in the same sequence, and 5 from each of the other 3 groups of new plates were included in each set. Thus each set contained the same 5 used BOP plates, the same 5 used RS plates, 5 new BOP plates, 5 new RS plates, and 5 new NP plates, each of the last 3 sets of 5 being randomly selected from the 10 plates available in each category. A sample test set is shown in Figure 5, together with a copy of the form on which observation data were recorded.

Observers. A total of 22 observers was engaged to participate in the tests, with the anticipation that of this number at least 20 complete sets of data could be obtained. The number of observations required for

Date: ________ Time: ________
Rainfall: __________ inches/hr

NAME: ____________________ Phone No: ______ Age: ___ Sex: ___

Address: ____________________ Occupation: ____________

Corrective Lenses: Yes ____ No ____ Date of Most Recent Eye Exam: ____________

| Obs Set 62 | | | | Nighttime Observations | | | Daytime Observations | | |
|---|---|---|---|---|---|---|---|---|---|
| . | Code | License | Treat | 1 | 2 | 3 | 1 | 2 | 3 |
| 1 | 27 | ENC562 | 3 | | | | | | |
| 2 | 38 | 21 801 | 5 | | | | | | |
| 3 | 16 | NCY405 | 2 | | | | | | |
| 4 | 20 | EPY650 | 2 | | | | | | |
| 5 | 3 | YPE642 | 1 | | | | | | |
| 6 | 37 | AO 849 | 5 | | | | | | |
| 7 | 40 | J4 634 | 5 | | | | | | |
| 8 | 39 | B2 537 | 5 | | | | | | |
| 9 | 15 | NPE064 | 2 | | | | | | |
| 10 | 33 | 11 966 | 4 | | | | | | |
| 11 | 19 | YNC025 | 2 | | | | | | |
| 12 | 30 | EPY650 | 3 | | | | | | |
| 13 | 34 | 70 146 | 4 | | | | | | |
| 14 | 6 | NCY405 | 1 | | | | | | |
| 15 | 31 | 16 863 | 4 | | | | | | |
| 16 | 4 | PNE240 | 1 | | | | | | |
| 17 | 11 | CNP426 | 2 | | | | | | |
| 18 | 2 | CYE265 | 1 | | | | | | |
| 19 | 32 | 24 767 | 4 | | | | | | |
| 20 | 29 | YNC025 | 3 | | | | | | |
| 21 | 35 | 87 987 | 4 | | | | | | |
| 22 | 5 | NPE064 | 1 | | | | | | |
| 23 | 23 | YPE642 | 3 | | | | | | |
| 24 | 22 | CYE265 | 3 | | | | | | |
| 25 | 36 | M2 970 | 5 | | | | | | |

Data Recorded by: ____________________ Set No: ______
Plates Displayed by: ____________________
Comments:

Figure 5. Sample test set and laboratory data sheet.

a statistically sound analysis was decreased by utilizing trained observers, such as highway patrolmen or their equivalent. Those participating included 4 Utah highway patrolmen, 8 sheriff's deputies from Cache County, and 10 policemen from Logan, North Logan, and Hyrum cities. These men were scheduled to participate in the tests on their off-duty time, and each one came into the laboratory on three different nights. In addition, five men also came during the daytime for 1 hour each to complete the daytime observations.

Test Procedures. As each observer came into the laboratory, he was given a set of instructions, shown in Figure 6. Oral instructions were also given at that time to answer any questions and to dispel any apprehensions he might have concerning the tests. Personal data for each individual were also recorded on the top of the data sheet. He was then taken to the test vehicle, and allowed to operate it briefly to get a "feel" for the test. A Chinese graduate student was seated in the vehicle also, directly behind the observer to serve as data recorder (see Figure 7). Another Chinese graduate student was stationed at the far end of the track, who positioned the plates to be observed in the sequence provided by the computer. These two students communicated freely via radio in their native language, with no fear of being understood by the observer. The choice of Chinese students to assist on the project proved to be a wise one, and totally eliminated any bias that could have been introduced to the observer had the communication between the two positions been in English. Each student had a copy of the set of 25 plates to be shown to the observer so that the displayer could know the sequence for showing them and the recorder had a means of checking each reading for correctness.

When all was ready, the observer was instructed to advance the car until he could read the first plate. When he thought he could read it, he stopped the car and read the number aloud, which was written by the recorder. The student also recorded the distance from the plate at which the reading was made, by viewing with a flashlight a measuring tape fastened to one of the vehicle tracks for that purpose. If the number was read correctly, the observer was instructed to back up to the

INSTRUCTIONS

1. Please stay out of the test area until your turn comes. (This is to avoid bias.) Wait in the break room.
2. Test is to determine reflectivity of license plates. It is not to test your eye sight.
3. You cannot fail the test, so avoid wild guessing.
4. Always begin the test at a distance beyond your eye sight, and advance the car until you can correctly read the plate. Do not read the plate and then back away to furtherest legible distance.
5. When you think you can see the license number, stop the car and read the number aloud. Don't advance further until instructed to do so.
6. If number is read incorrectly, you will be asked to proceed for a second or a third try.
7. Above procedures will be repeated for 25 different plates.
8. Don't run car off the end of the track!
9. Please watch your step in the dimly lighted lab.

Figure 6. Instructions given to observers.

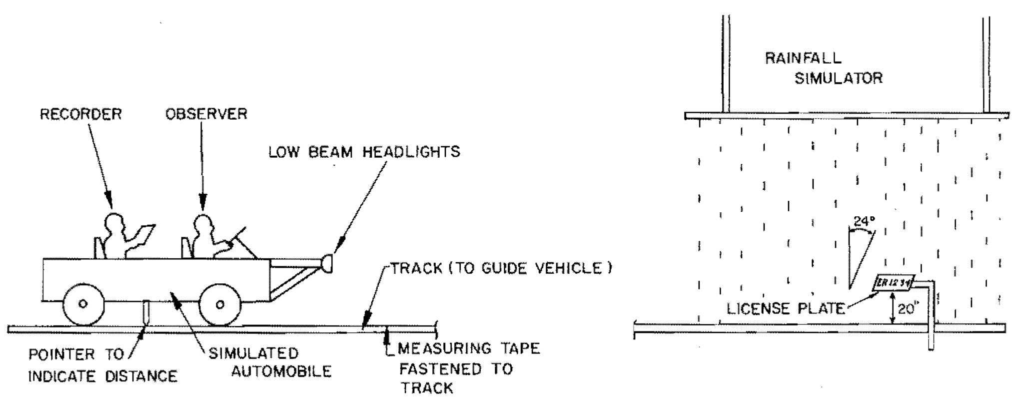


Figure 7. License plate testing facility.

end of the track and wait for the next plate. If read incorrectly, he was instructed to proceed forward and read it again. For each try, the number he read aloud was recorded, as was its corresponding distance.

