COMPARATIVE ANALYSIS OF REFLECTIVE SHEETING

by

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(The opinions, findings, and conclusions expressed in this report are those of the author and not necessarily those of the sponsoring agencies.)

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ABSTRACT

A comparative analysis was made of the initial brightness of seibulite brand super engineering grade and scotchlite brand high intensity grade reflective sheeting under road conditions. Overhead and ground-mounted guide signs were analyzed. Human factors were incorporated in the analysis through two subjective evaluations, and luminance measurements were made with a telephotometer at the driver's eye position of four automobiles under high and low beam headlights.

The study concluded that the high intensity reflective sheeting is significantly brighter than the seibulite super engineering grade for the silver/white legend material. For the green background material, the two sheetings are not significantly different except for the ground-mounted signs under high beam lights, where the high intensity sheeting is brighter.

A cost analysis based on the cost per lumen per year of useful life showed the high intensity sheeting to be more economical.

Based on the above findings, it is concluded that the seibulite super engineering grade reflective sheeting is not a viable alternative to high intensity reflective sheeting.

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INTRODUCTION

The nighttime visibility of traffic signs, delineators, and other guidance devices strongly depends upon the reflective characteristics of the sheeting used. Different types of reflective sheetings are used depending on the type of sign or device and road conditions, and where visibility is highly critical it is imperative that the most effective reflective sheeting available be used.

The Virginia Department of Highways and Transportation requires that encapsulated lens reflective sheeting be used on (1) all overhead signs; (2) all ground-mounted signs on limited access highways; (3) all signs, delineators, and reflective devices at high-hazard or accident-prone locations; and (4) all signs, delineators, and channelizing devices used at night on all construction and maintenance work sites.(1) The scotchlite brand high intensity grade reflective sheeting (HI), an encapsulated lens sheeting developed by the 3M Company, is the only sheeting used that provides the desired brightness. Consequently, because of the high cost of the sheeting and the lack of competition through bidding, other sheetings are being investigated as a substitute. The substitute should be comparable in performance to high intensity sheeting but less expensive.

The Mitsubishi International Corporation has manufactured the seibulite brand super engineering grade (seibulite SEG) sheeting as a competitor of high intensity sheeting. The seibulite SEG sheeting is an enclosed lens reflective sheeting and its initial cost is about 25% less than that of high intensity sheeting. Since the Department purchases a substantial quantity of high intensity sheeting, a significant cost savings could be realized if seibulite SEG could be substituted on the basis of comparable performance.

OBJECTIVE AND SCOPE

The seibulite SEG sheeting has been proposed as a potential competitor of high intensity sheeting. Therefore, the objective of this research was to make a comparative analysis of the initial brightness of seibulite super engineering grade and scotchlite brand high intensity grade reflective sheetings under road conditions.

For the study, luminance measurements and subjective evaluations were conducted under physical and environmental conditions experienced by the highway user. Because time did not permit tests of the durability of the reflective sheetings, a cost evaluation was made on the basis of expected performance life indicated in specifications for the sheetings. Only reflective sheeting with heat-activated adhesives was used.

REFLECTIVE SHEETINGS

The seibulite super engineering grade reflective sheeting used in this evaluation was ordered exclusively for the field tests; the scotchlite high intensity grade sheeting was taken from the stock of the Salem District sign shop. Moreover, a modified scotchlite brand high intensity grade sheeting is now available and being supplied to the Department by the manufacturer. The green modified sheeting is 1.5 times brighter than the high intensity sheeting tested. However, the modified sheeting was not available to the Salem District prior to the initiation of the field work.

The luminance specifications and effective performance life for the SEG and high intensity sheetings are given in Table 1. The minimum expected brightness values after 10 years are based on a conservative estimate for the seibulite SEG sheeting and on experience for the high intensity sheeting. Seibulite SEG reflective sheetings have undergone accelerated weathering tests for 2,000 hours and exposure tests for a maximum of three years.[2]

The product warranty relative to the durability of seibulite SEG reflective sheeting is given below.[3]

> <u>DURABILITY</u> The reflective sheeting processed and applied to approved sign substrates, and cleaned in accordance with manufacturer's recommendations, shall have a minimum effective performance life of ten years when used on urban and rural installations under normal environmental conditions. The reflective sheeting shall be considered as performing satisfactorily if the sign has not deteriorated due to natural causes to the extent that the sign is ineffective for its intended purpose when viewed from a vehicle.

