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16. ABSTRACT
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Six field tests were conducted with six 14" x 40" sign samples mounted outdoors on test racks during nights when dew was expected to form on the signs. The sign legends incorporated the same three reflective materials. The background materials used included baked enamel, porcelain enamel, and regular reflecting sheeting and were applied to two substrates. These were single sheet aluminum and aluminum bonded to a phenolic impregnated paper honeycomb core backing.

The effect of dew formation was recorded with a system of time lapse photography that was actuated every 20 seconds from dusk to dawn. The incident light angle was 5* or 20*; the camera lens was set at three light openings for different tests.

All of the reflective materials darkened gradually as dew formed on the signs; none of the materials exhibited consistently better legibility; there were only slight differences apparent within the group of materials.

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Dew, moisture conditions, night visibility, reflectance, reflective signs, retrodirective reflection, signs

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HIGHWAY RESEARCH REPORT

THE RELATIVE EFFECT OF DEW ON THREE REFLECTIVE SIGN MATERIALS

71-19

STATE OF CALIFORNIA

BUSINESS AND TRANSPORTATION AGENCY

DEPARTMENT OF PUBLIC WORKS

DIVISION OF HIGHWAYS

MATERIALS AND RESEARCH DEPARTMENT

RESEARCH REPORT

NO. M & R 636469

Prepared in Cooperation with the U.S. Department of Transportation, Federal Highway Administration June, 1971

STATE OF CALIFORNIA—TRANSPORTATION AGENCY

RONALD REAGAN, Governor

DEPARTMENT OF PUBLIC WORKS
DIVISION OF HIGHWAYS
MATERIALS AND RESEARCH DEPARTMENT
5900 FOLSOM BLVD., SACRAMENTO 95819

June 1971
Final Report
M & R No. 636469
D-4-84

Mr. J. A. Legarra
State Highway Engineer

Dear Sir:

Submitted herewith is a research report entitled:

THE RELATIVE EFFECT OF DEW ON THREE REFLECTIVE SIGN MATERIALS

Principal Investigators

Perry R. Lowden, Jr. and J. Robert Stoker

Principal Assistants

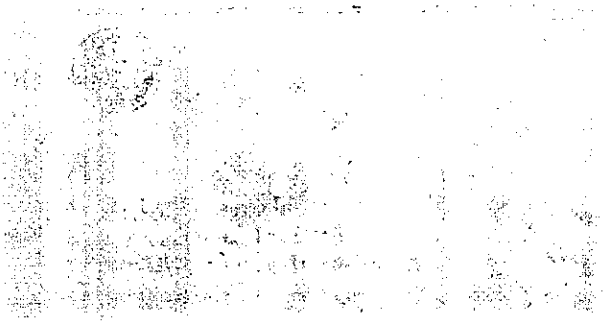
Robert N. Doty
Roger A. Pelkey
Roger L. Stoughton

Under the General Direction of

Eric F. Nordlin

Very truly yours,

JOHN L. BEATON
Materials and Research Engineer



ABSTRACT

REFERENCE: Nordlin, E. F., Lowden, Jr., P. R., and Stoker, J. R., "The Relative Effect of Dew on Three Reflective Sign Materials", State of California, Department of Public Works, Division of Highways, Materials and Research Department Research Report 636469.

ABSTRACT: A series of tests related to the effect of dew formation on reflective sign materials is reported.

Still photographs and motion picture photography were used to record the effect of steam condensing on chilled laboratory samples of (1) reflex reflector buttons, (2) regular reflective sheeting, and (3) a high intensity reflective sheeting, all of which conformed to California Division of Highways specifications. The same samples were also photographed while partially covered with a thin film of water. Darkening of the samples appeared to be due principally to the adverse optical properties of the condensed steam droplets (simulated "dew") rather than to any negative reflective properties of a thin film of water.

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The effect of dew formation was recorded with a system of time lapse photography that was actuated every 20 seconds from dusk to dawn. The incident light angle was 5° or 20°; the camera lens was set at three light openings for different tests.

All of the reflective materials darkened gradually as dew formed on the signs; none of the materials exhibited consistently better legibility; there were only slight differences apparent within the group of materials.

Due to the limited number of tests reported and the verbal reports of various observers that in-service reflective materials occasionally show more extreme loss of reflectance when dew is present than was observed during the tests reported, it was concluded that a much more extensive series of tests with a broad range of variables would be necessary to properly evaluate the different reflective sign materials under dew conditions. Prior to beginning this more extensive test series, an economic study of the relative severity of the problems caused by loss of sign reflectance, when dew is present, should be completed. Consequently, no recommendations are made regarding the desirability of using any one type of reflective sign material to counteract the effects of dew.

KEY WORDS: Dew, moisture conditions, night visibility, reflectance, reflective signs, retrodirective reflection, signs.

ACKNOWLEDGEMENTS

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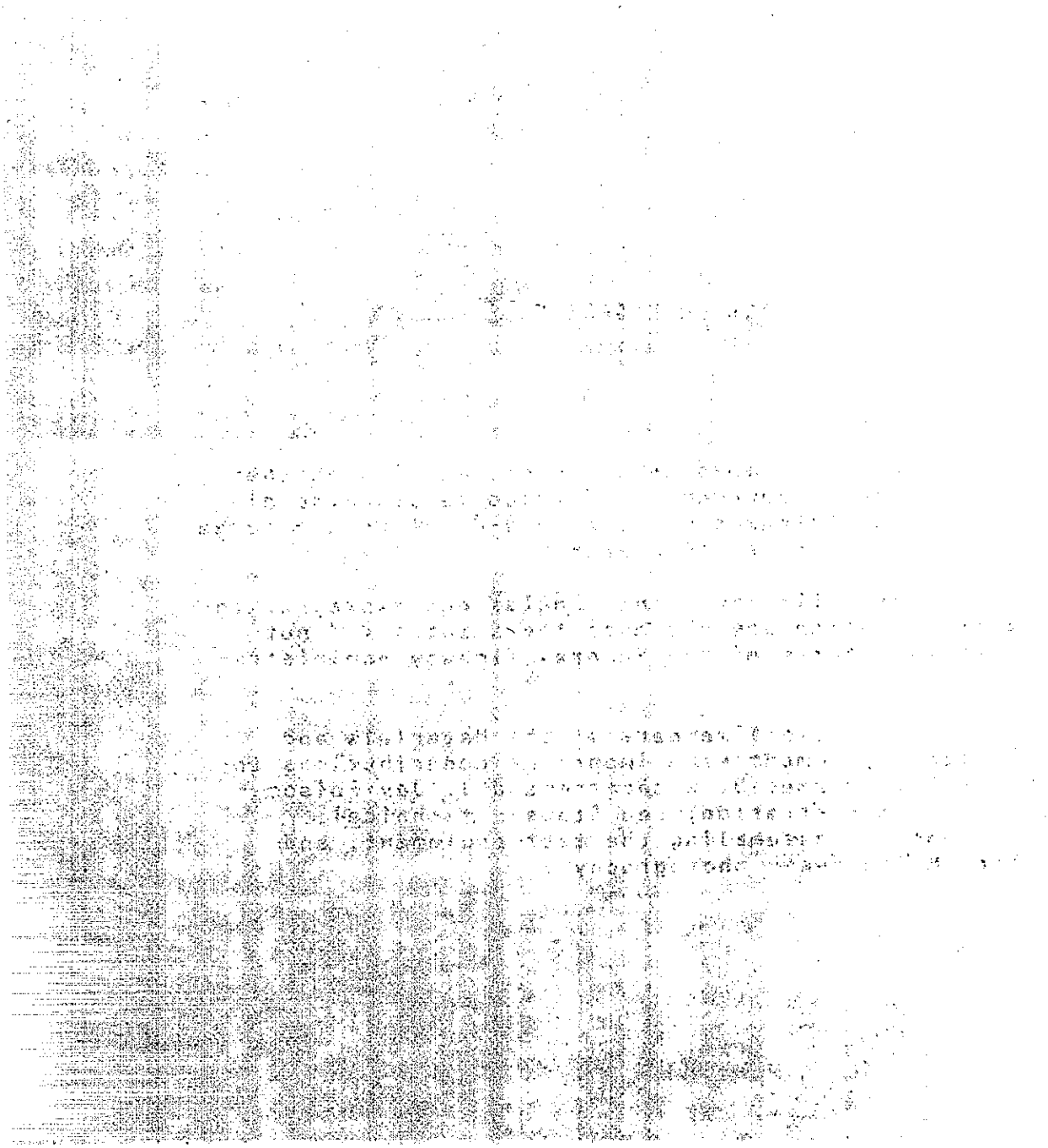
The opinions, findings, and conclusions expressed in this publication are those of the authors and not necessarily those of the Federal Highway Administration.

The following staff members of the Materials and Research Department made important contributions to this study: James H. Woodstrom and J. Jay Folsom - project administration; Lee Staus - technical assistance in assembling the test equipment; and Robert Mortensen - photography.



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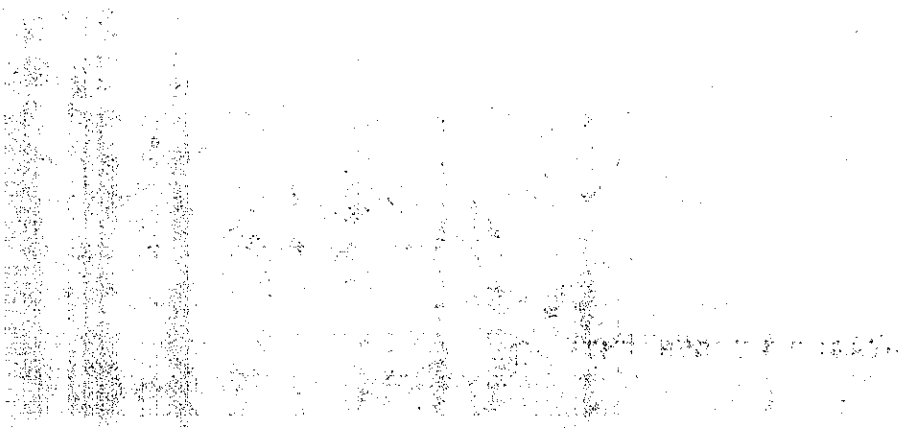
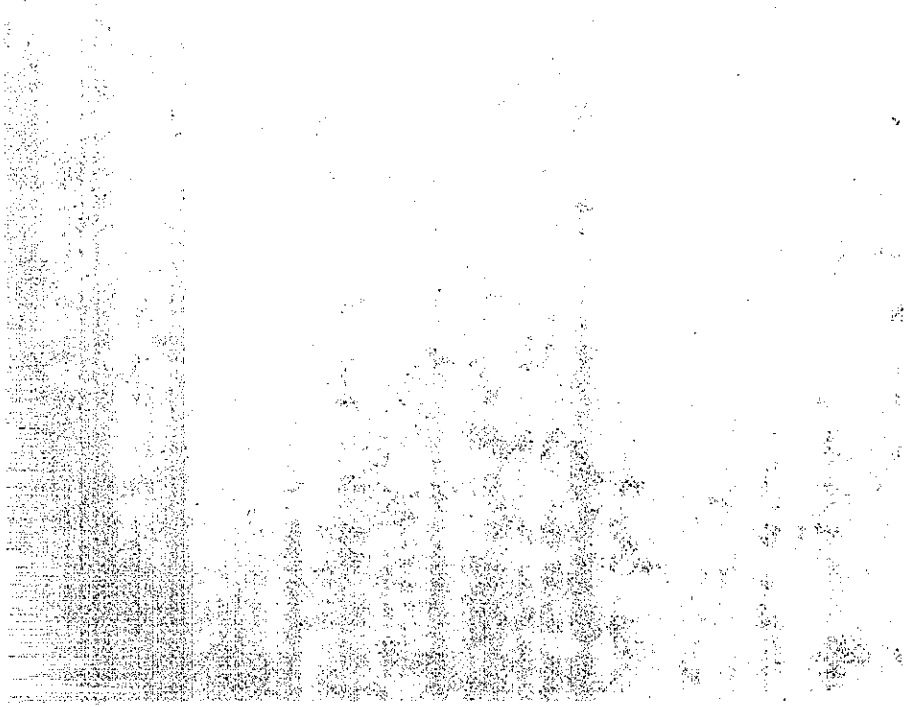




I. INTRODUCTION

Nighttime visibility of highway signing is of prime importance in the safe and orderly movement of traffic during the hours of darkness. Practically all warning, regulatory, and construction signs and many guide signs depend entirely on reflectorization for nighttime visibility. The presence of moisture on the surface of a retro-reflective material, which depends on the collimation of incident light for efficient reflection, refracts and scatters the light beam. A reflective material thus affected becomes non-reflective, or, at best, reflectance is significantly reduced.

The type of moisture deposition that creates this condition is that of "dew". The condensation of atmospheric moisture (dew) occurs when the temperature of the sign and substrate (or backing material) is lower than the dew point of the surrounding air.

Thus the following atmospheric conditions generally are required for dew to form (or frost formation at subfreezing temperatures)[1]:

1. Relatively clear sky -- The sign must lose enough heat by radiation to reach the dewpoint temperature of the surrounding air. A cloud cover, as well as trees and other objects, may reflect this radiation back to the sign and slow down its heat loss. On a clear night, however, the sky, which is at a temperature of absolute zero, reflects no radiation back to the earth so heat loss, by radiation, from the sign is maximized.