The test was conducted in four parts. On the first set of nights all 22 observers viewed the plates in a dry condition. On the second set of nights they viewed the plates under 1/2 inch/hour rainfall, and during the third set of nights, under 2 inches/hour rainfall. On the rainfall nights, the plates were stored in water to eliminate any waiting time for the plates to be wetted. Five of the observers were asked to come during daylight hours as well and complete the tests out-of-doors. Each of these five men viewed 25 plates. These tests were conducted during early afternoon hours on each of two different days, and lighting was fairly uniform with bright haze and minimum shadows.

Reflectance Measurements

Measurements were made previously in the 3M laboratory of each license plate used in the Utah Water Research Laboratory test, and these values are shown in Table 1. The same kinds of readings were taken in the UWRL with the plates in position beneath the rainfall simulator, and these values are shown in Table 6 in the Analysis and Discussion Section. The position of the equipment for making these measurements was as shown in Figure 3, with the divergence angles of the photo cells being 0.2° and 1.0°, respectively. The distance from the license plates, suspended beneath the rainmaker, to the modified carousel projector was set at 56.5 feet.

It can be noted that the values in Table 6 differ noticeably from corresponding values in Table 1. The major part of this difference is attributable to the 24° angle at which the plates were mounted in the

UWRL to ensure thorough and uniform wetting (the wetting of a license plate under road conditions is very complete due to factors such as road spray, wind currents, etc., not utilized in the rainfall simulator). A minor part of the difference is attributable to experimental variance encountered in photometric measurement.

Additional reflectance measurements were made with the photocell shown in Figure 3 mounted in the vehicle at the driver's eye position, and the carousel projector being replaced by the vehicle headlights. Measurements were made at distances of 60, 90, 120, and 150 feet from selected license plates suspended beneath the simulator. Results of this set of tests are recorded in Table 7.

# ANALYSES AND DISCUSSION

## Reflectance Measurements

The reflectance data were first analyzed using a two-way analysis of variance with factor 1, the license plate treatments (Table 2), and factor 2, rain intensity (Table 3). The reflectance data on the painted plates were omitted from this analysis because they had very little variation. The analysis indicated highly significant differences within both factors and interaction. The mean responses and standard deviations within each cell are given in Tables 4 and 5 for observation angles of 0.2° and 1.0° respectively. (Analysis based on laboratory data for these tests as given in Table 6.)

Interpretation of the data is enhanced by viewing the graphs in Figures 8-15. These graphs show the individual data points from Table 6, and the means connected by straight lines. Numbers on graphs indicate number of data points at each location. Aside from the high reflectivity of the reflective sheeting, the most interesting response is the interaction between rain intensity and plate treatment. Beads-on-paint (Figures 8, 9, 14, 15) show a significant degradation in reflectivity with wetting. The amount of rain appears unimportant. In contrast the new reflective sheeting shows no significant degradation between dry and wet conditions at 0.2° (Figure 10) and very little degradation at 1.0° (Figure 11). The used reflective sheeting shows some improvement with wetting (Figures 12 and 13).

Two additional effects of reflective sheeting seem interesting. The first is that there seems to be no degradation of the reflectivity with

Table 2. License plate treatments.

| Code | Treatment |
|---|---|
| 1 | New Beads on Paint (NBOP) |
| 2 | New Reflective Sheeting (NRS) |
| 3 | New Paint (NP) |
| 4 | Old Reflective Sheeting (ORS) |
| 5 | Old Beads on Paint (OBOP) |

Table 3. Rain intensity.

| Code | Intensity (inches/hr) |
|---|---|
| 1 | 0 |
| 2 | 0.5 |
| 3 | 2 |

Table 4. Mean/standard deviation ($0.2^{o}$) (candlepower/foot candle/plate).

| Rain Intensity Code | Plate Treatment Code | | | | |
|---|---|---|---|---|---|
| | 1 (NBOP) | 2 (NRS) | 3 (NP) | 4 (ORS) | 5 (OBOP) |
| 1 | 1.66/0.08 | 9.67/0.42 | 0.09/0 | 9.68/1.66 | 0.92/0.12 |
| 2 | 0.27/0.07 | 9.81/0.46 | 0.09/0 | 10.92/1.13 | 0.09/0.03 |
| 3 | 0.20/0.05 | 9.78/0.51 | 0.087 | 11.10/1.01 | 0.09/0.01 |

Table 5. Mean/standard deviation ($1.0^{o}$)(candlepower/foot candle/plate).

| Rain Intensity Code | Plate Treatment Code | | | | |
|---|---|---|---|---|---|
| | 1 (NBOP) | 2 (NRS) | 3 (NP) | 4 (ORS) | 5 (OBOP) |
| 1 | 0.48/0.03 | 3.48/0.13 | 0.087 | 2.96/0.39 | 0.35/0.06 |
| 2 | 0.14/0.02 | 3.44/0.14 | 0.09/0 | 3.04/0.29 | 0.08/0.01 |
| 3 | 0.12/0.02 | 3.36/0.12 | 0.087 | 3.21/0.34 | 0.08/0.01 |

Table 6. Reflectance test data (candlepower/foot candle/plate).