Table 1

Luminance Specifications and Effective Performance Life

Seibulite SEG Sheeting* (enclosed lens)

Observation Angle	Entrance Angle	Specific Intensity, Min. (cp/fc/sf) White	Green	Est. Min. after 10 Yrs. White	Green
0.2	- 4°	140	30	50	11
	30°	65	8		
0.5	- 4°	48	7		
	30°	28	3.5		

Effective performance life = 10 yrs. with minimum 35.7% and 36.7% reflectivity retained for the white and green sheetings, respectively.**

High Intensity Grade (encapsulated lens)+ Sheeting

Observation Angle	Entrance Angle	Specific Intensity, Min. (cp/fd/sf) Silver	Green	Min. after 10 Yrs. Silver	Green
0.2	- 4°	250	30	200	24
	30°	140	17		
0.5	- 4°	95	12		
	30°	55	6		

Effective performance life = 10 years with minimum 80% reflectivity retained is included in manufacturer's warranty.++

*Source: Reference 2.

**Source: F. J. Moran, Mitsubishi International Corporation, correspondence, October 1981.

+Source: Reference 4.

Note: These values are for the green high intensity sheeting used in the study; not the new, modified green sheeting currently supplied to the Department.

MANUFACTURER'S LIABILITY The manufacturer of the reflective sheeting shall be liable for the replacement of all reflective sheeting or all sheeting processed with inks supplied by the sheeting manufacturer which fail to meet this specification.

The product warranty for high intensity reflective sheeting is the following.(4)

> SCOTCHLITE Brand Reflective Sheeting, High Intensity Grade, Series 2870, 3870, or 5870 which is processed and applied to sign base materials according to sheeting manufacturer's recommendations for traffic control signs, is considered as performing effectively for the number of years stated below if the sheeting has not deteriorated due to natural causes to the extent that: (1) the sign is ineffective for its intended purpose when viewed from a vehicle, or (2) if after removal of surface dirt according to the recommendations of the reflective sheeting manufacturer, the average nighttime reflective brightness is less than that specified in Table III below. Where required, 3M Company's liability will be the pro rata replacement of materials supplied which have been used according to 3M recommendations and which have failed to give effective performance for the life stated.
>
> Experience has shown that effective performance of 10 years can be expected under normal, vertical, stationary, exterior exposure conditions in northern states.
>
> (The information from Table III mentioned above is shown in Table 1 of this report under minimum after 10 years.)

The warranty for seibulite SEG reflective sheeting is based on a subjective judgement of failure in sheeting performance whereas high intensity reflective sheeting warrants an average brightness value for the duration of the effective performance life.

The Department has field experience with the high intensity reflective sheeting but not with the seibulite SEG sheeting.

STUDY SITE

A section of I-581 South near the interchange with Rte. 101 (Hershberger Rd.) in Roanoke, Virginia, was chosen as the study site. Overhead guide signs are located near the first exit ramp, and the left and center signs were used for the study. The high intensity and seibulite SEG sheetings were installed on the left and center signs, respectively (Figures 1 and 2). The overlay method of sign refurbishment was used. There are three lanes of traffic, and the left sign is on the left lane and the center sign is over the center and right lanes. There was no ambient lighting.

Three ground-mounted guide signs with the message TEST SIGN were installed on the right shoulder an average distance of 16.3 ft. (4.96 m) from the travel lanes (Figures 1 and 2) and 300 ft. (91.5 m) apart. These signs were 5 ft. x 5 ft. (1.52 m x 1.52 m) and were fabricated in the sign shop.

The study section began about 2,100 feet (640.1 m) in advance of the overhead signs. Proceeding through the study section, the ground-mounted signs were in the following order: (1) high intensity sheeting legend and seibulite SEG sheeting background (HI/SEG), (2) all seibulite SEG sheeting (SEG), and (3) all high intensity sheeting (HI).

The overhead guide signs were refurbished on May 5 and 6, 1981. The ground-mounted signs were installed on June 1, 1981.

SUBJECTIVE EVALUATION

The evaluation included the collection and analysis of subjective data as well as the taking of luminance measurements. It is important to incorporate human factors into such analyses because motorists do not perceive all the differences in reflectance brightness that are revealed by photometric instrumentation. Moreover, the effectiveness of a sign depends on the motorist's ability to detect and understand the message being imparted.

The comparative evaluation investigated the differences in brightness, uniformity of brightness, and legibility under low and high beam headlamps. The observers were asked to indicate their preferences between the signs and to indicate the signs that were sufficiently bright to gain the attention of the motoring public.