2. Still air -- Except when fog is present, the air temperature near the earth's surface is higher than the dewpoint. Thus, heat loss from the sign by radiation must occur faster than heat gain by the sign due to convection currents. Air movement, such as wind, keeps the sign temperature at or near that of the surrounding air and no dew can form.

3. Moisture -- With increasing humidity a smaller differential temperature between the sign and the surrounding air, and hence, a smaller heat loss from the sign, is required to reach the dew point. A dew condition is most prevalent during the time of year when there are warm days and cool nights with a temperature change, for example, from 60° F to 35° F. This increases the chances of reaching the dewpoint.

As dew is formed, there is a definite loss in the reflective quality of the signing material. Frequently, the reflectance loss is non-uniform across the face of a given sign due to variations of sign thickness and amount of backing material. For example, it has occasionally been noted that the portion of the sign face directly in front of the posts will be the last to be affected by dew since it takes longer for this greater mass of material to cool. Likewise this same area will generally be the last to regain its

reflectance because, once cooled, it stays cold longer. The use of thicker sign panels and/or different materials can minimize this "heat sink" effect of the posts. However, all known reflective materials currently used in highway signing are affected in this manner to varying degrees.

There are three basic reflectorized legend systems for highway signs used in California at the present time. These are (1) reflex reflectors, (2) regular reflective sheeting, and (3) high intensity reflective sheeting. As a result of dew formation, each of these materials has a blackout time or period when the reflectance of the sign has been significantly reduced. This is commonly referred to as down time. It is desirable that down time be of minimum duration and that loss of sign reflectance during that time be as small as possible so that the sign legend can be seen clearly by motorists most or all the time. There is no available data to show the number of accidents directly or indirectly attributable to illegible signs that were darkened with dew. However, the down time of a sign undoubtedly relates directly to motorist inconvenience and anxiety and, as such, is a factor in some accidents.

II. OBJECTIVES

The primary objective of this project was to study the relative darkening effect of dew on highway signs with various legend, background, and backing materials currently in use in California.

A secondary objective was to verify that droplets of water on the surface of reflective sign materials were the main cause of visual deterioration rather than a thin film of water.

III. CONCLUSIONS

1. All of the various reflective legends examined appeared to have a nearly equal degree of reflectance loss under dew conditions.

2. The adverse optical properties of dew (droplets), rather than a thin film of water, appears to be the main cause of loss of reflectance.

3. A much more comprehensive series of tests, covering a broad range of variables, would be necessary to thoroughly evaluate the different types of reflective legend, background, and substrate materials under dew conditions. A carefully standardized system of photography would be necessary to acquire accurate and uniform test data.

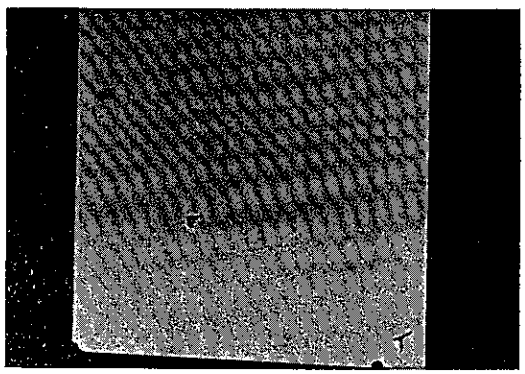
IV. DESCRIPTION OF TESTS

A. Effects of Different Forms of Moisture on Sign Reflectivity.

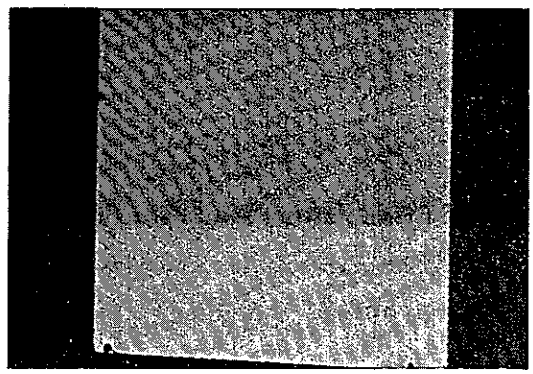
Publications by reflective material manufacturers and other agencies contain differing opinions on both the manner in which dew forms on the surface of the various materials and its effect on the reflectivity of the material. One source states that dew forms as "minute spherical droplets with distinct optical qualities because of the high surface tension of water" and that these droplets refract and scatter the light beam, thus rendering inefficient the reflective materials which depend on collimated incident light for proper reflection[1]. Another source states that dew "tends to form a relatively smooth film over the plane surface. This smooth film acts as a mirror and reflects most of the beamed light in one direction, according to the law that the angle of reflection equals the angle of incidence"[2]. Since signs are located above or to the side of the highway, this reflected light would not come back to the driver. It also seems possible that both phenomena, refraction and reflection, may operate in varying degrees to scatter the light incident on the sign[3].

A simple laboratory test was conducted to gain some insight into the process of dew formation and its effect on reflected light. Small samples of the three reflective materials (regular reflective sheeting, high intensity reflective sheeting, and reflex reflector buttons) were initially chilled in a cold box, then mounted vertically above a pan of hot water. Motion photography recorded the effects the condensing moisture had on the reflective efficiency of the material. Figure 1, which contains selected frames from the motion photography film, shows considerable darkening of the reflective sheeting samples but not of the reflex reflector button. A closeup still photo was then taken of each sample which showed that the moisture had formed as spherical droplets (Figure 2). It is unknown why the reflector button did not darken; the incident light angle may have been a factor.

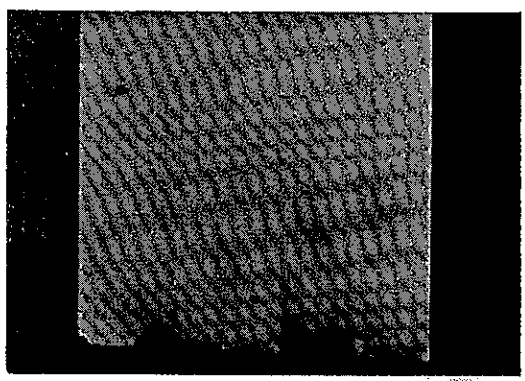
Next, the three samples were placed face up in a tray of water. The depth of the water was such that by breaking the surface tension, a portion of the exposed face of the specimen was flooded by a thin film of water. Photographs of this indicated that the thin film of water did not appreciably affect the reflective properties of the materials (Figure 3). Thus, the "mirror" theory of decreased reflection appeared to be disproved. However, since the camera and light source were not placed to record a series of photos showing the effects of many different angles of incident light, including the angles to be expected between a car and a highway sign, the theory was not rigorously voided.