| License Plates | Treatment (inches/hour) | | | | | |
|---|---|---|---|---|---|---|
| | Dry | | 1/2 | | 2 | |
| | $0.2^{o}$ (a) | $1.0^{o}$ (b) | $0.2^{o}$ | $1.0^{o}$ | $0.2^{o}$ | $1.0^{o}$ |
| Code 1 - New Beads-on-Paint | | | | | | |
| CNP 426 | 1.68 | 0.48 | 0.33 | 0.16 | 0.23 | 0.13 |
| CYE 265 | 1.49 | 0.42 | 0.19 | 0.11 | 0.14 | 0.09 |
| ENC 562 | 1.63 | 0.46 | 0.31 | 0.15 | 0.20 | 0.12 |
| EPY 650 | 1.61 | 0.46 | 0.18 | 0.11 | 0.14 | 0.10 |
| NCY 405 | 1.73 | 0.49 | 0.31 | 0.15 | 0.22 | 0.12 |
| NPE 064 | 1.82 | 0.52 | 0.38 | 0.17 | 0.32 | 0.15 |
| PNE 240 | 1.69 | 0.49 | 0.30 | 0.15 | 0.21 | 0.12 |
| PYC 504 | 1.68 | 0.48 | 0.24 | 0.13 | 0.19 | 0.12 |
| YNC 025 | 1.66 | 0.48 | 0.17 | 0.11 | 0.14 | 0.10 |
| YPE 642 | 1.64 | 0.47 | 0.28 | 0.14 | 0.22 | 0.12 |
| Code 2 - New Reflective Sheeting | | | | | | |
| CNP 426 | 10.2 | 3.51 | 9.84 | 3.36 | 9.79 | 3.33 |
| CYE 265 | 9.53 | 3.43 | 9.31 | 3.38 | 9.98 | 3.44 |
| ENC 562 | 9.85 | 3.55 | 9.98 | 3.52 | 9.58 | 3.28 |
| EPY 650 | 10.1 | 3.60 | 10.2 | 3.62 | 9.47 | 3.44 |
| NCY 405 | 9.93 | 3.57 | 10.4 | 3.60 | 10.4 | 3.49 |
| NPE 064 | 9.95 | 3.49 | 10.4 | 3.52 | 10.5 | 3.52 |
| PNE 240 | 9.12 | 3.28 | 9.18 | 3.25 | 9.20 | 3.25 |
| PYC 504 | 9.76 | 3.57 | 9.98 | 3.52 | 10.0 | 3.41 |
| YNC 025 | 8.96 | 3.22 | 9.26 | 3.20 | 8.86 | 3.12 |
| YPE 642 | 9.29 | 3.57 | 9.58 | 3.38 | 9.98 | 3.36 |
| Code 3 - New Painted | | | | | | |
| CNP 426 | 0.09 | 0.09 | 0.09 | 0.09 | 0.09 | 0.09 |
| CYE 265 | 0.09 | 0.09 | 0.09 | 0.09 | 0.09 | 0.09 |
| YPE 642 | 0.09 | 0.08 | 0.09 | 0.09 | 0.08 | 0.08 |
| Code 4 - Used Refl. Sheeting | | | | | | |
| 24767 | 11.8 | 3.47 | 12.2 | 2.80 | 12.2 | 3.57 |
| 70146 | 8.80 | 2.71 | 10.8 | 2.80 | 10.5 | 2.77 |
| 11966 | 11.1 | 3.28 | 12.0 | 3.46 | 12.2 | 3.52 |
| 16863 | 8.66 | 2.74 | 10.1 | 3.22 | 10.4 | 3.12 |
| 87987 | 8.05 | 2.61 | 9.52 | 2.90 | 10.2 | 3.06 |
| Code 5 - Used Beads-On-Paint | | | | | | |
| B2537 | 0.84 | 0.35 | 0.07 | 0.07 | 0.07 | 0.07 |
| Z1801 | 0.75 | 0.27 | 0.09 | 0.08 | 0.09 | 0.07 |
| A0849 | 0.96 | 0.33 | 0.09 | 0.08 | 0.09 | 0.09 |
| M2970 | 1.03 | 0.45 | 0.14 | 0.10 | 0.11 | 0.09 |
| J4634 | 1.00 | 0.34 | 0.08 | 0.07 | 0.09 | 0.07 |

Note: Test position for plates = $24^{o}$ from vertical, and normal to track.

(a) $0.2^{o}$ = observation angle corresponding to 600-800 feet distance on the roadway. (Suitable for long range detection of license plate.)

(b) $1.0^{o}$ = Observation angle corresponding to 120-150 feet distance on the roadway. (Suitable for reading license plate.)

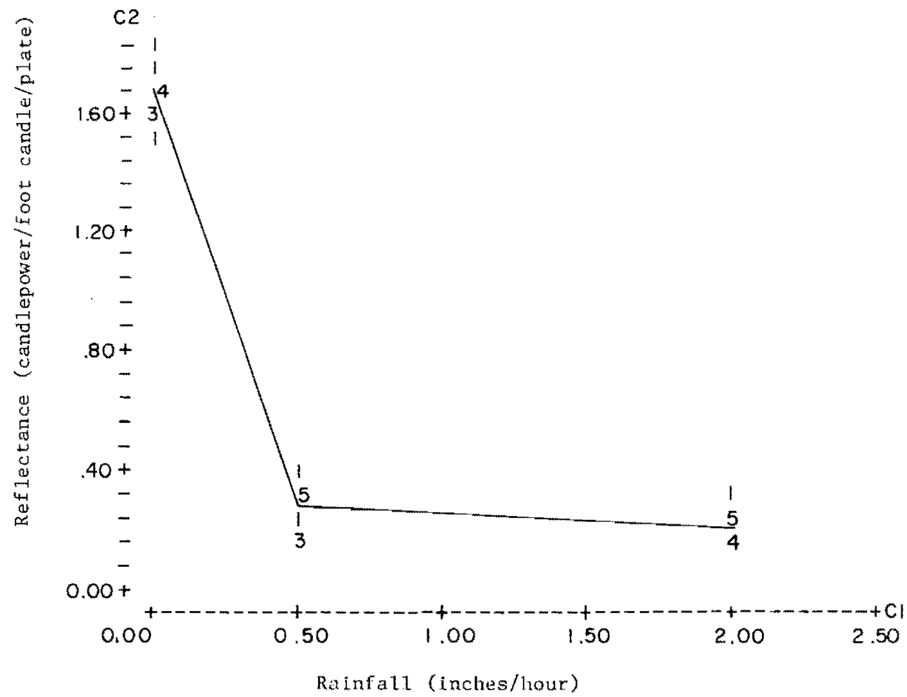


Figure 8. Code 1 reflectance values ($0.2^{o}$) (new beads-on-paint).