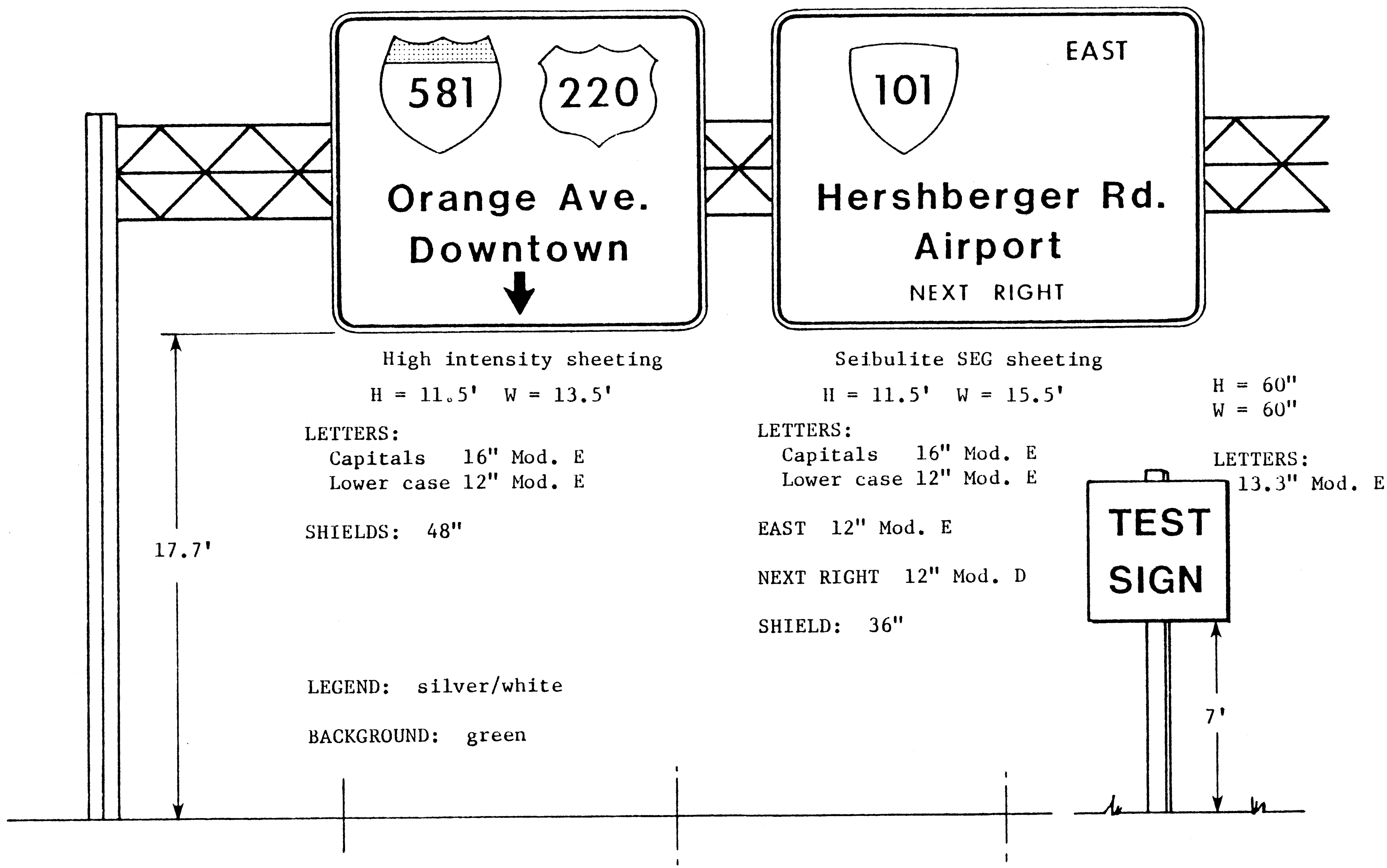
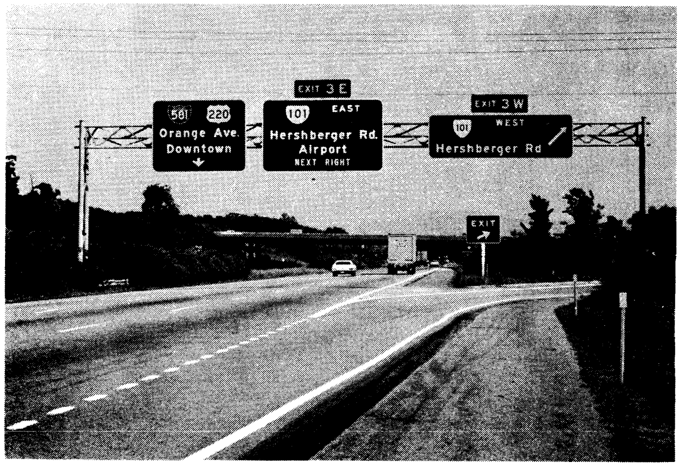
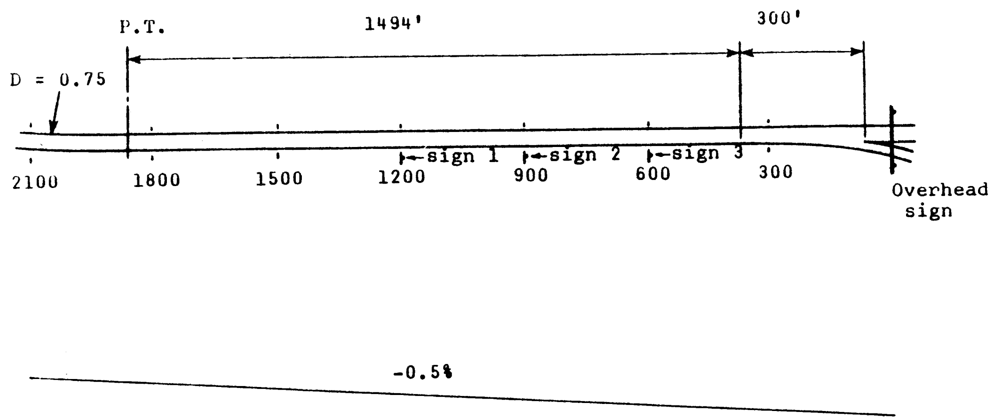