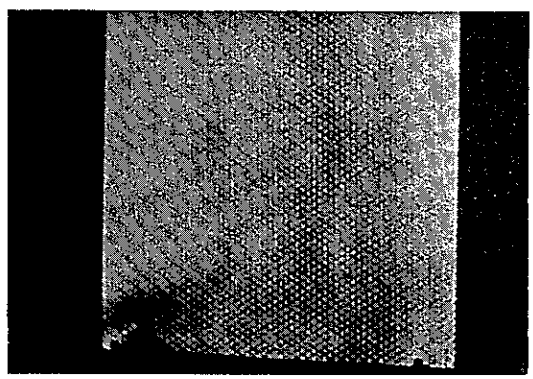
STANDARD REFLECTIVE SHEETING--DRY



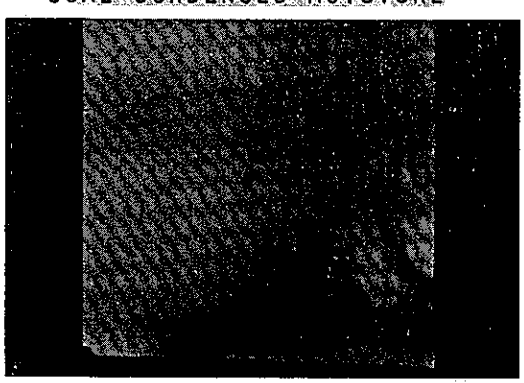
HIGH INTENSITY REFLECTIVE SHEETING--DRY



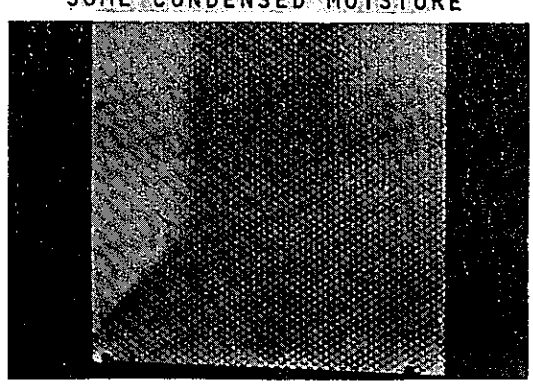
STANDARD REFLECTIVE SHEETING SOME CONDENSED MOISTURE



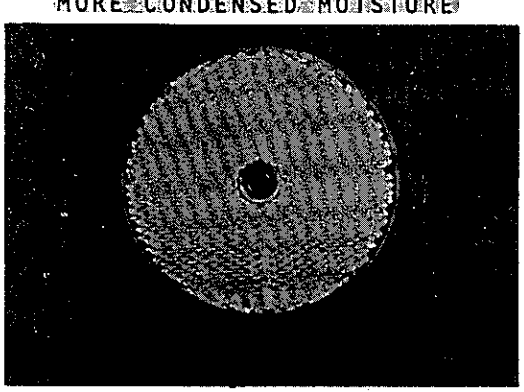
HIGH INTENSITY REFLECTIVE SHEETING SOME CONDENSED MOISTURE



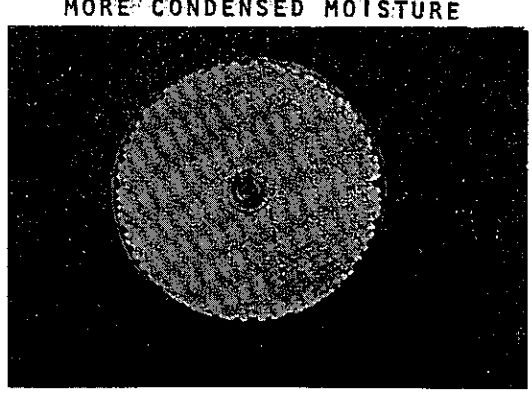
STANDARD REFLECTIVE SHEETING MORE CONDENSED MOISTURE



HIGH INTENSITY REFLECTIVE SHEETING MORE CONDENSED MOISTURE

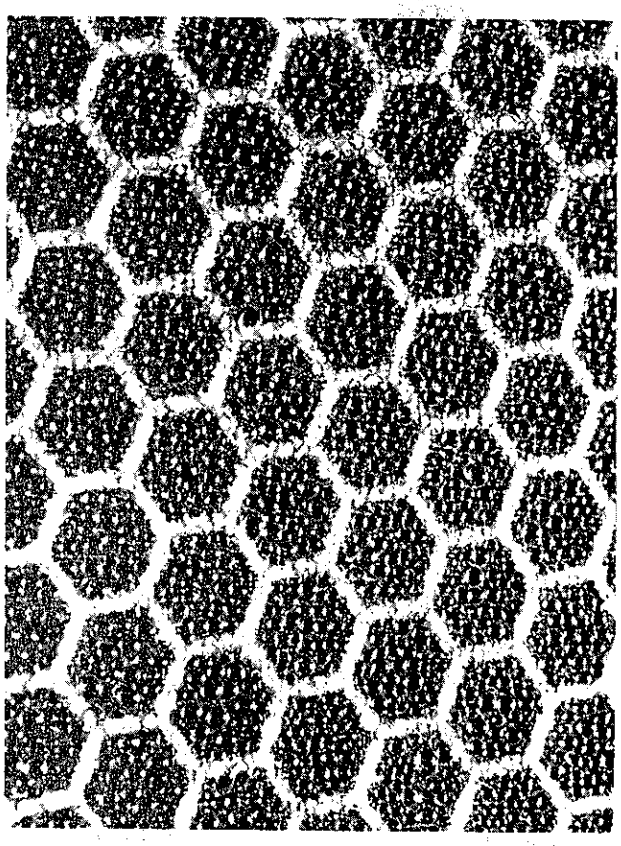


REFLEX REFLECTOR BUTTON--DRY

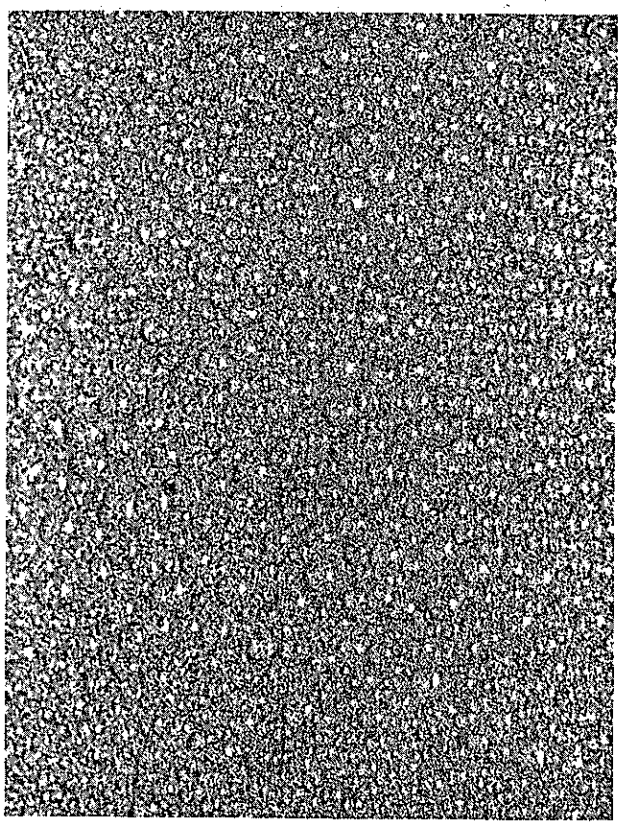


REFLEX REFLECTOR BUTTON WITH CONDENSED MOISTURE

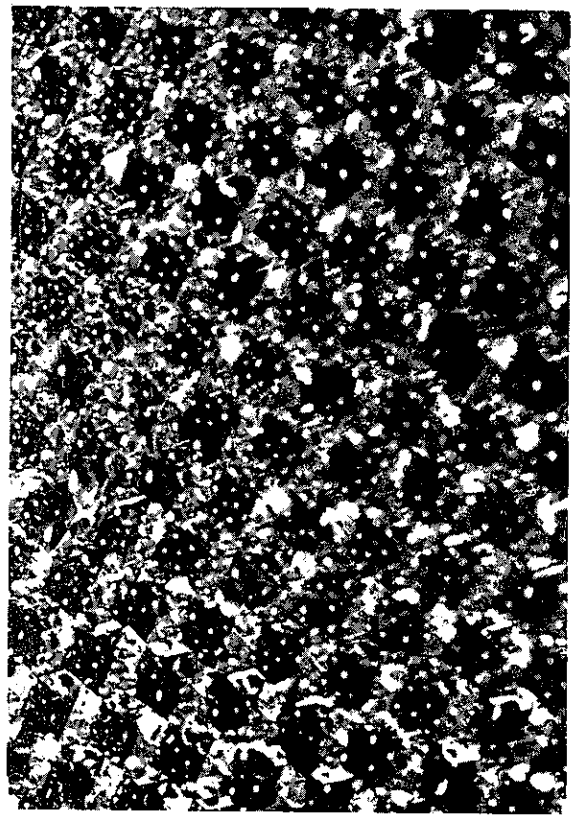
FIGURE 1



HIGH INTENSITY REFLECTIVE SHEETING



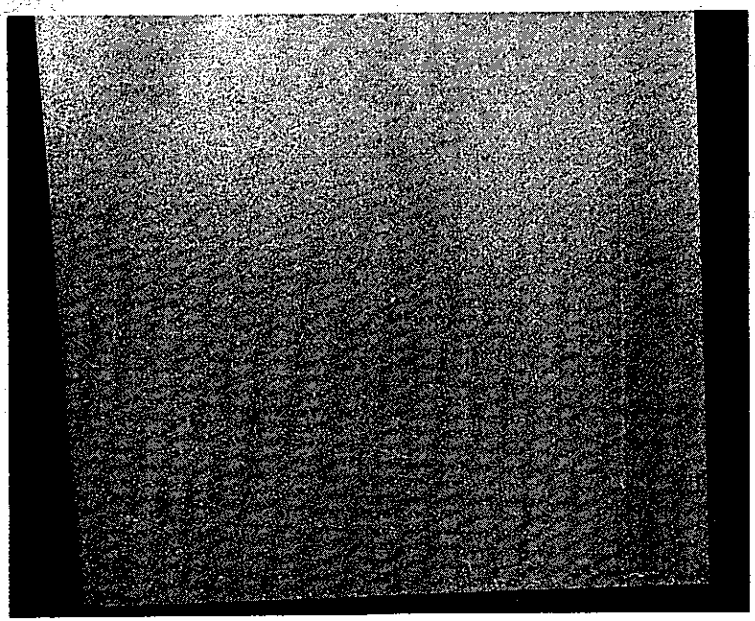
REGULAR REFLECTIVE SHEETING



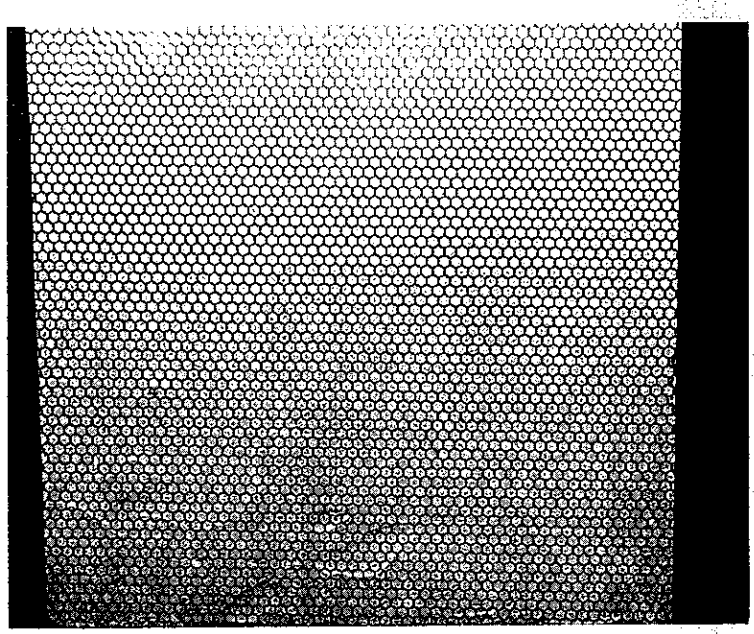
REFLEX REFLECTOR BUTTON

CONDENSED DROPLETS OF MOISTURE ON REFLECTIVE SIGN MATERIALS

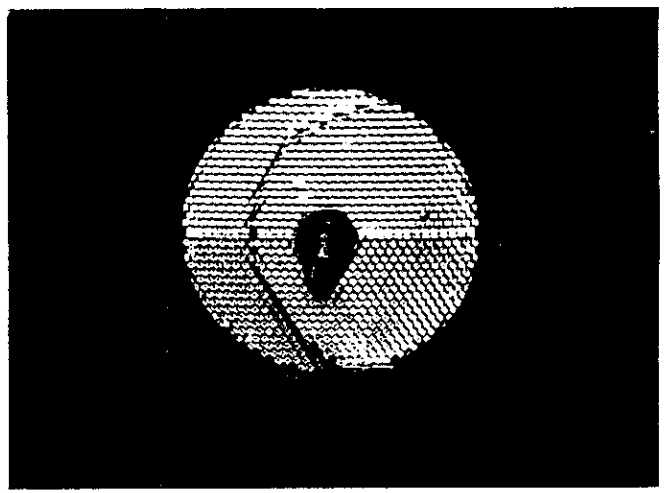
FIGURE 2



REGULAR REFLECTIVE SHEETING
WATER ON UPPER PORTION OF SAMPLE



HIGH INTENSITY REFLECTIVE SHEETING
WATER ON UPPER PORTION OF SAMPLE



REFLEX REFLECTOR BUTTON
WATER ON LEFT PORTION OF SAMPLE

FIGURE 3

Other observations, however, did add doubt to the accuracy of the mirror theory. For example, when the specimens were viewed from different angles in a dark room with a flashlight held close to the eye and water was splashed on the specimens, the trail of water (a thin film) running down the specimen did not appear darker than the specimen, but smaller drops which did not run appeared somewhat darker than the remainder of the sample. This same effect was observed in our later tests of signs set up outdoors overnight when the dew became so heavy that it ran down the sign. These trails of water appeared as lighter streaks across the sign which was otherwise darkened because of the dew droplets. To the naked eye, dew appears to form as droplets. It was concluded that the principal deterrent to effective reflectance was moisture droplets scattering the light rather than a film of water causing mirror-like reflection.

The above observations, apart from their usefulness in understanding dew phenomena, are principally important in reinforcing the suggestion made by others in the past that one solution to the dew problem would be the development of surfactant coating on signs that convert dew droplets to a thin film of water.

B. Dew Study of Sign Specimens on Racks.

The major effort in this project was directed towards a time-lapse photographic study of dew formation on sign samples which incorporated the reflective sign materials in use by the California Division of Highways. Six 14" x 40" signs were mounted on two sign racks (Figure 4).

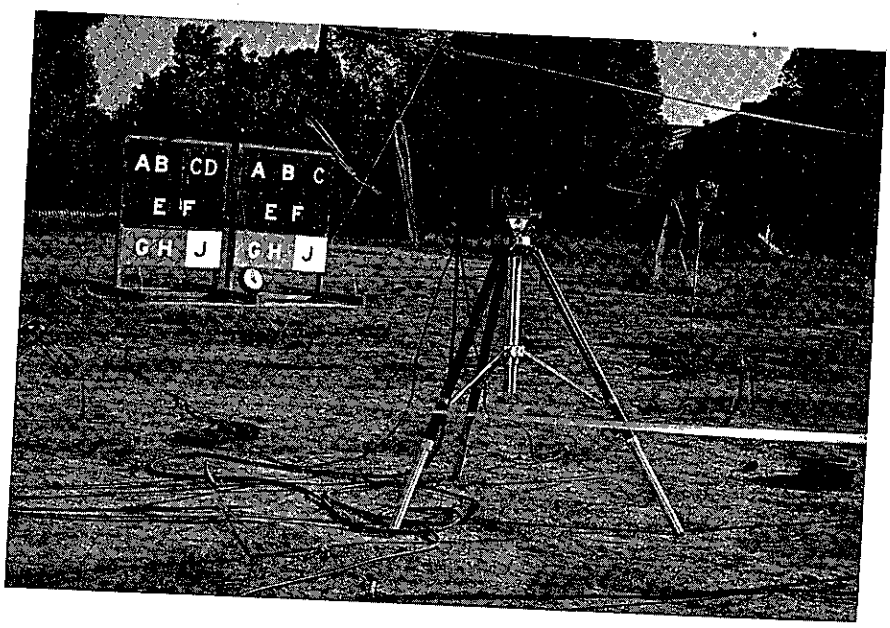


FIGURE 4

SIGN RACKS AND TIME LAPSE PHOTOGRAPHY EQUIPMENT

Exhibit 1 shows a diagram of the sign samples with the different materials identified. The samples included (1) regular reflective sheeting, (2) high intensity reflective sheeting, and (3) reflex reflector legend materials; baked enamel, porcelain enamel, and regular reflective sheeting background materials; single sheet aluminum and aluminum bonded to a phenolic impregnated paper honeycomb core backing as the two basic substrate materials; and legend letters that were demountable, screened-on, applied cut-outs, or formed from reflector buttons. The California Division of Highways specifications for reflective sheeting and reflector buttons that were in effect when the samples were ordered are included in the Appendix.

Figure 5 and Exhibit 2 show the construction of the sign racks. They were made stable enough to resist overturning due to wind forces and as light as possible so that they would not act as heat reservoirs and raise the temperature of the sign specimens at night. The sign specimens were made small so that many different materials could all be compared under identical conditions and viewed by one camera.