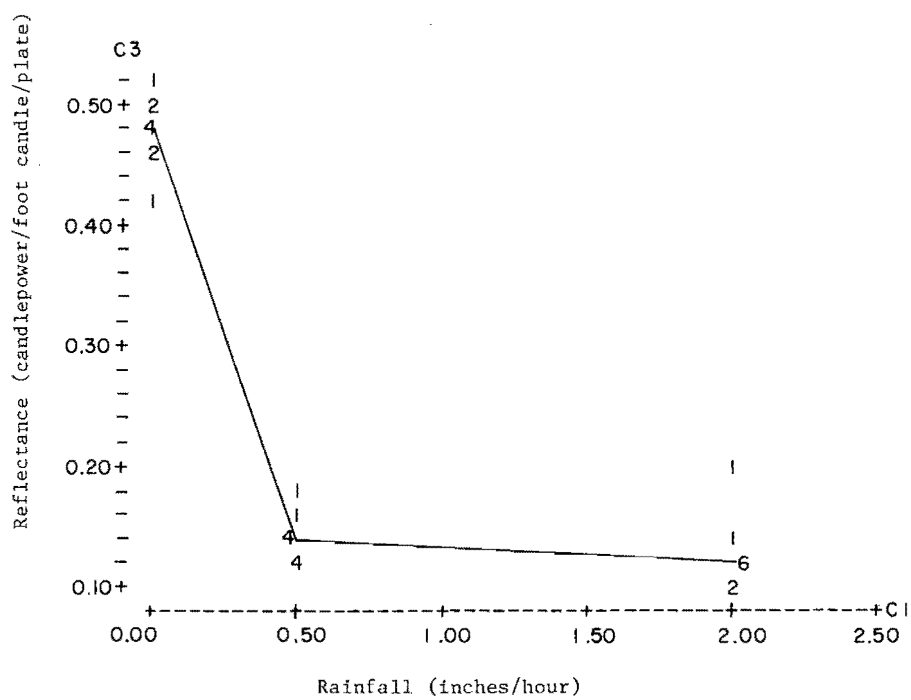


Figure 9. Code 1 reflectance values ($1.0^{o}$) (new beads-on-paint).

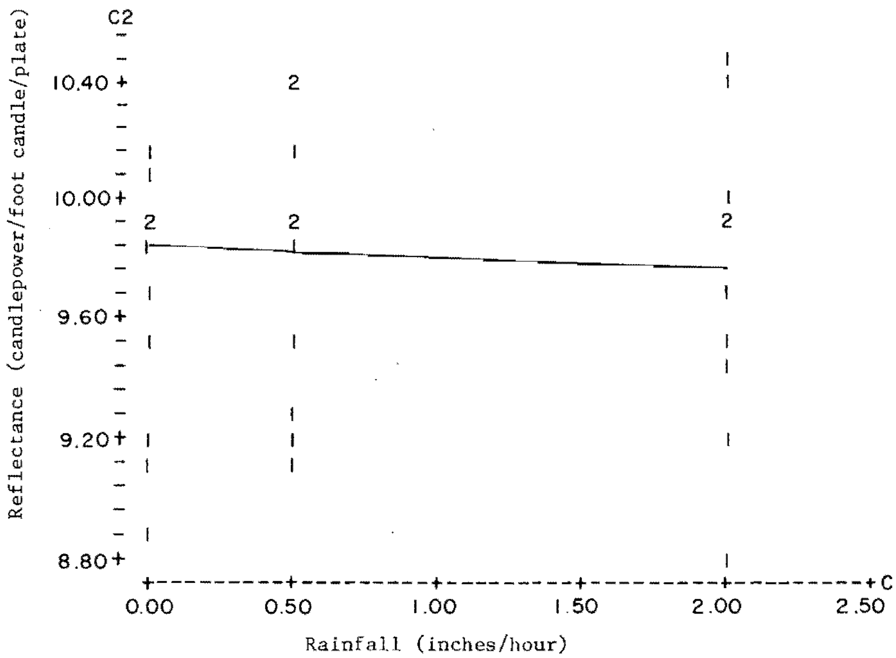


Figure 10. Code 2 reflectance values (0.2°) (new reflective sheeting).

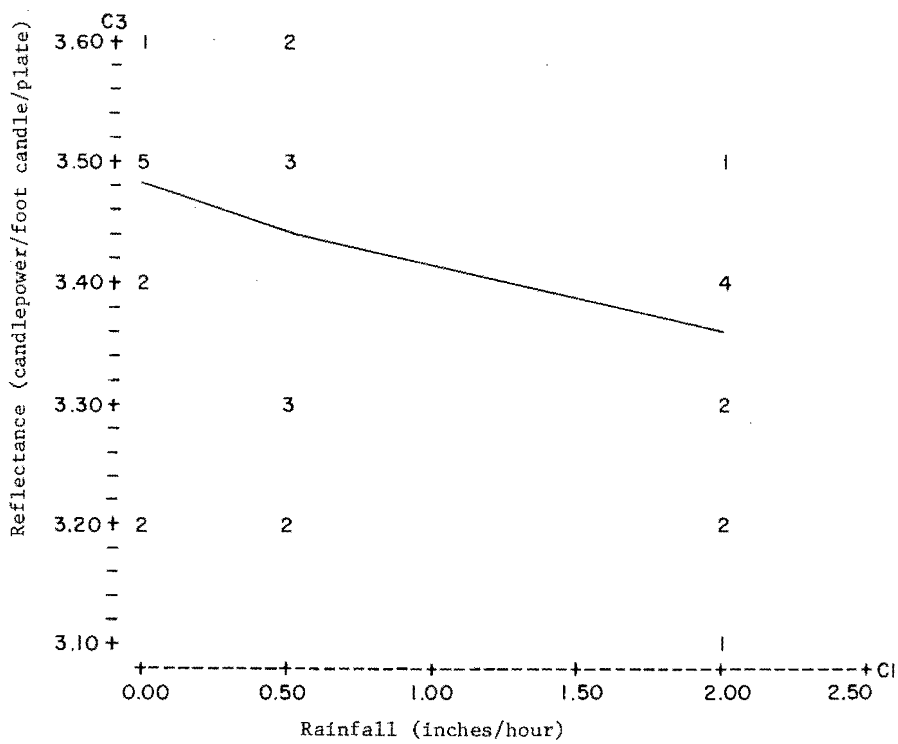


Figure 11. Code 2 reflectance values (1.0°) (new reflective sheeting).