Figure 1. Overhead and ground-mounted guide signs.
Unit Conversions: 1 inch = 2.54 cm
1 foot = 0.3048 meter





Distance from right travel lane

Sign 1 15.33 feet
Sign 2 15.83 feet
Sign 3 17.67 feet

1 Foot = 0.3048 meter

Figure 2. Study site at interchange of I-581 South with U. S. Rte. 101 West.

The subjective evaluation consisted of three parts: evaluation of overhead signs from the center lane, ground-mounted signs from the center lane, and ground-mounted signs from the left lane. No special maintenance was performed on the vehicles.

Two groups participated in the subjective evaluation; one made up of the traffic research advisory committee (TRAC) and the other of employees of the Salem District in non-traffic-related work. The results for these two groups are discussed below.

Traffic Research Advisory Committee

The TRAC evaluation was conducted with 12 observers in three vehicles on June 1, 1981. The evaluation was conducted in the rain, which increased the brightness of the reflective sheetings(5) while reducing the vision of the observers.

Overall, 75% of the observers preferred the high intensity overhead sign and 92% felt that both overhead signs were sufficiently bright. For the ground-mounted signs, 67% of the observers preferred the high intensity sign. The seibulite SEG sign was rated second. The third sign, with a high intensity legend and seibulite SEG background, was rated low because it was aligned with the exit ramp taper instead of the through lanes. Ninety-one percent of the observers indicated that both the high intensity and seibulite SEG ground-mounted signs were of sufficient brightness.

Based on comments from the observers on inadequate time to evaluate the signs, the evaluation was expanded from three to six trips for the next evaluation. In this way, each part required a trip through the study section with headlamps on high beam and a trip with the headlamps on low beam. The third ground-mounted sign, with a high intensity sheeting legend and seibulite SEG background, was placed 300 feet (91.4 m) in front of the first ground-mounted sign to correct the alignment problem. (Note that this change was incorporated into the previous description of the ground-mounted signs.) A detailed summary is presented in the Appendix.

Salem District Employees

This evaluation was conducted on July 27, 1981, under fair weather conditions. There were eighteen observers in five vehicles. A detailed summary is presented in the Appendix and the general results are given below. Because this evaluation was done under clear weather conditions, these results are reviewed more thoroughly.

Part I — Overhead Signs

Sixty-one percent of the observers indicated that the left sign (high intensity sheeting) was slightly or much brighter than the right sign (seibulite SEG sheeting) for low beams, and 78% indicated the same for high beams. There was no difference, as indicated by 72% of the observers for low beams, in the uniformity of brightness for the two signs under low beams; however, 50% of the observers preferred the high intensity sheeting under high beams. The high intensity sign was at least slightly more legible for low beams (55%) and high beams (67%). Overall, 72% of the observers preferred the high intensity sign and 22% had no preference. Sixty-one percent felt that both signs were of sufficient brightness to gain the attention of the motoring public.

Part II — Center Lane and Part III — Left Lane Views of Ground-Mounted Signs

As noted previously, these signs were designed as follows:

First sign — high intensity legend, seibulite SEG background, HI/SEG

Second sign — seibulite SEG background and legend, SEG

Third sign — high intensity background and legend, HI

The brightness, uniformity of brightness, and legibility rankings under low beams were in the following order: HI sign, HI/SEG sign, SEG sign. For the high beams, the HI sign was ranked slightly higher than the HI/SEG sign on brightness and the HI/SEG sign was ranked higher than the HI sign on uniformity of brightness and legibility. The SEG sign was consistently ranked last. Overall, the preference rankings were: HI sign (ranked first by 72.2% of the observers), HI/SEG sign (ranked second by 61.1% of the observers), and SEG sign (ranked third by 100% of the observers). Eighty-nine percent of the observers thought that both the HI/SEG and HI signs were of sufficient brightness; only 22% felt that the SEG sign was of sufficient brightness.