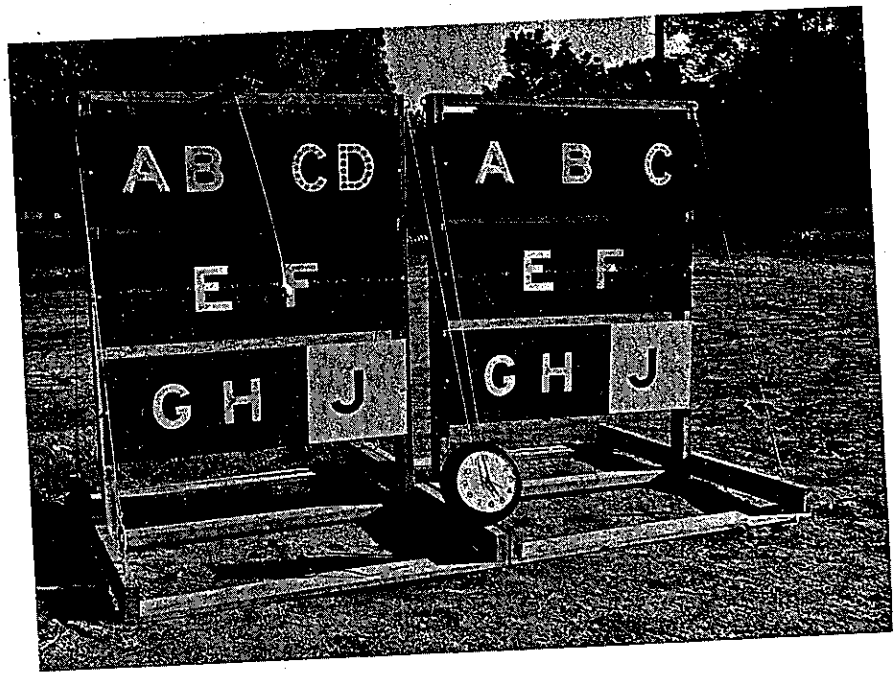
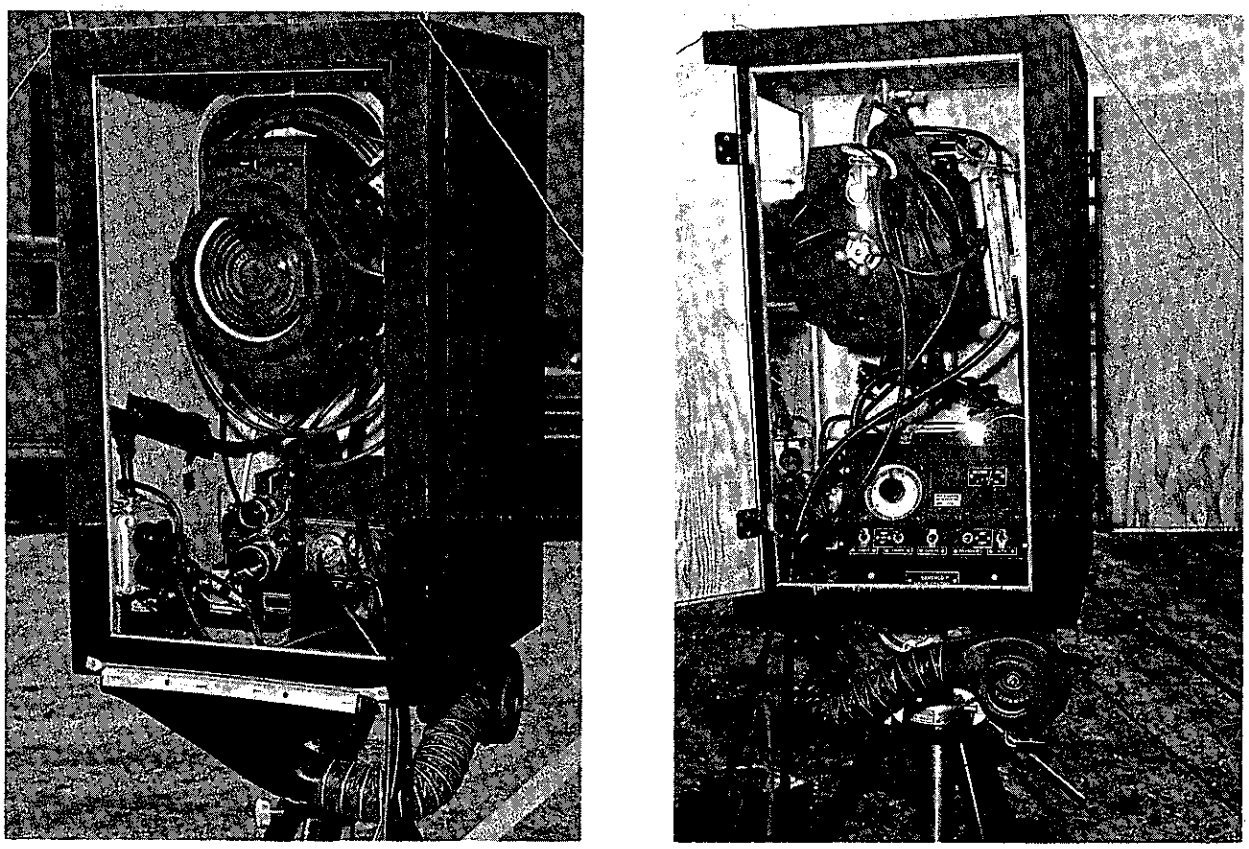


FIGURE 5

REFLECTIVE SIGN MATERIAL
SPECIMENS ON SIGN RACKS

A system of time-lapse photography was devised to record the effects of dew formation on the reflective qualities of the sign specimens. Exhibits 3 and 4 show diagrams of the type and layout of the equipment used. See also Figures 4 and 6. The camera and floodlights were actuated every 20 seconds. The camera was set, focused, and turned on in the evening just after darkness. A clock timer turned it off about 7:00 AM the following morning.

The camera and accessory equipment were placed in a wooden box mounted on a tripod to protect them from the elements. The camera and photo floodlight were aimed through a glass window in the box; an automobile window defroster fan was used to blow air across the window so that dew would not form on it. Removable guy wires anchored to heavy pieces of steel plate were used to stabilize this equipment.



FRONT VIEW SIDE VIEW

FIGURE 6

ENCLOSURE FOR TIME LAPSE PHOTOGRAPHY EQUIPMENT

A ping pong ball wrapped in a strip of reflective sheeting was suspended from a string in front of one sign rack as a wind indicator.

A clock face, with the glass cover removed to prevent dew formation, was placed in front of the sign racks to record the time continuously during the night. Reflective sheeting was placed on the hands of the clock and a "baby" spotlight used to increase the visibility of the clock.

The light from the photo floodlight incident on the sign specimens was 4-6 foot candles for all the tests.

C. Field Test Results.

A brief summary of each test follows. An extensive discussion and comparison of test results is provided in Section V, Discussion, which also contains some additional photos of the results.

Selected black and white prints have been made from the time-lapse movie film and are included in this report. The prints show the effects of some of the test variables under dew conditions. Some variability in interpretation of the tests may have occurred due to the difference in appearance of the colored time-lapse movie film and the black and white prints which appear darker than the movie film and lack its fine detail. Also, slight differences in the black and white photos may be due as much to photographic printing differences as to the effects of dew. In general, interpretations of tests have been made from the motion picture records.

Figure 7 includes two photos from each of four tests. The first photo for each test is an early evening view when there is no dew on the sign, and the second photo in each sequence shows the sign in its most darkened condition for the night.

Test No. 1

The first test was conducted November 17-18, 1970. The equipment was about 100 feet from the closest building and trees. The day-night-day high and low temperatures were 68-45-70° F (temperatures for city of Sacramento; temperature not recorded at test site); there were light winds; the sky was clear except for a few high clouds. See Exhibit 3 for a diagram of the equipment locations. The camera setting was 1/25 second at f 2.8. The angle of incident light on the sign racks was 20°. The signs faced N 66° W.

The equipment operated as planned; the film results were generally good. Both "GHJ" signs took on a mottled, then a dirty brown look as the dew formed (Figure 7). Eventually the dew began dripping which showed as light streaks down the face of the signs. Discoloration of the signs was evident all over the "GHJ" signs except along the edges where the signs were attached to the wood

sign rack. This was expected because the wood 2 x 4's in the rack acted as a heat reservoir and kept the edges of the sign from cooling as much as the mid portions. It could also be seen that the "GHJ" sign on a single aluminum sheet became discolored slightly faster and more completely than the "GHJ" sign with a honeycomb core backing. This honeycomb core apparently acted as a heat reservoir also. All legends remained legible; there was some darkening of the "ABCD" and "EF" signs. There was very little movement of the wind indicator.

Test No. 2

This test, conducted on November 18-19, 1970, was a repeat of Test No. 1 and was conducted to acquire additional observations during good "dew weather" and to observe variations in dew formation, if any, from one night to the next. Unfortunately, the wind was strong enough, as graphically shown by the ping pong ball which swung furiously most of the night, that dew did not form until about one hour before sunrise when the wind died down. The effects of the dew were similar to those observed in Test No. 1 except that the dew did not become heavy enough to start dripping. Downtown Sacramento day-night-day high and low temperatures were 70-43-66° F, respectively.

Test No. 3

This test was conducted at the Lincoln Airport about 40 miles northeast of Sacramento on November 19-20, 1970, with the same equipment layout and camera settings that were used for Test Nos. 1 and 2, except the signs now faced S 20° E. The dew did not appear to be quite as heavy as that observed during Test No. 1. Also, all the reflective materials, with the exception of the left "EF" sign, darkened considerably more than was observed during Test No. 1 (Figure 7). The new site was used to determine whether the geographic location would have a significant effect on dew formation; evidently, it did not. Weather conditions were similar to those for Test No. 1. Day-night-day high and low temperatures were 66-43-65° F (Sacramento temperatures; they would have been similar at Lincoln).

Test No. 4

This test was conducted on January 5-6, 1971, in the same location and with the same equipment as Test No. 1. The day-night-day high and low downtown Sacramento temperatures were 55-32-53° F.

Two changes were made in the test procedure: (1) the camera lens opening was reduced from f 2.8 to f 5.6 and (2) the sign racks were rotated to make the incident angle of the photo floodlight 5° instead of 20° (see Exhibit 3). The lens opening was changed in an effort to make the darkening effects of dew on the sign specimens more obvious. The sign racks were rotated because it was felt that the 20° incident angle used for Test Nos. 1-3 was near the outside limit for efficient reflection of the reflector buttons in a dry condition. The angle was not

reduced to 0° for that might have caused photographic difficulties due to specular glare.

As expected, both the "no dew" and the "blacked out" condition exhibited less reflectance than had been observed during Test Nos. 1, 2, and 3 (Figure 7). The darker "no dew" condition was caused by the increased "f" stop on the camera lens. The darker "blacked out" condition was attributed to both the increased "f" stop and the formation of frost sometime prior to 4:00 AM. There was still frost on the sign at 7:30 AM. There was not too much difference in the legibility of the letters with reflective sheeting and those with high intensity reflective sheeting; however, the reflective sheeting appeared a little brighter. The various other sign materials, such as the different background materials, did not appear to exert any significant influence on the legibility of the signs.

Test No. 5

This test was conducted on January 21-22, 1971, in the same location and with the same equipment as Test No. 4. The downtown Sacramento day-night-day high and low temperatures were 61-42-60° F.

One change was made in the test procedure: the lens opening was set at f 11.0 to further accentuate any deterioration in legibility of the sign legends when covered with dew.

The results were not quite as dramatic as those for Test No. 4 (Figure 7). However, the worst condition occurred before 9:30 PM and the dew lessened somewhat after that time. The silver reflective sheeting ("J" sign) appeared quite mottled. The other reflective materials with the exception of "CD" on the left side darkened noticeably but did not black out completely.

Test No. 6

The last test was conducted February 25-26, 1971, in the same location and with the same equipment as Test No. 5 except that a fiberglass sign under consideration as an alternate roadside sign for California highways was added to the sign rack.

It was quite windy all night and no dew formed; consequently, no photos of that test have been included in this report and the time-lapse film is not included with the film report.

V. DISCUSSION

Two variables can be compared in the series of photos included on Figure 7. They are (1) the incident light angle of 5° and 20° away from normal to the sign face and (2) the camera lens opening of f 2.8, 5.6, and 11.

It appears that the reflector buttons are brighter in Test No. 5 (5° incident light angle, f 11) with and without dew than in Tests Nos. 1 and 3 (20° incident light angle, f 2.8). This seems to emphasize the influence of the incident light angle on reflector buttons.

The letters in Test No. 4 all appear duller than in tests where either a larger or smaller f stop was used. Perhaps this is due to a difference in film or in processing the film from the time-lapse camera.

Comparing all tests when no dew is on the signs, the BFH letters (high intensity reflective sheeting) become darker than the AEG letters (standard reflective sheeting) as the f stop number is increased. The photographer felt the BFH letters, as seen on the movie film of Test No. 5, were darker because of underexposure, so the optimum f stop number may have been closer to f 5.6 than to f 11.

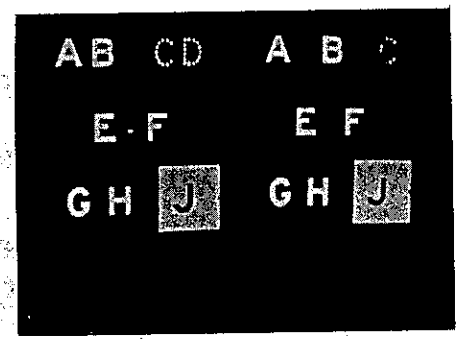
Test No. 1 shows the signs under a heavy dew condition at 5:00 AM when the moisture was dripping off the sign. This was more evident on the movie film, which showed a "moving streakiness" due to the dripping dew, which did not appear on any of the other test results. Despite this heavy dew, the letters do not appear especially dark. This must be due, at least in part, to the large lens opening, f 2.8.

In Test No. 4 the darkened sign is covered with frost. This appeared to cause considerably more visual deterioration than the dew of Test No. 1 as only a few reflector buttons were reflecting any significant amount of light.

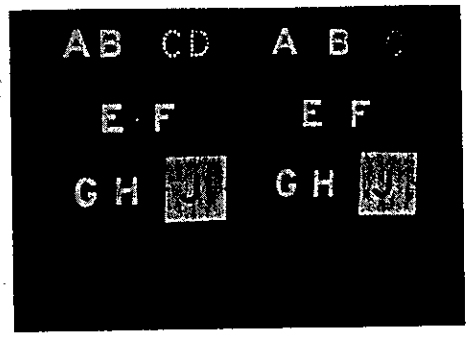
Figure 8 is a series of photos showing the rate at which the dew affected the reflective surfaces over a period of 1½ hours during Test No. 5. There is no dew on the sign in the first photo at 8:00 PM. The letters do not blink on and off as the dew changes; they lighten and darken gradually. All the different legend materials seem to be almost equally darkened by the dew with the exception of the reflector buttons on the "C" (left only) and "D" letters. The regular reflective sheeting (AEG letters) appears slightly brighter than the high intensity reflective sheeting (BFH letters), but this may be due to photographic underexposure as mentioned earlier. The aluminum substrate material seemed to be dark longer than the aluminum with honeycomb substrate (compare GHJ signs).