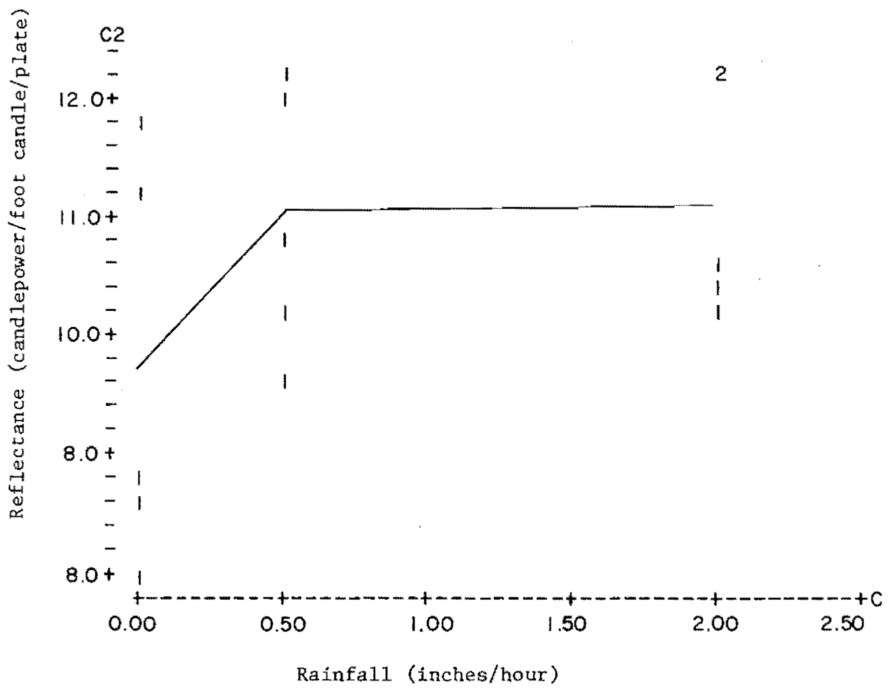


Figure 12. Code 4 reflectance values ($0.2^{o}$) (used reflective sheeting).

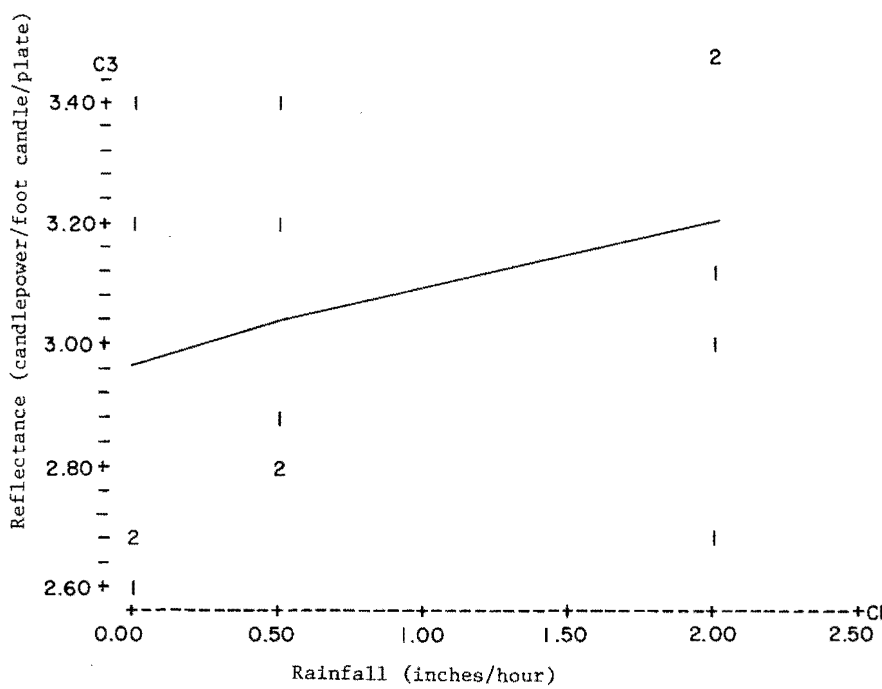


Figure 13. Code 4 reflectance values ($1.0^{o}$) (used reflective sheeting).

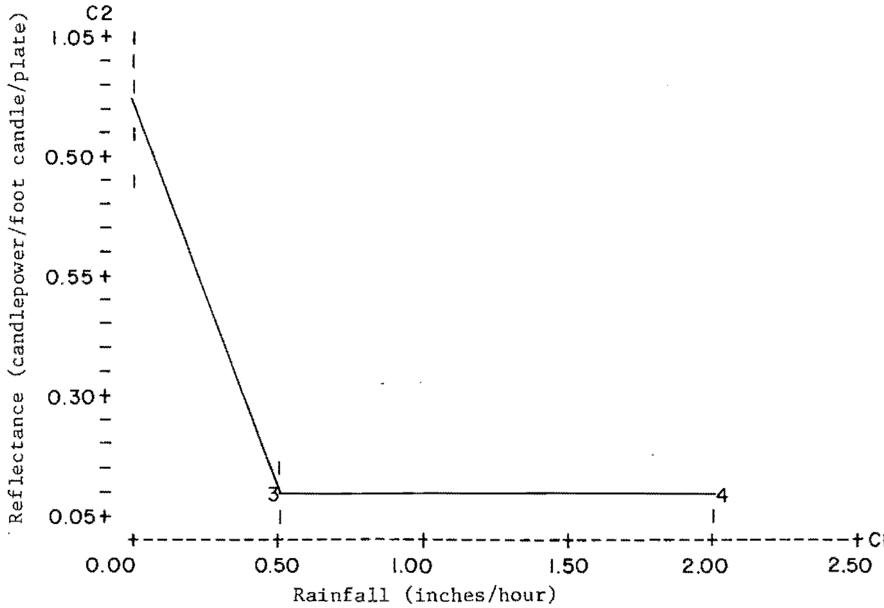


Figure 14. Code 5 reflectance values ($0.2^{o}$) (used beads-on-paint).