For part III, the HI sign was consistently ranked higher than the HI/SEG sign for low beams and slightly higher for high beams. The SEG sign again was consistently ranked third. Overall preferences and indications of sufficient brightness were similar to the results of part II.

Two general comments were noted. Three observers (16.7%) noted that the high intensity overhead sign appeared brightest at greater distances and that close up there was no difference in brightness. The high intensity background and legend sign appeared too bright and was difficult to read in the opinion of four observers (22.2%).

In general, the high intensity sheeting was preferred over the seibulite SEG sheeting. For the overhead signs, most observers felt that both sheetings were sufficiently bright. On the ground-mounted signs, however, the majority felt that the seibulite SEG sign was not sufficiently bright compared to the other two signs with high intensity sheeting on the legend.

Summary — Subjective Evaluations

The overall results of the subjective evaluations are shown in Table 2, where the percentage preferred means the percentage of observers who ranked that sign number one. For the ground-mounted signs, the percentages for the center and left lane rankings were averaged. The most dramatic difference between the two evaluations is the difference in the percentages of observers who considered the seibulite SEG ground-mounted sign as sufficiently bright (91% for the TRAC versus 28% for the Salem District). The corrected alignment of the sign with high intensity sheeting legend and seibulite SEG sheeting background significantly changed the relative brightness ratings for the sign with seibulite SEG sheeting.

In general, the subjective evaluation data indicated a preference for the high intensity sheeting.

Table 2

Summary of Overall Results from Subjective Evaluations

TRAC*	Salem District
Overhead Signs	**Overhead Signs**
75% preferred HI	72% preferred HI
92% considered both signs to be sufficiently bright	61% considered both signs to be sufficiently bright
Ground-Mounted Signs	**Ground-Mounted Signs**
64% preferred HI	67% preferred HI
19% preferred SEG	0% preferred SEG
	34% preferred HI/SEG
100% considered HI to be sufficiently bright	99% considered HI to be sufficiently bright
91% considered SEG to be sufficiently bright	28% considered SEG to be sufficiently bright
	89% considered HI/SEG to be sufficiently bright

*Note — Evaluated in rain when brightness of sign generally improves.

LUMINANCE MEASUREMENTS

Photometric Instrumentation

A Gamma Scientific, Inc. Model 2009K telephotometer was used to obtain luminance readings by measuring the amount of light reflected from the sign surface.

The 2 minutes of angle sensing probe was chosen because it approaches closely the 20/40 acuity eyesight required for driver licensing in Virginia.

The optical head of the instrument was mounted on a tripod at driver eye height above the back of the driver's seat. Two operators were required: one to align the optical head and the other to record the reading.

Procedure

The procedure used in taking the luminance measurements was based on that employed in a study by Robertson.(6) The distances for luminance measurements were 300, 600, and 900 ft. (91.5, 182.9, and 274.3 m) for both the overhead and ground-mounted signs.

In order to obtain true luminance readings on the sign legend sheeting at all distances, strips of sheeting were added to the signs as shown in Figure 3. The additional sheeting was necessary because the telephotometer measures an area with a diameter of 6.28 in. (15.95 cm) at 900 ft. (274.3 m) when using a 2 minute aperture. An area of this magnitude is not available when using the letters in the legend on both the overhead and ground-mounted signs. The ground-mounted sign with a high intensity sheeting legend and a seibulite SEG sheeting background was omitted. Luminance measurements were taken in the positions shown in Figure 3 to obtain average values. Special care was taken to obtain measurements exclusively on the positions indicated in the figure.

Luminance readings were taken from the right lane for the center overhead sign and the ground-mounted signs and from the left lane for the left sign. Readings were taken only of the portion of the center overhead sign that was over the right lane to eliminate any effects of angularity. Readings were made under both high and low beam headlamps. Data were recorded on the form shown in Table 3.