NO DEW

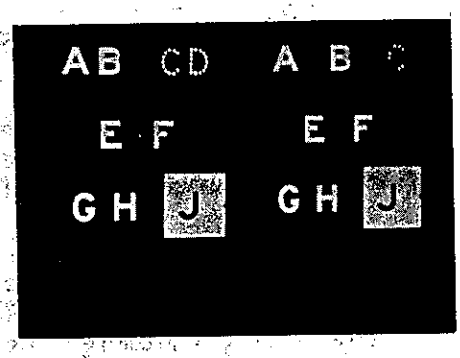
MAXIMUM OBSERVED REFLECTANCE LOSS



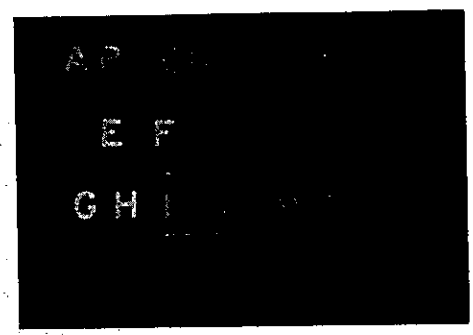
TEST 1; 6:00 PM;
20° INCIDENT LIGHT; f 2.8



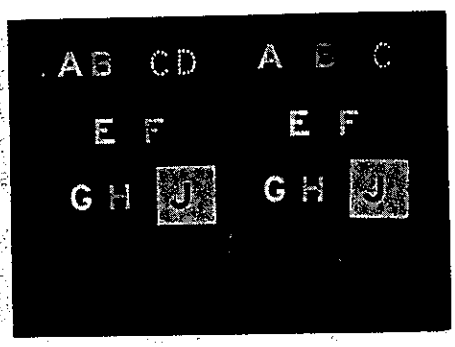
TEST 1; 5:00 AM
20° INCIDENT LIGHT; f 2.8



TEST 3; 5:00 PM;
20° INCIDENT LIGHT; f 2.8

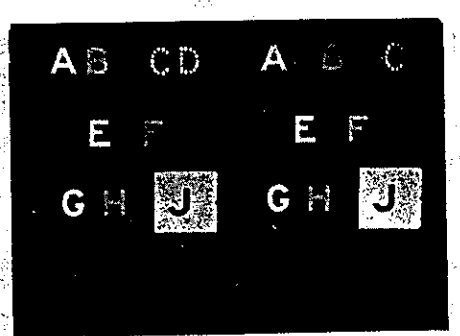


TEST 3; MIDNIGHT
20° INCIDENT LIGHT; f 2.8

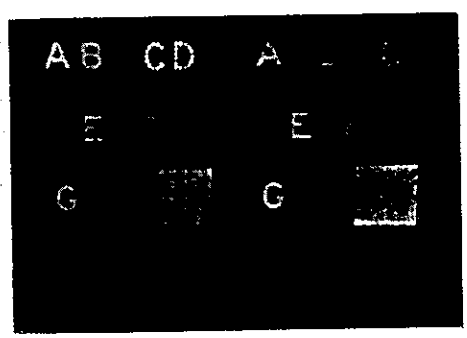


TEST 4; 6:00 PM;
5° INCIDENT LIGHT; f 5.6

TEST 4; 4:00 AM;
5° INCIDENT LIGHT; f 5.6

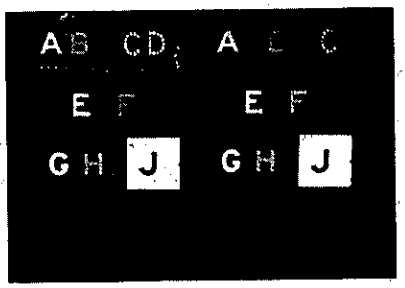


TEST 5; 8:00 PM;
5° INCIDENT LIGHT; f 11

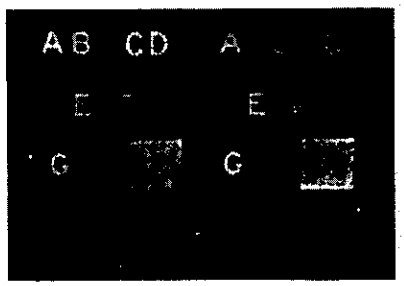


TEST 5; 8:50 PM;
5° INCIDENT LIGHT; f 11

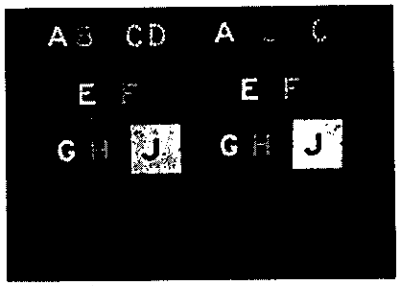
FIGURE 7



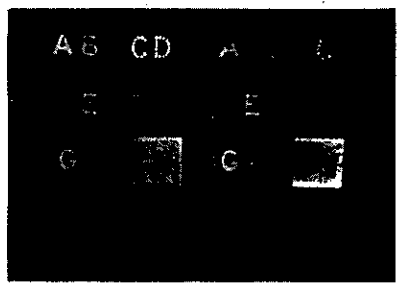
8:00 PM (NO DEW)



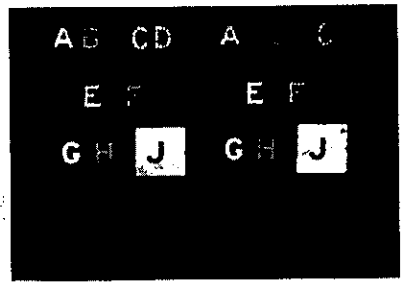
8:50 PM



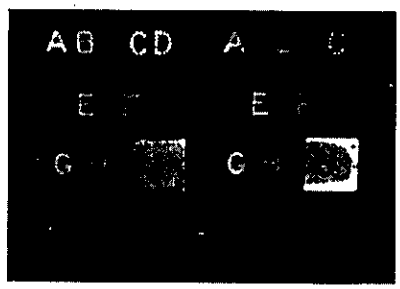
8:10 PM



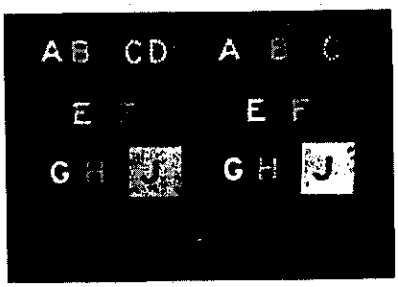
9:00 PM



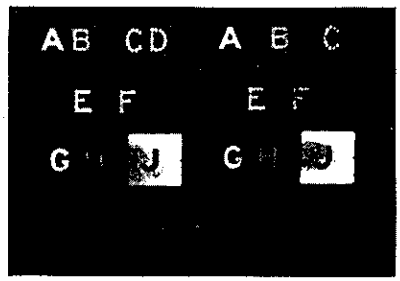
8:20 PM



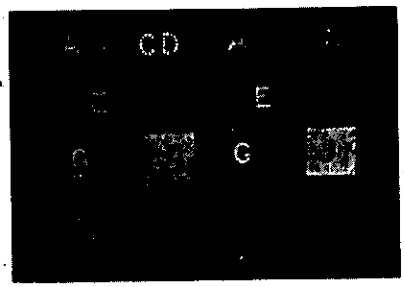
9:10 PM



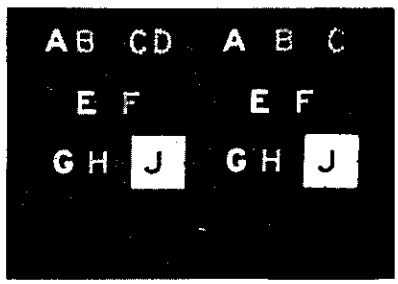
8:30 PM



9:20 PM



8:40 PM



9:30 PM

TEST NO. 5

FIGURE 8

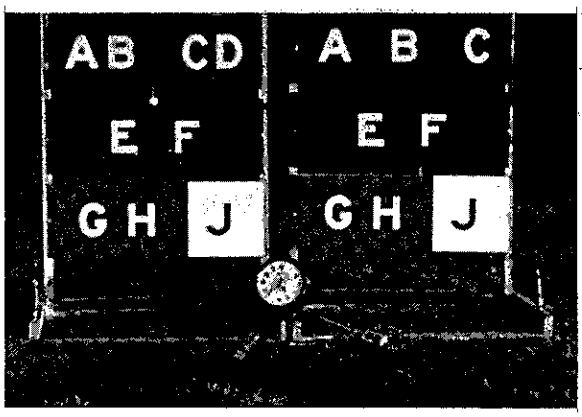
Figure 9 shows a series of photos from Test No. 4. It includes two daylight photos for comparison with the nighttime photos and includes one in the late afternoon when the sun shone on the face of the sign and another after dawn when the sun was behind the sign. Frost formed that night and was still on the signs and grass in the photo at 7:10 AM. It is unknown whether the sign was covered with dew or with frost at 11:00 PM, but frost was definitely there by 4:00 AM. It can readily be seen that the frost has a significant darkening effect on the sign. As noted previously, the black and white photos appear somewhat darker than the original time-lapse color movie film.

Observations by persons who have viewed reflective signs covered with dew or frost along the highway indicate that sign messages sometimes black out enough to become virtually invisible under dew conditions. Comments in reports of other dew studies indicated that this blacking out occurs over a short period of time. In contrast, the film from our time-lapse study portrayed legends that darkened and lightened gradually as the amount of dew varied, and never blacked out completely even though the dew was excessive and dripping at least one night during this study. The film also generally showed insignificant differences in legibility of the different sign materials under all dew conditions. The almost total blackout during Test No. 4 indicated on Figure 7 did not appear to be as severe when viewed on the film.

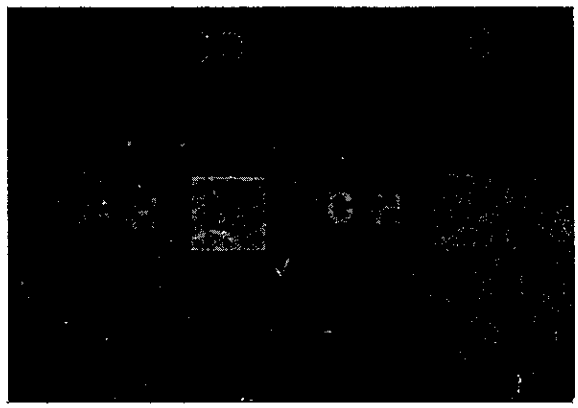
The motion picture film of all the tests has been assembled on one reel as a film report which documents the observations and conclusions in this study.

Due to the limited number of tests in this study, it is not considered prudent to conclude that our film results completely represent the images presented to a motorist viewing dew covered signs along the highway.

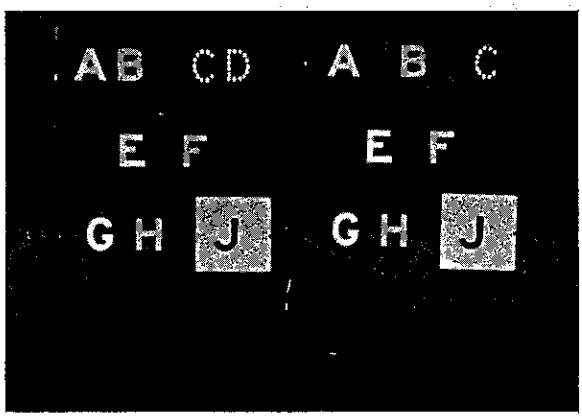
Figure 10 shows reproductions of two photographs taken by a representative of a sign material manufacturing company of a sign in Oregon that had legends using both reflex reflector buttons and high intensity reflective sheeting with a background of regular reflective sheeting[5]. These pictures clearly show the effect, reported by various observers, of darkened reflector buttons but they show a much greater difference in the two types of legend materials than was ever observed in the test films reported herein. The vagaries of film exposure, development, and printing would not seem to explain the extreme difference; hence, two reasons for the contrast in the Oregon sign photographs might be (1) that reflex reflector buttons are ineffective beyond certain angles of incident light regardless of dew conditions or (2) the reflex reflector buttons are blackened with varying combinations of incident light angle and dew intensity. In either event, the tests reported herein were not designed to systematically evaluate the effects of the incident light angle or to determine the cone of incident light angles commonly encountered when viewing a highway sign from a vehicle.