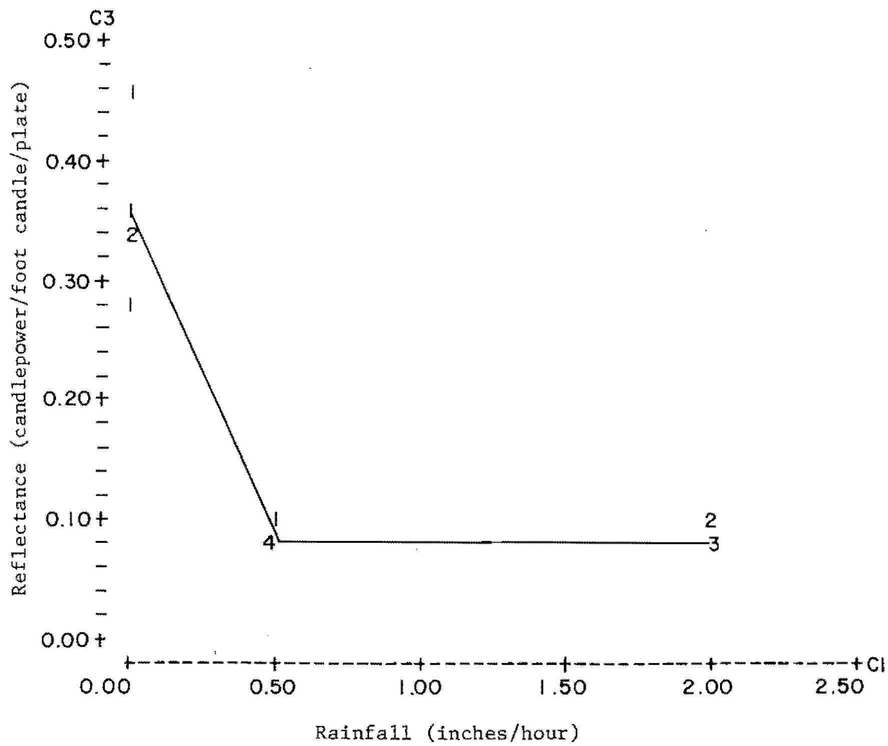


Figure 15. Code 5 reflectance values ($1.0^{o}$) (used beads-on-paint).

time (in fact the data show greater reflectivity with time). The second effect can be noted from Tables 4 and 5. Although there is no degradation in reflectivity, the standard deviation of reflectivity increases. This is to be expected since each plate experiences a different environment during its use.

Three plates in each treatment category were used to investigate the effect of distance on reflectivity under the various plate and rain intensity combinations. These measurements were made from the observation vehicle with the photometric equipment mounted at the driver's eye position. Data from these tests (Table 7) indicate that the pattern of reflectivity is similar to that measured at a fixed location and recorded in Figures 8 - 15. Also, the RS plates are significantly superior in all instances to the other plate treatments.

Human Observations

Nighttime. The plate legibility data consist of the distances from the plate at which correct reading of the license symbols occurred. The plates were subjected to surface material treatments and rain intensity levels shown in Tables 2 and 3. In addition to these two factors observers were considered as a third factor (blocks) in order to eliminate a large variation in observer performance. A fourth intensity level or condition is also included in this experiment. This condition is daylight with no rain. All other observations were conducted at night. Only five of the 22 observers participated in the daylight test.

Analysis of the plate legibility data presented some difficulty. It was evident from the performance of some of the observers that repeating

Table 7. Reflectance values at driver's eye position in test vehicle (candlepower/foot candle/plate).

| License Plates | Dry | | | | 1/2 iph | | | | 2 iph | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 60[a] | 90 | 120 | 150 | 60 | 90 | 120 | 150 | 60 | 90 | 120 | 150 |
| Code 1 New BOP | | | | | | | | | | | | |
| NPE 064 | 0.21 | 0.28 | 0.35 | 0.47 | 0.08 | 0.11 | 0.08 | 0.10 | 0.08 | 0.09 | 0.11 | 0.03 |
| ENC 562 | 0.19 | 0.29 | 0.28 | 0.52 | 0.08 | 0.09 | 0.11 | 0.10 | 0.06 | 0.08 | 0.05 | 0.03 |
| CYE 265 | 0.15 | 0.24 | 0.16 | 0.41 | 0.08 | 0.04 | 0.08 | 0.10 | 0.04 | 0.01 | 0.11 | 0.01 |
| Code 2 New R/S | | | | | | | | | | | | |
| EPY 650 | 1.20 | 1.75 | 2.94 | 3.57 | 1.20 | 2.55 | 3.00 | 3.32 | 1.18 | 2.34 | 2.96 | 3.51 |
| CYE 265 | 1.20 | 1.69 | 2.64 | 3.31 | 1.16 | 2.66 | 3.34 | 3.48 | 1.24 | 2.40 | 3.26 | 3.46 |
| YNC 025 | 0.98 | 1.61 | 2.50 | 3.21 | 1.05 | 2.30 | 3.00 | 3.17 | 1.09 | 2.26 | 3.07 | 3.15 |
| Code 3 New Paint | | | | | | | | | | | | |
| CNP 426 | 0.07 | 0.10 | 0.05 | 0.05 | 0.07 | 0.08 | 0.11 | 0.10 | 0.05 | 0.07 | 0.08 | - |
| CYE 265 | 0.08 | 0.12 | 0.05 | 0.16 | 0.07 | 0.05 | 0.11 | 0.10 | 0.07 | 0.07 | 0.11 | - |
| YPE 642 | 0.08 | 0.10 | 0.05 | 0.16 | 0.07 | 0.05 | 0.08 | 0.10 | 0.05 | 0.07 | 0.03 | - |
| Code 4 Used R/S | | | | | | | | | | | | |
| 24767 | 1.20 | 2.04 | 2.70 | 3.36 | 1.24 | 2.61 | 3.45 | 3.63 | 1.20 | 2.65 | 3.40 | 3.46 |
| 70146 | 0.71 | 1.28 | 1.84 | 2.38 | 0.80 | 1.69 | 2.39 | 2.66 | 0.76 | 1.73 | 3.36 | 2.45 |
| 11966 | 1.00 | 1.82 | 2.57 | 3.16 | 1.20 | 2.60 | 3.34 | 3.53 | 1.15 | 2.53 | 3.23 | 3.46 |
| 16863 | 0.96 | 1.60 | 2.12 | 2.53 | 1.13 | 2.30 | 2.93 | 3.22 | 1.11 | 2.32 | 3.10 | 2.95 |
| 87987 | 0.87 | 1.51 | 2.08 | 2.38 | 1.09 | 2.14 | 2.93 | 3.02 | 1.05 | 2.19 | 2.80 | 3.00 |
| Code 5 Used BOP | | | | | | | | | | | | |
| B 2537 | 0.12 | 0.16 | 0.23 | 0.31 | 0.05 | 0.08 | 0.08 | 0.15 | 0.03 | 0.13 | 0.11 | 0.08 |
| Z 1801 | 0.08 | 0.14 | 0.19 | 0.26 | 0.04 | 0.09 | 0.05 | 0.15 | 0.03 | 0.05 | 0.08 | 0.08 |
| A 0849 | 0.12 | 0.21 | 0.16 | 0.31 | 0.06 | 0.13 | 0.11 | 0.20 | 0.04 | 0.12 | 0.05 | 0.13 |
| M 2970 | 0.15 | 0.26 | 0.21 | 0.41 | 0.07 | 0.10 | 0.13 | 0.15 | 0.04 | 0.05 | 0.05 | 0.18 |
| U 4634 | 0.13 | 0.19 | 0.21 | 0.36 | 0.05 | 0.15 | 0.08 | 0.15 | 0.03 | 0.08 | 0.08 | 0.03 |