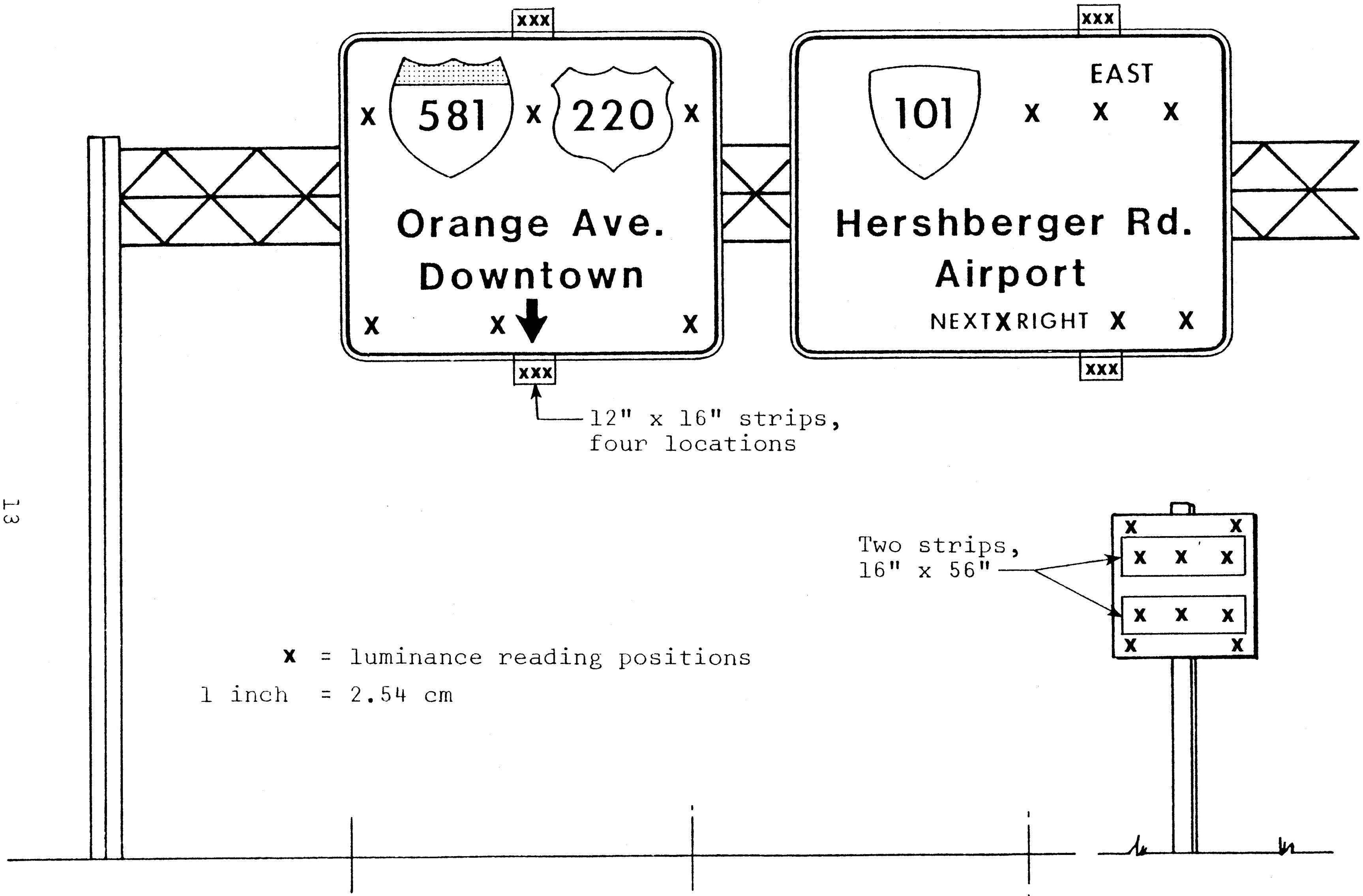


Figure 3. Position of luminance readings on guide signs.

Table 3

Luminance Data Form

SIGN LUMINANCE READINGS
(Foot-Lamberts)

Location 581 S AT HBERGER RD Date ______ Time ______

Weather ______ Temp. ______ Vehicle ______

Overhead ______ Ground Mount ______ Ambient Cond. ______

Distance ______ FT. Lane ______ Apperture 2'

High Beam	Background		Legend	
	H.I.	S.E.G.	H.I.	S.E.G.
U.L.				
U.C.				
U.R.				
L.L.				
L.C.				
L.R.				

Low Beam	Background		Legend	
	H.I.	S.E.G.	H.I.	S.E.G.
U.L.				
U.C.				
U.R.				
L.L.				
L.C.				
L.R.				

Vehicles

Four domestic automobiles were used in the data collection (Table 4): a compact, a mid-size, and 2 full-sized vehicles. The headlamp alignments were checked at an official inspection station. Prior to the readings the fuel tanks were filled and the windshield and surfaces of the headlamps were cleaned. All of the vehicles had tinted windshields.

Table 4

Vehicles Used in the Study

Year	Make and Model	No. of Headlamps
1980	Chevette; 2-door hatchback	2
1979	Dodge Diplomat; 4-door	4
1979	Plymouth Volare; station wagon	2
1979	Chevrolet Impala; station wagon	4

Results of Luminance Measurements

The t-test was used to determine if the difference in luminance for the two types of sheeting was statistically significant. Calculations were performed using the t-test computer program of the Statistical Package for the Social Sciences.[7] Based on the specifications of the reflective sheetings, the hypotheses were that (1) the mean luminances of the high intensity and seibulite SEG sheeting are not equal for the background sheeting (two-tailed test), and (2) the mean luminance of the high intensity sheeting is greater than that of the seibulite SEG sheeting for the sign legends (one-tailed test). The level of significance equals 0.05 for both tests.