LATE AFTERNOON - SUN ON SIGNS

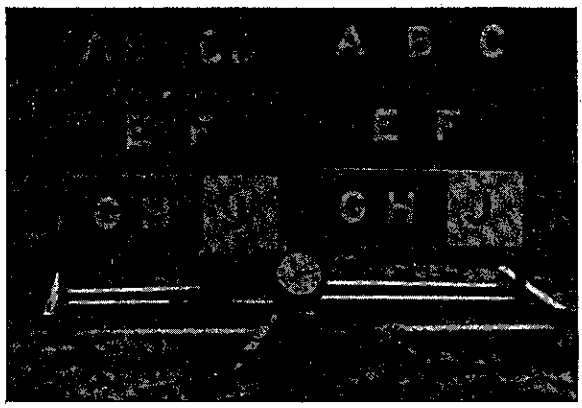


11:00 PM DEW AND/OR FROST



6:00 PM - NO DEW

4:00 AM - FROST



7:10 AM - FROST

TEST NO. 4

FIGURE 9

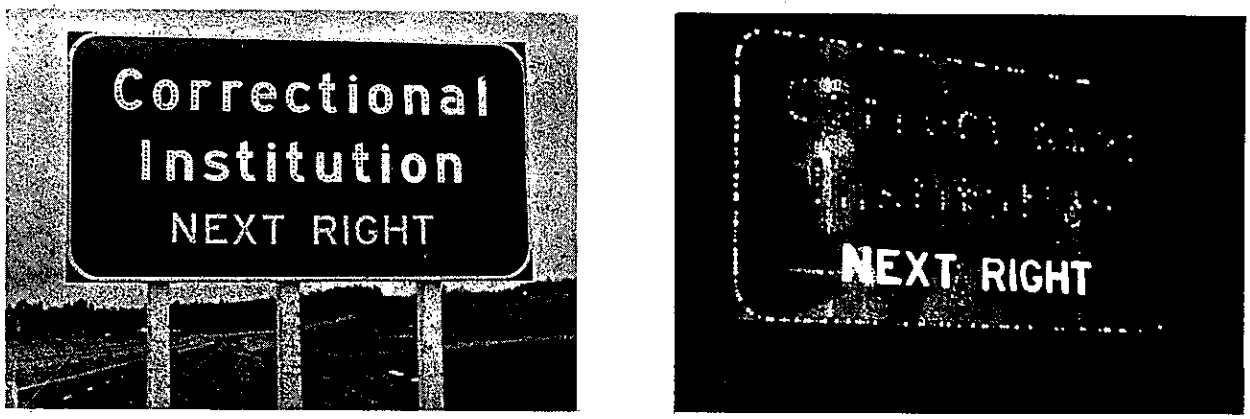


FIGURE 10

OREGON SIGN WITH REFLEX REFLECTOR BUTTONS AND HIGH INTENSITY REFLECTIVE SHEETING

Future Research

It now appears that the entire investigation reported herein was not nearly extensive enough to produce conclusive results; however, time and funds were not available to extend the study. It is recommended that future work on the effects of dew should include the following items:

1. A benefit/cost study should be conducted to answer the questions:

   a. Do the dew covered signs cause accidents, and, if so, what kind and how many?

   b. To what extent are dew covered signs an inconvenience to drivers, causing them, for instance, to miss a turn?

   c. How many hours per year are signs out of service because of dew or frost at various locations in California?

   A portion of the benefit/cost analysis should be completed before additional studies are justified; however, an accurate estimate of downtime for dew covered signs may depend on the results of a detailed study which defines downtime and

provides a reliable technique for recording downtime photographically or with photometers.

2. An evaluation of various reflective sign materials as attempted in this study, but with emphasis placed on (a) discovering typical intensities of incident light on actual highway signs measured at varying distances and angles, and using these light intensities, angles, and distances for tests, (b) comparing, in particular, the effects of dew on the angularity of various reflective materials, i.e., measuring reflected light from signs having different incident light angles to determine the variations under dew and dry conditions, (c) using a telephotometer (as described in Reference 4) to measure reflected light so that the study has a quantitative basis.

3. A light ray analysis based on macro photography of dew droplets which might clarify the reason for one type of reflective material being less affected by dew or suggest a new type of material.

4. A search for methods of reducing the amount and/or type(s) of moisture found to be most detrimental to the reflectance of the sign materials.

An extensive research program such as that outlined above would be expensive. Until a more accurate estimate of the severity of the detrimental effect of nonreflecting reflective signs is obtained, an extensive project of this type is not considered economically justifiable.

Implementation

Due to the inconclusiveness of this study, no recommendations can be made for the implementation of findings.

VI. REFERENCES

1. "A Study of Dew and Frost Formation on Retro-Reflectors" by H. L. Woltman, Supervisor, Signs & Markings, Reflective Products Division, Minnesota Mining & Manufacturing Co.

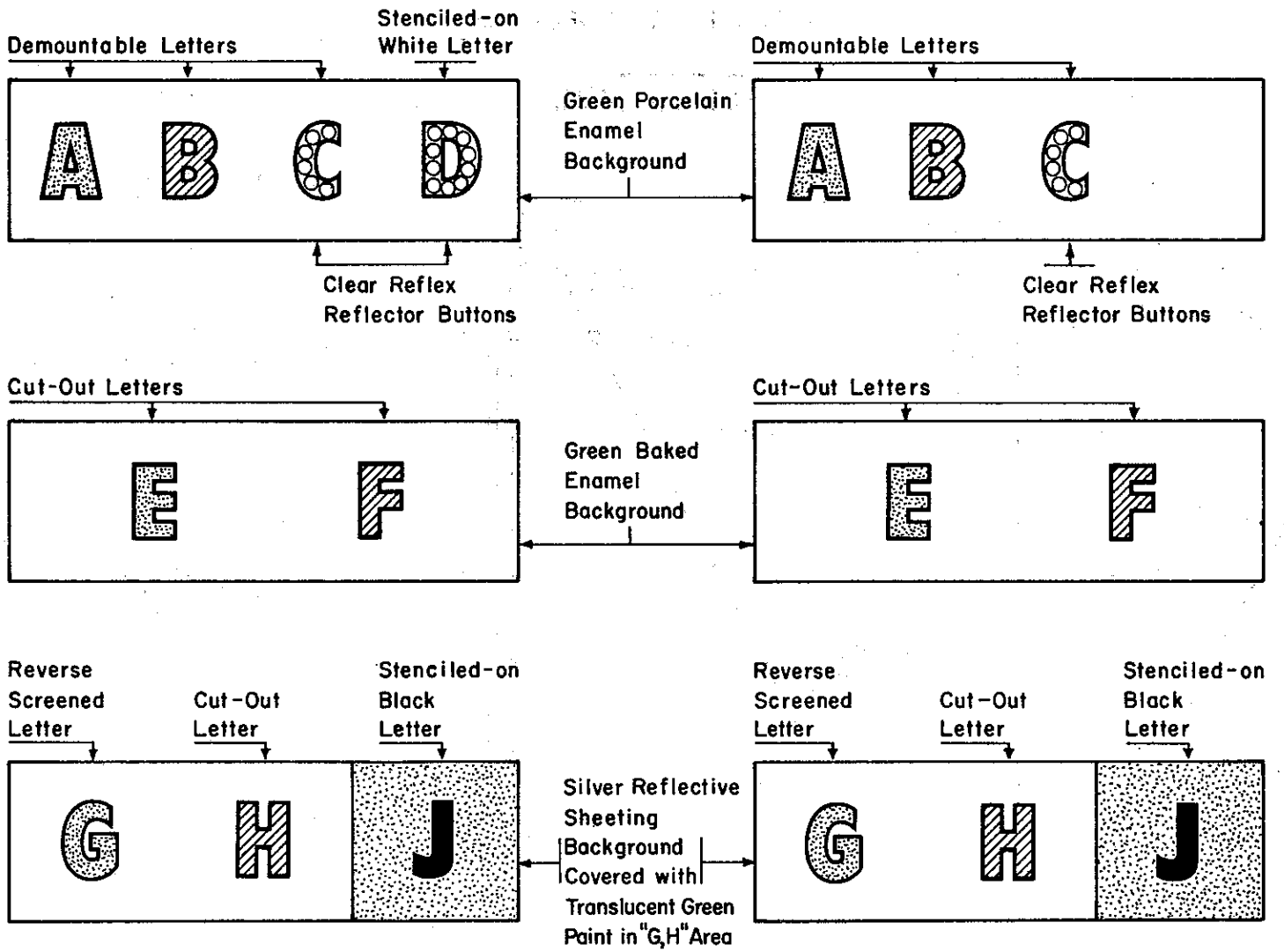
2. "Preliminary Investigation of Moisture Condensation on Highway Signs", March 24, 1960, Douglas Aircraft Co., Inc., Santa Monica Division, prepared by Don J. Lynn, Air Conditioning Section.

3. "Nighttime Use of Highway Pavement Delineation Materials" by John M. Dale, Southwest Research Institute, Interim Report.

4. "A Brightness Inventory of Contemporary Signing Materials for Guide Signs" by W. P. Youngblood and H. L. Woltman, Minnesota Mining & Manufacturing Co.

5. "The Great Adventures in Roads", Tenth in a series, 3M Company, Reflective Products Division.

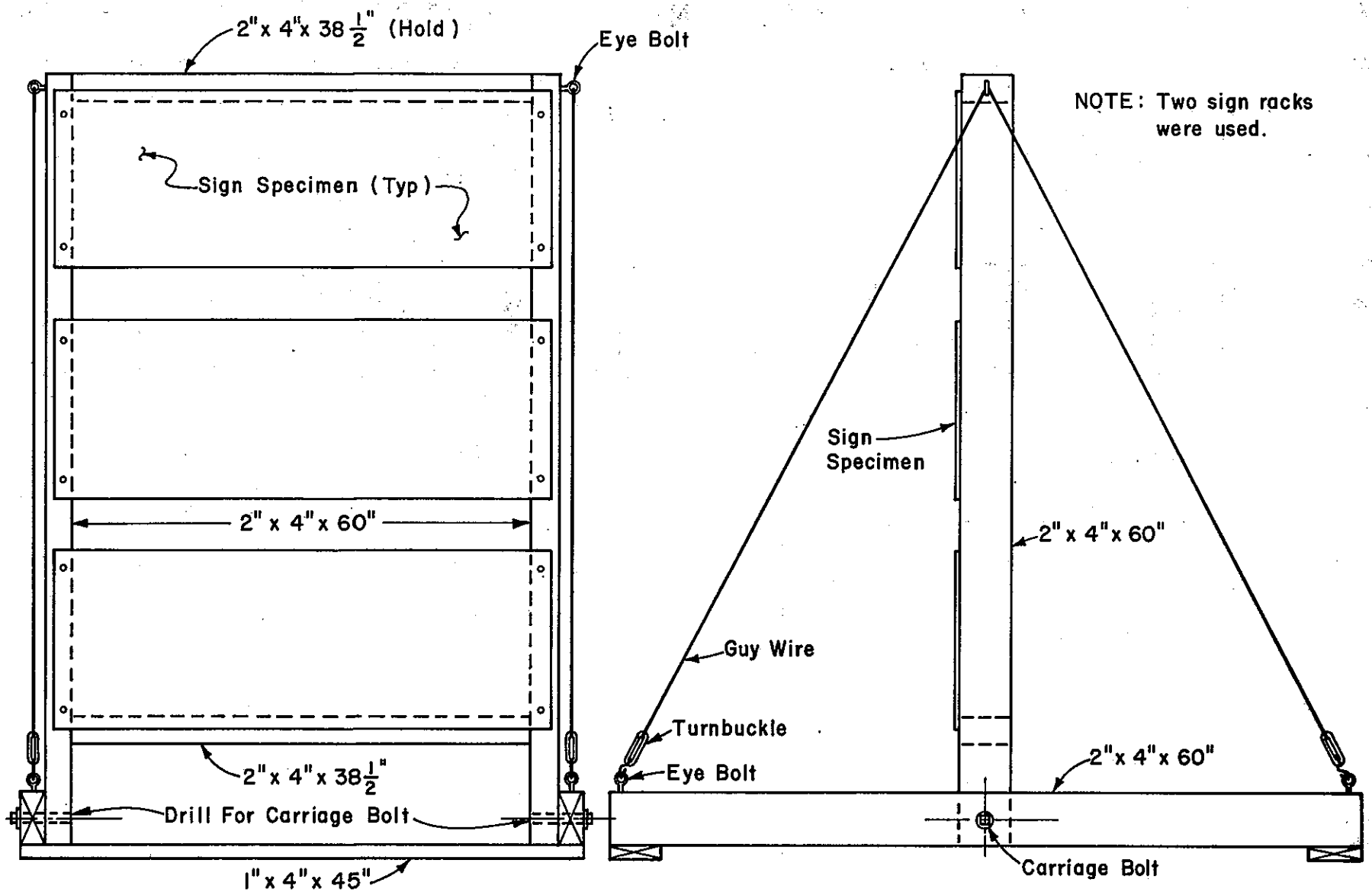
EXHIBIT 1



NOTE: These sign specimens were mounted on the test sign racks in the relative positions shown above.