Rainfall Rates: Dry, 1/2 iph, 2 iph.

[a]Distance from license plate in feet.

the license plate symbols on each treatment provided a great opportunity for learning. This effect was also evident from discussions with observers. Thus the time (learning) is confounded with rain intensity levels. Because of this treatment uncorrected comparisons which cross rain intensity levels are not valid. Comparisons within an intensity level are valid.

An initial analysis of variance indicated differences among all main effects (treatments, intensity and observers). In addition a significant interaction between intensity and treatments was noted. Because of the confounding effect of learning, no comparisons of interaction involving rain levels seem justified. However the effect of treatments within intensity levels provides interesting information. Table 8 gives the mean legibility distances (in feet) of all observations within a cell of plate treatment x rain intensity. A least significant difference of 6.3 at the 95 percent level may be used to determine significant differences between any pair of treatments within the first three intensity levels. An LSD of 13.3 is appropriate for comparing means within condition 4 (daytime, dry).

A very interesting effect may be noted in comparing the beads-on-paint (BOP) treatment with reflective sheeting (RS). At zero rain intensity there is no significant difference between the two treatments although the RS data have a higher mean. However at both nonzero rain levels, the reflective sheeting is significantly better than beads-on-paint. This agrees with the reflectivity measurements which indicate no degradations of reflectivity with application of water.

The effect of learning by the observers due to repeated sightings of the same plate numbers can effectively be measured from the data on

Table 8. Mean legibility distance (feet).

| Rain Intensity (inches/hr) | Plate Treatment Code | | | | |
|---|---|---|---|---|---|
| | 1 (NBPO) | 2 (NRS) | 3 (NP) | 4 (ORS) | 5 (OBOP) |
| 0 | 113.4 | 118.1 | 95.7 | 114.6 | 97.9 |
| 0.5 | 116.2 | 125.1 | 102.9 | 117.3 | 99.0 |
| 2 | 121.0 | 133.4 | 114.2 | 122.8 | 104.2 |
| 0 (day) | 161.5 | 165.6 | 171.4 | 154.6 | 117.3 |

new painted plates (code 3). The reflectance data on the painted plates (Table 6) indicate no effect due to rain. Assuming that there is no influence in this experiment other than reflectance which might affect legibility distance, the increase in distance of the painted plates as rain is applied is a measure of the learning effect. Therefore from Table 8 the effect of learning from the first cycle averages + 7.2 feet, and + 11.3 feet in the second cycle. Table 9 shows the mean recognition distances for the rainfall intensities 0, 0.5 and 2 inches/hour corrected for these learning effect distances.

Table 9. Corrected mean legibility distance (feet).

| Rain Intensity (inches/hr) | Plate Treatment Code | | | | |
|---|---|---|---|---|---|
| | 1 (NBOP) | 2 (NRS) | 3 (NP) | 4 (ORS) | 5 (OBOP) |
| 0 | 113.4 | 118.1 | 95.7 | 114.6 | 97.9 |
| 0.5 | 109.0 | 117.9 | 95.7 | 107.4 | 90.7 |
| 2 | 102.5 | 114.9 | 95.7 | 104.3 | 85.7 |

It is useful to adopt the new painted (Code 3) plates' legibility distance (95.7 feet) as a standard and compare the deviations of the various treatments from this value. The comparisons are shown in Table 10 with

Table 10. Percent deviation of mean legibility distance from new paint distance (from Table 9).

| Rain Intensity (inches/hr) | Plate Treatment Code | | | | |
|---|---|---|---|---|---|
| | 1 (NBOP) | 2 (NRS) | 3 (NP) | 4 (ORS) | 5 (OBOP) |
| 0 | + 18.5% | + 23.4% | Std | + 19.7% | + 2.3% |
| 0.5 | + 13.9% | + 23.4% | Std | + 12.2% | - 5.2% |
| 2 | + 7.1% | + 20.1% | Std | + 9.0% | - 10.4% |

the deviations being expressed as percentages of the standard (corrected for learning effect). The superiority of reflective sheeting is seen in Table 10 on both new and used plates (Codes 2 and 4, respectively), with the new RS plates significantly out performing all others. In addition the reflective sheeting appears to better withstand the effects of age. The used reflective sheeting maintains a slight advantage over new beads-on-paint in two of the three rainfall rates and is considerably better than used beads-on-paint under all rain conditions. It is evident from Table 10 that the margin of advantage of legibility distance which reflective sheeting maintains, increases with rainfall rate. These results correlate closely with those determined in the reflectance tests (Figures 8 - 15). The new reflective sheeting shows little degradation of reflectance under rain.

Daytime. Condition 4 (daytime, dry) data must be handled separately. Under dry, daytime conditions, subjects were able to read much farther than under nighttime conditions. New plates under these conditions were read over 40 percent farther than new reflective plates under dry nighttime conditions (averages not corrected for the learning effect). There were no significant differences between any of the new plates. Neither used RS or used BOP were read as far as the new plates. Used RS plates retained 93 percent of their legibility new, whereas used BOP plates retained only 73 percent of their new legibility. Used BOP had significantly less dry daytime legibility than used RS plates, averaging 24 percent less distance. However, no definitive conclusions can be drawn from this last statement because the letter styles of the two plates were slightly different.