A total of 516 luminance readings were recorded.

The results of the tests for the overhead signs are summarized in Table 5 and those for the ground-mounted signs in Table 6.

Table 5

Summary of Results for Overhead Signs

Sign	Distance, ft.	Mean Luminance, fL	Number of Readings	Standard Deviation	t Value	Significance
BACKGROUND — HIGH BEAMS						
HI	300	1.81	18	2.36	0.20	0.845
SEG	300	1.67	18	1.92		
HI	600	5.87	18	2.10	1.33	0.192
SEG	600	4.60	18	3.44		
HI	900	5.81	18	1.56	1.68	0.102
SEG	900	4.73	18	2.24		
LEGEND — HIGH BEAMS						
HI	300	15.10	18	20.81	0.51	0.306
SEG	300	11.98	18	15.20		
HI	600	29.82	18	12.74	2.14	0.020*
SEG	600	20.13	18	14.42		
HI	900	22.14	18	7.06	2.15	0.020*
SEG	900	16.92	18	7.50		
BACKGROUND — LOW BEAMS						
HI	300	0.126	18	0.10	-0.12	0.906
SEG	300	0.130	18	0.10		
HI	600	0.168	18	0.06	0.08	0.940
SEG	600	0.166	18	0.11		
HI	900	0.180	18	0.09	0.13	0.894
SEG	900	0.175	18	0.11		
LEGEND — LOW BEAMS						
HI	300	0.91	18	0.77	0.99	0.166
SEG	300	0.69	18	0.55		
HI	600	0.96	18	0.31	2.30	0.014*
SEG	600	0.69	18	0.39		
HI	900	0.77	18	0.52	1.79	0.042*
SEG	900	0.51	18	0.34		

1 fL = 3.4.26 cd/m^2.

*There is a statistically significant difference in the mean luminances.

Table 6

Summary of Results for Ground-Mounted Signs

Sign	Distance, ft.	Mean Luminance, fL	Number of Readings	Standard Deviation	t Value	Significance
BACKGROUND — HIGH BEAMS						
HI	300	5.88	24	2.37	2.36	0.022*
SEG	300	4.29	24	2.32		
HI	600	8.66	24	3.63	2.58	0.013*
SEG	600	6.48	24	2.02		
HI	900	4.48	24	2.30	0.76	0.453
SEG	900	3.97	24	2.40		
LEGEND — HIGH BEAMS						
HI	300	46.08	18	13.29	4.65	0.000*
SEG	300	30.24	18	5.71		
HI	600	61.13	18	13.03	5.19	0.000*
SEG	600	38.13	18	13.55		
HI	900	31.43	18	8.79	6.29	0.000*
SEG	900	17.37	18	3.58		
BACKGROUND — LOW BEAMS						
HI	300	0.48	24	0.28	1.73	0.091
SEG	300	0.35	24	0.21		
HI	600	0.94	24	0.69	2.50	0.016*
SEG	600	0.54	24	0.38		
HI	900	0.48	24	0.49	-0.61	0.546
SEG	900	0.58	24	0.65		
LEGEND — LOW BEAMS						
HI	300	4.37	18	2.53	2.23	0.016*
SEG	300	2.80	18	1.57		
HI	600	7.04	18	4.86	2.25	0.017*
SEG	600	4.19	18	2.25		
HI	900	4.13	18	2.34	1.87	0.036*
SEG	900	2.86	18	1.69		

1 fL = 3.4.26 cd/m^2.

*There is a statistically significant difference in the mean luminances.

Overhead Signs

For the sign legends under both high and low beam lights the high intensity sheeting was significantly brighter than the seibulite SEG sheeting at 600 and 900 ft. (182.9 and 274.3 m). It is noted that under high beams at 300 ft. (91.5 m) the standard deviation was greater than the mean luminance. The luminance readings varied widely by vehicle and by reading position on the signs at 300 ft. (91.5 m). There were no significant differences in the background luminance readings. The relationship between luminance data and distance is shown in Figure 4. The luminance readings and the differences in luminance between the two sheetings were maximum at 600 ft. (182.9 m) under high beams. The background readings under low beams were quite similar for the two sheetings.

Ground-Mounted Signs

The high intensity sheeting was significantly brighter than the seibulite SEG for the legend at all distances under high and low beams. For the background, the high intensity sheeting was significantly brighter than the seibulite SEG at 300 and 600 ft. (91.5 and 182.9 m) for high beams and 600 ft. (182.9 m) for low beams. It is noted that at 900 ft. (274.3 m) under low beam lights the background readings had standard deviations greater than the mean for both sheetings. Figure 5 presents graphs of luminance versus distance. The peak luminance readings at 600 ft. (182.9 m) are noted.