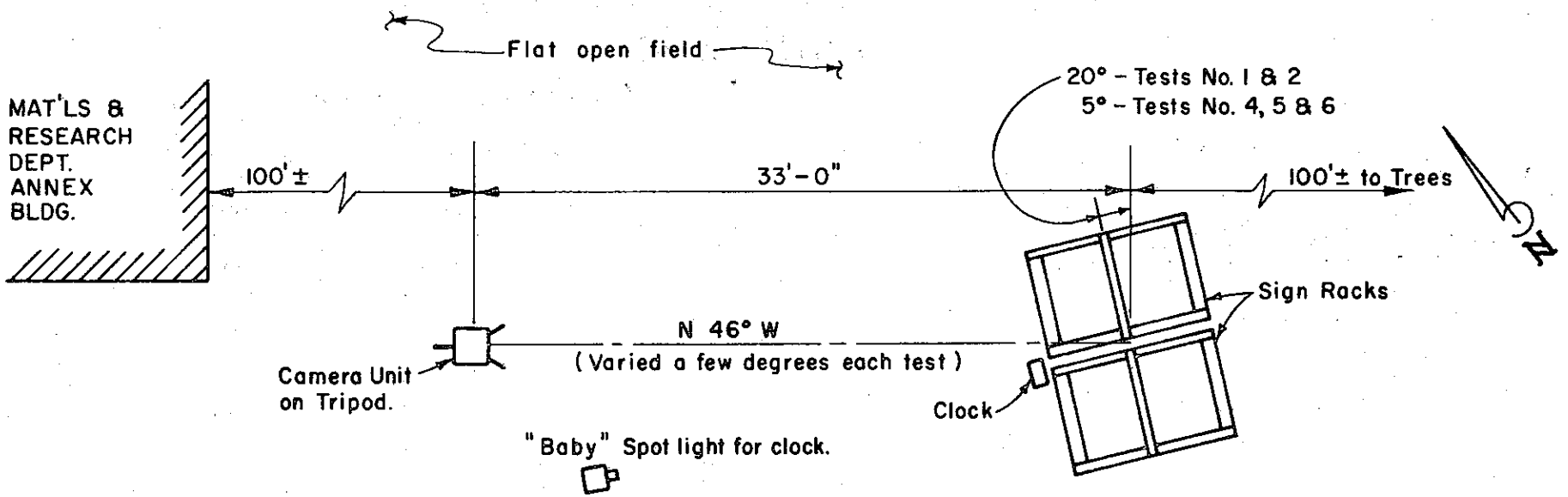
REFLECTIVE SIGN SPECIMENS

EXHIBIT 2



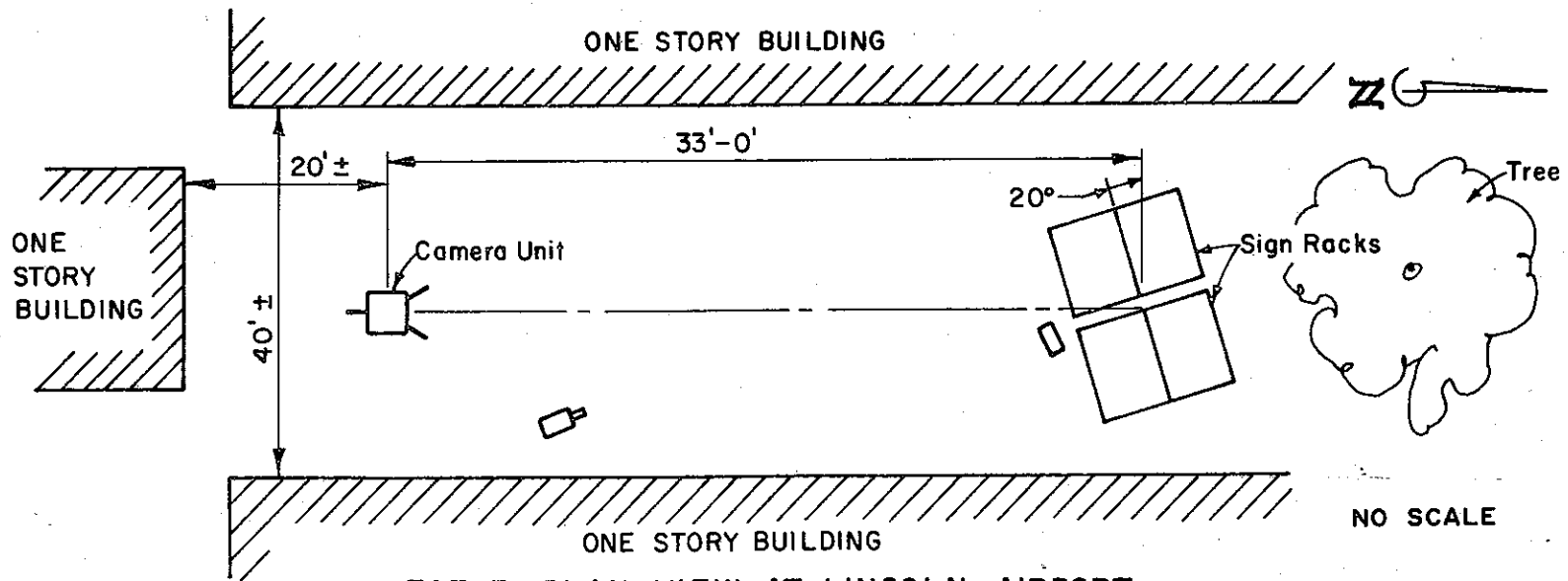
DEW STUDY

PORTABLE SIGN RACK



TESTS 1, 2, 4, 5 & 6 - PLAN VIEW

EXHIBIT 3

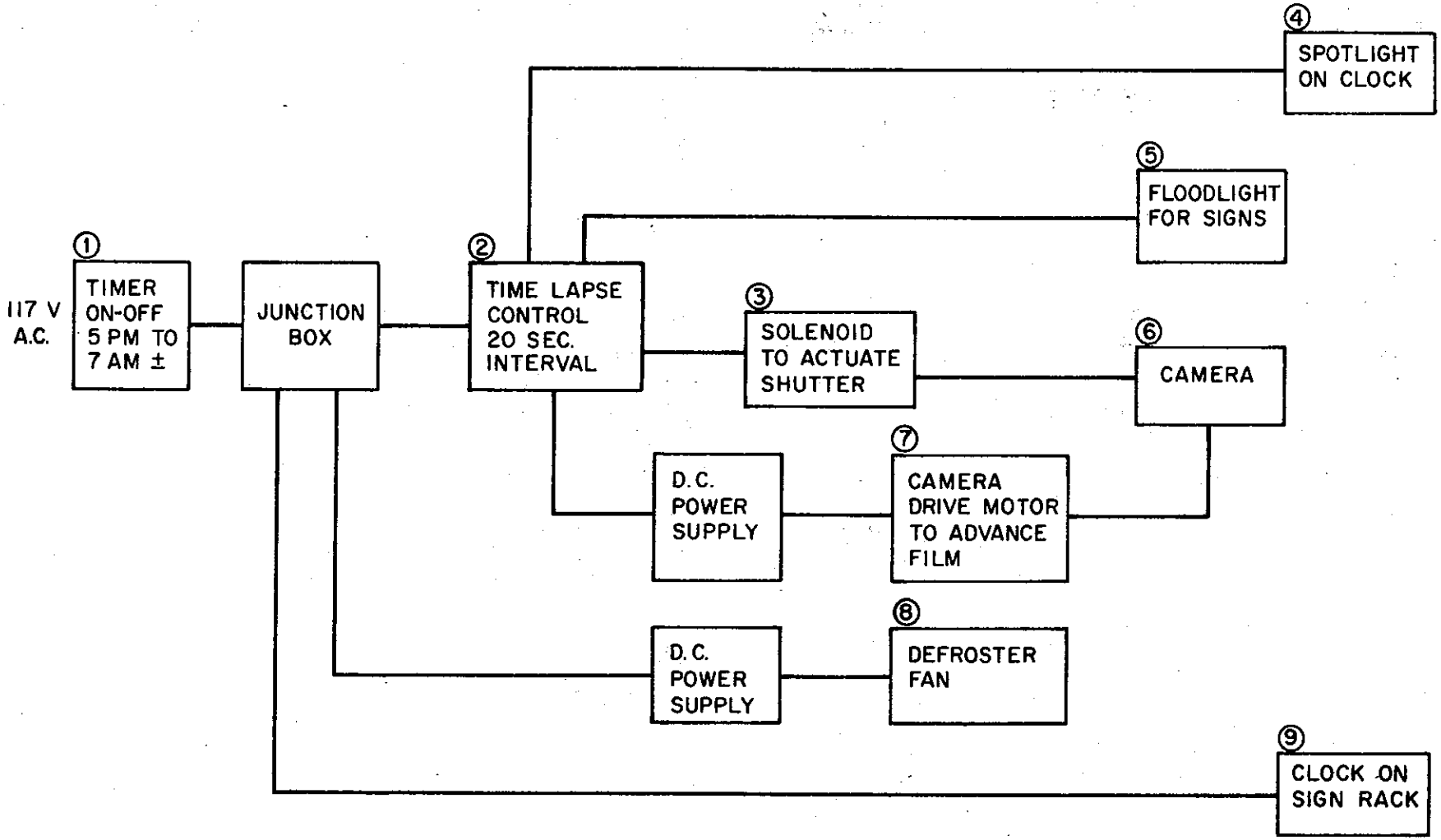


TEST-3-PLAN VIEW AT LINCOLN AIRPORT

DEW STUDY

EQUIPMENT LAYOUT FOR TIME LAPSE PHOTOGRAPHY

EXHIBIT 4



1. T-101 Intermatic Timer (24 hr.)
2. Samenco Intervolometer.
3. 110 V A.C.
4. 500 Watt "Baby" Spotlight.
5. 750 Watt Photo Flood.
6. Bolex 16 m.m., Ektachrome Commercial Film No. 430, single frame at 20 second intervals.
7. Bolex D.C. Drive Motor.
8. 12 V D.C. Auto rear window defroster.

DEW STUDY

EQUIPMENT FOR TIME LAPSE PHOTOGRAPHY

VIII. APPENDIX

STATE OF CALIFORNIA
DEPARTMENT OF PUBLIC WORKS
DIVISION OF ADMINISTRATIVE SERVICES
SERVICE AND SUPPLY DEPARTMENT

SPECIFICATIONS FOR REFLECTIVE SHEETING ON ALUMINUM HIGHWAY SIGNS

I. SCOPE

These specifications cover reflective sheeting on aluminum, single sheet sign panels required by the Division of Highways during the contract period, when and as requested.

II. GENERAL

1. All items shall be new; the material and workmanship of the best quality for the purpose. All signs shall be made in accordance with drawings furnished by the Division of Highways or as mutually designed and agreed to by the contractor and the Division of Highways. All sign layouts shall be the contractor's responsibility and shall be subject to the Division of Highways' approval.
2. The data shown on the proposal, and Part 8 "Traffic" of the California Division of Highways Planning Manual, shall govern all bids. In the event of a discrepancy in detail between the proposal and the Manual, data shown on the proposal shall prevail.
3. Any sign delivered under this contract which does not conform to these specifications shall be replaced by the contractor at no cost to the State.
4. The year of manufacture and the manufacturer's initial shall be permanently marked or etched on the back of the signs. All

identification letters and numerals shall be approximately one (1) inch high and shall be so placed as not to fall behind any post or frame member.

5. Reduced detail drawings of standard signs shall be furnished to the contractor by the Division of Highways and shall be part of these specifications.

6. The Division of Highways may change, delete or add signs to the number of signs specified. The Division of Administrative Services will advise the contractor of such revisions.

III. DETAILED REQUIREMENTS:

1. Base Metal:

a. The base metal shall be new sheet aluminum of alloy 6061-T6 or alloy 5155-H36. The thickness of the aluminum sheet shall be as designated in Table No. 1 of these specifications unless otherwise specified. The material shall be subject to inspection prior to degreasing operations. Alloy and temper designations shall be verified by mill certification.

b. The fabrication of all metal parts shall be accomplished in a uniform and workmanlike manner. The sign panels are to be cut as shown on the sign specification sheets. The Dimensional tolerance of the panels shall be plus or minus 1/16". Metal panels shall be cut to size and shape and shall be free of buckles, warp, dents, cockles, burrs, and any other defects resulting from fabrication. Base plates for Standard Size G26R, G27R1, and G28R signs shall be die cut. All possible fabrication, including shearing, cutting and punching of holes shall be completed prior to the base metal preparation.

2. Base Metal Preparation:

The aluminum base sheets shall be treated with a chromate conversion coating for aluminum conforming to the requirements of Federal Specification MIL-C-5541. The coating shall be applied according to the manufacturer's specifications and recommended sequence of operation. The base metal shall be thoroughly cleaned and the trademark removed with lacquer thinner, controlled alkaline cleaning system or other approved method. All treatment tanks shall provide for total immersion of at least 5' by 12' panels. Solution strengths shall not vary more than 10% from the manufacturer's recommendations and in addition all treatment tanks shall be charged with fresh chemicals at least once a year. Titration equipment shall be available for the Inspector's use to check the solution strengths. The cleaned and coated base metal shall be handled only by a mechanical device or by operators wearing clean cotton or rubber gloves. After cleaning and coating operations, the panels shall be protected at all times from contact or exposure to greases, oils, dust or other contaminates. The conversion treatment shall produce a uniform golden irridescent coating that is light, tight and completely free of any powdery residue. The color shall match color chips furnished by the Inspector.