# SUMMARY AND CONCLUSIONS

## Photometric Tests

A summarization of reflectance test data is contained in Table 6. Referring to these data it can be determined that, under conditions suitable for long range detection of the license plates (0.2° observation angle), the following averages are obtained (values in candlepower per foot candle per plate).

| | Treatment | | |
|---|---|---|---|
| Plates | Dry | 1/2 iph | 2 iph |
| New Beads-on-Paint | 1.66 | 0.27 | 0.20 |
| New Reflective Sheeting | 9.67 | 9.81 | 9.78 |
| New Paint | 0.09 | 0.09 | 0.09 |
| Used Reflective Sheeting | 9.68 | 10.92 | 11.10 |
| Used Beads-on-Paint | 0.92 | 0.09 | 0.09 |

New reflective sheeting plates showed no loss under rainfall conditions. New BOP plates decreased to 16 percent of their original brightness at 1/2 inch per hour (iph) rainfall and to 12 percent at 2 iph. BOP plates were only 17 percent of the brightness of reflective sheeting plates when dry, and this decreased when both were wet, to 2.8 percent at 1/2 iph and 2.0 percent at 2.0 iph.

The performance of the used plates showed a similar pattern but with even greater loss of reflectance for BOP plates under wet conditions. In rain, the BOP plates lost over 90 percent of their dry brightness and ultimately were measured at only 0.8 percent of the brightness of reflective sheeting plates. Painted plates and BOP plates were about equal under wet conditions.

Again referring to Table 6, the following averages were obtained under conditions suitable for reading license plates (1.0° observation angle). Values shown are in candlepower per foot candle per plate.

| | Treatment | | |
|---|---|---|---|
| Plates | Dry | 1/2 iph | 2 iph |
| New Beads-on-Paint | 0.48 | 0.14 | 0.12 |
| New Reflective Sheeting | 3.48 | 3.44 | 3.36 |
| New Paint | 0.09 | 0.09 | 0.09 |
| Used Reflective Sheeting | 2.96 | 3.04 | 3.21 |
| Used Beads-on-Paint | 0.35 | 0.08 | 0.08 |

Reflective sheeting plates began at a level 7-8 times brighter than BOP plates, and showed very little degradation under rainfall when new, and even a slight increase for used ones. BOP plates fell to between 25 and 29 percent of the original brightness new and 23 percent for used plates when wet. The brightness average of wet used BOP plates was equal to that of the painted plates, and only 2.5 percent that of the reflective sheeting plates.

In summary, BOP plates show a sizable degradation in reflectivity with wetting. The amount of rain appears unimportant. In contrast, the new reflective sheeting shows no significant degradation between dry and wet conditions at an observation angle of 0.2° and very little degradation at 1.0°. The used reflective sheeting plates show some improvement with wetting.

## Legibility Tests

Nighttime. The following information is reproduced from Table 10 and represents legibility distances of reflective plates as compared with painted plates as a base standard (legibility distance equal to 95.7

feet), after having been corrected for learning effects. Values shown are percentages of painted plate legibility distance.

| Plates | Treatment: Dry | 1/2 iph | 2 iph |
|---|---|---|---|
| New Beads-on-Paint | +18.5 | +13.9 | + 7.1 |
| New Reflective Sheeting | +23.4 | +23.2 | +20.1 |
| New Paint | Standard | Standard | Standard |
| Used Reflective Sheeting | +19.7 | +12.2 | + 9.0 |
| Used Beads-on-Paint | + 2.3 | -5.2 | -10.4 |

The reflective sheeting plates were read farther than the corresponding BOP plates under all conditions with the margin increasing under rainfall conditions. Used BOP plates fell substantially below the legibility of painted plates under wet conditions whereas the RS plates maintained a significant advantage under all conditions tested.

Daytime. Under dry daytime conditions subjects were able to read all plates much farther than the same plates under dry nighttime conditions, and new plates could be read farther than old ones. Used RS plates retained 93 percent of their new legibility, while used BOP plates retained only 73 percent of theirs. Used BOP also had less dry daytime legibility than used RS plates.

In summary both the photometric and legibility parts of this test show reflective sheeting plates to outperform both beads-on-paint plates and painted plates.

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APPENDIX

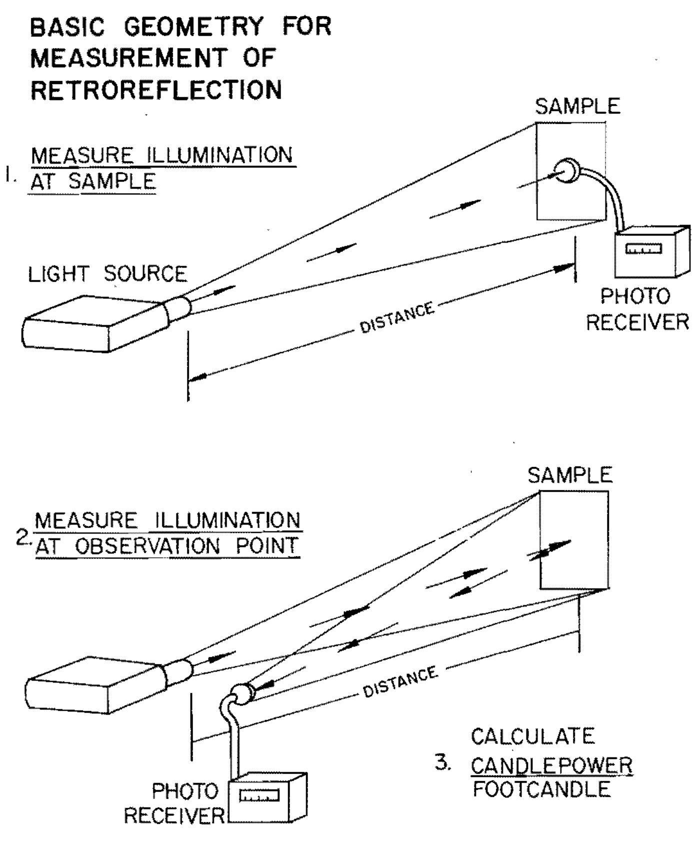


Figure 16. Measurement of reflectance.