3. Reflective Sheeting

a. The surface of the reflective sheeting shall be of a flexible, transparent plastic material and shall be smooth. The backing medium shall be of synthetic sheet resin or other suitable non-cellulosic material. The bonding adhesive shall have no staining effect and shall be mildew resistant. The sheeting

shall permit cutting and color processing at temperatures of 60 to 100°F. and relative humidities of 20 to 80%. The sheeting shall be heat resistant and permit force curing of unapplied sheeting at temperatures up to 150°F. and up to 200°F. on applied sheeting. The sheeting surface shall be solvent resistant to gasoline, VM&P napntha, mineral spirits, turpentine and methanol.

b. The reflective sheeting shall be applied to the face of the sign by either (1) an approved vacuum applicator using a combination of vacuum and heat, as recommended by the reflective sheeting manufacturer, or (2) a squeeze roller applicator as recommended by the reflective sheeting manufacturer. After aging for 48 hours, the adhesive shall produce a durable bond equal to or greater than the strength of the reflective sheeting. No air pockets or bubbles shall exist between the sheeting and the base material.

4. Edge Sealing: The edges of each completed reflective sheeting sign face and of all cut out letters, numbers, arrows, symbols and borders shall be sealed in a manner and with a sealing solution as recommended by the manufacturer of the reflective sheeting.

5. Finish:

a. The finished sign shall be flat within a ratio of 0.04 inches per linear foot when measured across the plane of each panel from opposite corners, or at any location on the panel. All finished signs shall have smooth flat surfaces without defects or objectionable marks of any kind on either the front or back faces.

b. All letters and designs shall be clearly cut and sharply defined.

c. Splices in the reflective sheeting.

(1) Vacuum applied sheeting - There shall be no splices in the reflective sheeting on panels with a minor dimension of 48" or less. On all rectangular signs with a minor dimension of more than 48", the splice shall be horizontal.

(2) Squeeze roller applied sheeting - No splices other than those occurring in the manufactured roll of reflective sheeting will be allowed, and no roll shall contain more than one splice for every 60' of material.

(3) No finished sign shall have more than one splice and no splice shall fall within 2" of the sign edge. When splices do occur, the adjoining reflective sheeting shall be color matched under both incident and reflected light.

d. Repairs to damaged reflective sheeting due to poor workmanship or defective material will not be allowed.

e. Reflective sheeting screening coats shall be oven cured as recommended by the reflective sheeting manufacturer.

6. Frames:

a. All rectangular signs, over 53" measured along the horizontal axis, and all diamond shaped signs 60"x60" and larger shall be framed unless otherwise specified. The frames shall be constructed of aluminum channel as indicated in Framing Detail for Sheet Aluminum Signs, drawings No. 1 through 3, and Table No. 1 of these specifications. All framing dimensions have a plus or minus 1/8" tolerance unless otherwise specified.

b. In the horizontal direction, unless otherwise specified, the sign panel must be a continuous sheet (no vertical splice is permitted). For signs higher than 48", a horizontal splice is permitted. See drawing No. 2 for location of the splice channel and rivet spacing.

c. The frame shall be affixed to the sign with 3/16" diameter aluminum rivets of a type approved by the Division of Highways. The rivets shall be placed through the face of the sign with the web of the channel placed against the back of the sign. The maximum rivet spacing shall be 12" on centers. See rivet details. No rivets shall be placed closer than 1/2" from edge of the aluminum face sheet. All rivets shall fall within the web of the channel frame.

d. All joints of the aluminum channel frame shall be welded with an inert gas shielded-arc welding process using 4043 electrode filler wire in accordance with good shop practice. The width of the fillet shall be equal to the wall thickness of the smallest channel being welded.

7. Legend:

a. Message size, letter style, and spacing, figure and arrow size will be furnished to the contractor.

b. The message shall be one or a combination of the following types:

(1) Silk screened or reverse silk screened with a "process paste" as supplied or recommended by the manufacturer of the reflective sheeting. The screening paste shall be of a type and color as approved by the Division of Highways (color chips are available from the Materials and Research Department).

(2) Pressure sensitive, cut-out reflective sheeting of the same type as specified in Section III, Paragraph 3, a and b of these specifications.

(3) Silver, high intensity, pressure sensitive, cut-out reflective sheeting. The high intensity reflective sheeting shall consist of spherical lens elements adhered to a synthetic resin and encapsulated by a flexible, transparent, weatherproof plastic having a smooth outer surface. The reflective sheeting shall be backed with a precoated, pressure sensitive adhesive which will adhere to flat, clean, sign surfaces. The precoated adhesive shall be protected by an easily removed liner, shall have no staining effect on the reflective sheeting and shall be mildew resistant.

IV. TEST METHODS AND INSPECTION

1. Inspection:

All materials and finished signs are subject to inspection and release by the Materials and Research Department of the Division of Highways at the place of manufacture, and shall be subject to final inspection at the Service and Supply Warehouse at the time of delivery. Twelve inch by twelve inch test panels representative of any stage of production shall be furnished on request of the Materials and Research Department inspector. These panels shall be processed along with the regular production run and witnessed by the inspector. All surfaces exposed to weathering shall be free of any defects in the coating that may impair the service-ability or detract from the general appearance or color matching

of the sign. The finished signs shall be clean and free from all router chatter marks, burrs, sharp edges, loose rivets, delaminated reflective sheeting and aluminum marks. Signs with any defects or damage that would affect their appearance or serviceability will not be acceptable. No repairs shall be made to the face sheet without the approval of the State inspector. All signs not conforming in all respects to the requirements of these specifications will be rejected.

2. Test Methods:

a. Reflective Sheeting Optical Requirements: The reflective sheeting after application to the sign shall meet the following minimum values at 1/3 degree divergence, expressed in units of candle power per foot candle per square foot as measured from a distance of 50 feet between the test panel and light source:

COLOR	ANGLE OF INCIDENCE				
	0°	10°	20°	30°	40°
High Intensity Silver	160.0	140.0	100.0	-	-
Silver or white	54.0	47.0	36.0	25.0	15.0
Yellow	20.0	17.0	13.0	-	-
Red	8.2	5.4	4.6	3.4	2.2
Green	4.2	3.0	2.2	1.5	1.0
Blue	3.4	2.2	1.7	-	-

NOTE: Reflectance values for angles of 10, 20, 30 and 40 degrees shall be an average of the reading left and right of 0 degrees. The brightness values shall be determined by Test Method California No. 642-A, Materials and Research Department

of the California Division of Highways, Department of Public Works, State of California.

The reflectance values noted above for incidence angles of 30 and 40 degrees are required for only the following signs: R1R, STOP: R11R, DO NOT ENTER: R65R, WRONG WAY; and the G92R, FREEWAY ENTRANCE sign.

b. Reflective Sheeting Flexibility: The reflective sheeting when applied according to manufacturer's recommendations to a cleaned and amorphous chromate treated 0.063"x2"x8" aluminum panel, conditioned for 48 hours and tested at 68° ± 5°F. and 50% ± 10% relative humidity shall be sufficiently flexible to show no cracking when bent around a 3/4" mandrel.

c. Adherence: The test panel, after a 72 hour curing time, shall be immersed in 95°F. ± 3° water for a period of 24 hours. Immediately after removal from the bath, the reflective sheeting shall be sufficiently bonded so that it cannot be readily removed from the aluminum surface with a 1" round nose spatula. If the sheeting can be peeled rather than chipped from the surface, the bond is considered unsatisfactory.

V. PACKAGING

All signs shall be packaged in such a manner to insure delivery in perfect condition.

All Route Markers and signs up to 48"x60" in size shall be properly slip-sheeted with reflective sheeting backing paper or a paper similar to Western Waxide #734. The signs shall be wrapped and packaged in cartons made of 275 lb. test, double-faced corrugated cardboard. The cartons shall be suitable for reshipment and properly labeled showing

the size, type, quantity, lot number, and Purchase Order number. All signs larger than 48"x60" shall be suitably protected in a mutally accepted manner for proper shipment and storage.

VI. PATENTS

The Contractor shall assume all costs arising from the use of patented materials, equipment, devices, or processes used on or incorporated in the work, and agrees to indemnify and save harmless the State of California, the Director of Public Works, and State Highway Engineer, and their duly authorized representatives from all suits at law, or action of every nature for, or on account of, the use of any patented materials, equipment, devices or processes.

VII. WARRANTY

Vendor shall present proof that the type of reflective sheeting they intend to use in the manufacture of the signs has been used on highway signs located on California highways for a period of at least two years and has proven entirely satisfactory.

STATE OF CALIFORNIA
DEPARTMENT OF PUBLIC WORKS
DIVISION OF ADMINISTRATIVE SERVICES
SERVICE AND SUPPLY

Specifications for Reflex Reflectors for Traffic Signs, Delineators and Warning Devices.

(a) Description

Reflex reflectors for use in traffic signs, delineators, and warning devices shall be made of methyl methacrylate plastic molded into a shape which will reflect incident light in a narrow pattern back toward the source of the light. They may be of various sizes and colors as required.

Reflectors shall be of either flange-mount or center-mount design.

The flange-mount reflectors shall be circular and flanged so that they may be individually retained in a punched out legend and cannot be removed without dismantling the sign.

The center-mount reflectors shall be circular and be provided with a single aluminum grommeted mounting hole through the center of the reflector. The aluminum grommet shall have a minimum inside diameter of 0.188 inch and a maximum inside diameter of 0.203 inch. The reflector shall have the capacity of accommodating a 3/16 inch nominal diameter blind rivet expanded to 0.196 inch without fracturing or stressing.

Both flange-mount and center-mount reflectors shall be backed by a vapor tight hermetically sealed backing to prevent vapor or dust from reaching the reflex surface.

(b) Materials and Construction

Reflectors shall conform to the following physical requirements:

(1) SEAL TEST: The reflector shall withstand five cycles of being immersed in a 40 degree F. water bath for 15 minutes, then being immersed in a 140 degree F. water bath for 15 minutes. The test shall be performed in accordance with test method 603A in use by the Laboratory of the Division of Highways.

(2) Backing used to protect the reflective system from dirt and moisture shall be non-corrodible under field conditions and shall remain effective for the life of the reflector.

(3) COLOR: The color of the reflectors when illuminated by an automobile headlight shall be an approved clear or yellow color as called for in the proposal. Off-color reflection shall constitute grounds for rejection. Color fastness may be tested by the method specified in ASTM designation D620-49.

(c) Optical Requirements

(1) Definitions

ANGLE OF INCIDENCE. The angle formed by a ray from the light source to the reflector and the normal to the reflector surface.

ANGLE OF DIVERGENCE. The angle formed by a ray from the light source to the reflector and the ray from the reflector to the receptor.

REFLECTANCE. The ratio in percent of the output of receptors receiving reflected light to the photocell output resulting from the incident light.

(2) Uniformity

The reflectance shall decrease uniformly without gaps as the angle of incidence is changed from 0 degrees to 20 degrees on either side.

(3) Reflectance

The reflectance at incident angles of 0 degrees to 20 degrees for various sizes and colors of reflectors shall conform to the values shown below.

(4) Test Methods

The reflectance of the reflex reflectors is measured as the percentage of incident light reflected by a reflector under standardized test conditions in accordance with test method 602A in use by the Laboratory of the Division of Highways.

The incident light and the reflected light are both measured for this specification by the same set of four receptors, color corrected Weston Photronic cells No. 594 RR-OV. The receptors are mounted in a square whose diagonal measures 5-1/4" center to center, and which produce a 2-5/8" divergence when the light source is centered in the square. The reflected light is measured at a distance of 100 feet from the reflector at a divergence angle of 1/8 degree, for all sign reflectors with the exception of the 1/2" reflector. The 1/2" reflex reflector shall be measured at a distance of 50 feet with a divergence angle of 1/4 degree for the values given in Table 1.

TYPE	COLOR	NOM. DIA. (INCHES)	MINIMUM % REFLECTANCE 0°	MINIMUM % REFLECTANCE 20°
Center Mount	Clear	3-1/4	.92	.36
Center Mount	Amber	3-1/4	.55	.22
Center Mount	Clear	2	.38	.15
Center Mount	Amber	2	.23	.09
Flange Mount	Clear	1-5/8	.20	.080
Flange Mount	Clear	1-1/4	.126	.050
Flange Mount	Clear	7/8	.060	.024
Flange Mount	Clear	5/8	.036	.014

Color	Diameter	Minimum % Reflectance 0°	Minimum % Reflectance 20°	Cluster Arrangement
Clear	1/2 inch	0.030		Single reflector
Clear	1/2 inch	--	0.41	19 reflectors in cluster. Six and twelve reflectors are set symmetrically around central reflector at a respective radius of 3/4" and 1-1/2" from center to center.

(d) Tolerance

Not less than 48 out of every 50 reflectors shall pass all tests. When less than 48 but more than 44 reflectors pass all tests, a resample will be allowed at the request of the vendor. When less than 45 reflectors from the original sample pass all tests, the lot represented by the sample will be rejected and no resample will be allowed.

(e) Sampling

Fifty reflectors will constitute a sample to represent each lot. One hundred reflectors will constitute a resample.

(f) Packing

Shipments shall be made in containers which are acceptable to common carriers and packed in such manner as to insure delivery in perfect shape. Any damaged shipments shall be replaced by the vendor. Each package shall be clearly marked as to size, color, type and lot number.

(g) Patents

The vendor shall assume all costs arising from the use of patented materials, equipment, devices, or processes used in producing or incorporated in the produce, and agrees to indemnify and save harmless the State of California, the Director of Public Works, the State Highway Engineer, and their duly authorized representatives from all suits at law, or actions of every nature for, or on account of the use of any patented materials, equipment, devices or processes.