Contrast Ratios

A contrast ratio (also called luminance ratio) of a sign is a ratio of the legend luminance and background luminance with the brighter luminance being the numerator.[8] Research has demonstrated the importance of contrast on sign legibility and visibility.[8,9] Forbes et al. reported that ratios between 6 and 13 to 1 were associated with the optimum legibility distance for white letters on blue or green signs based on laboratory results.[8] The suggested required minimum contrast ratio was 5 to 1 based on field results for high and low beams and lab results.

Contrast ratios for the luminance readings are given in Table 7. In general, the ratios were greater for the higher intensity than the seibulite SEG. They decreased with distance for both overhead signs and the seibulite SEG ground-mounted sign. For the high intensity ground-mounted sign they were fairly constant. These relationships are indicated in Figures 4 and 5.

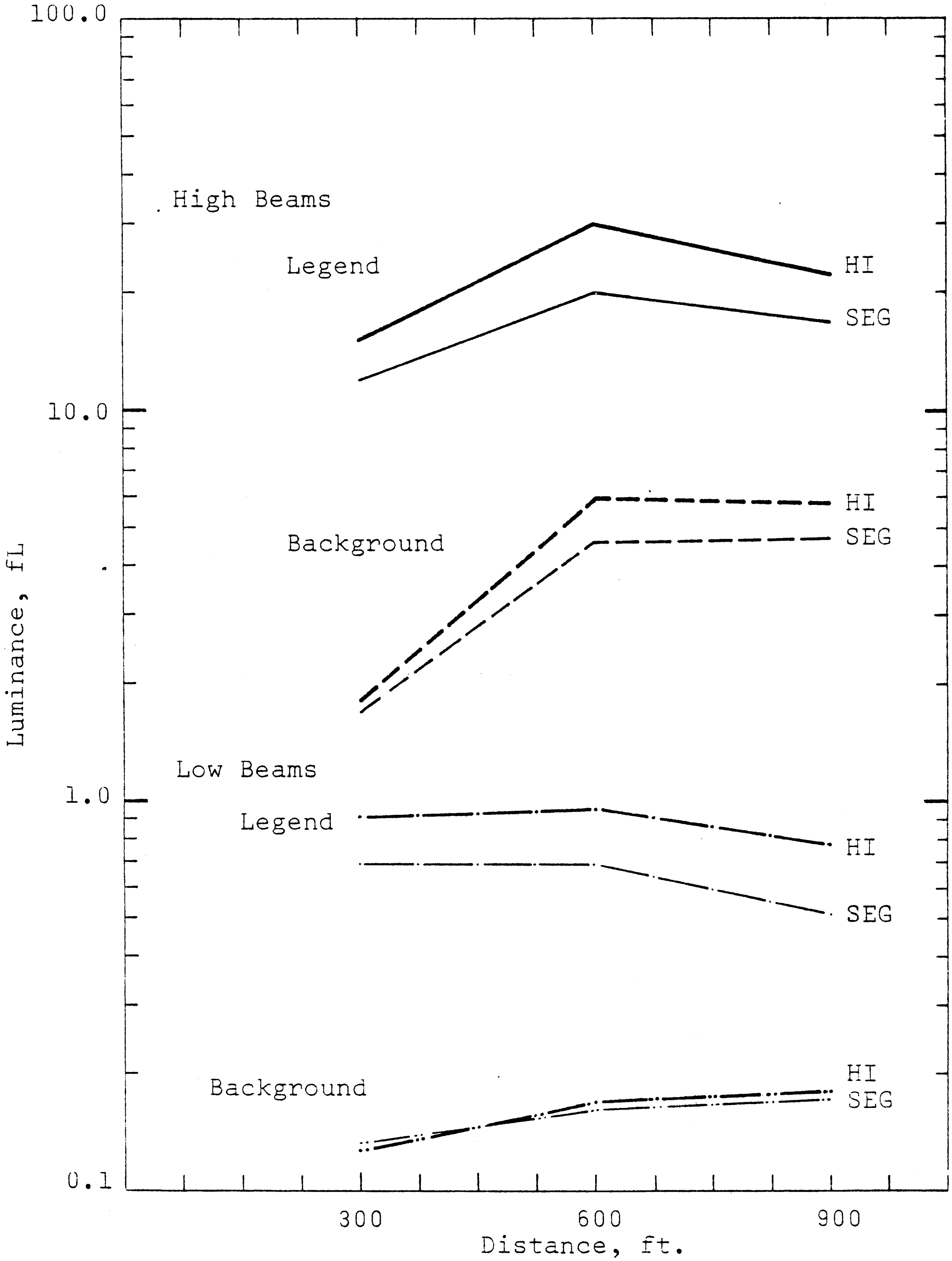


Figure 4. Luminance versus distance — overhead signs.
Conversion Units: 1 ft = 0.3048 meter
1 fL = 3.426 cd/m^2

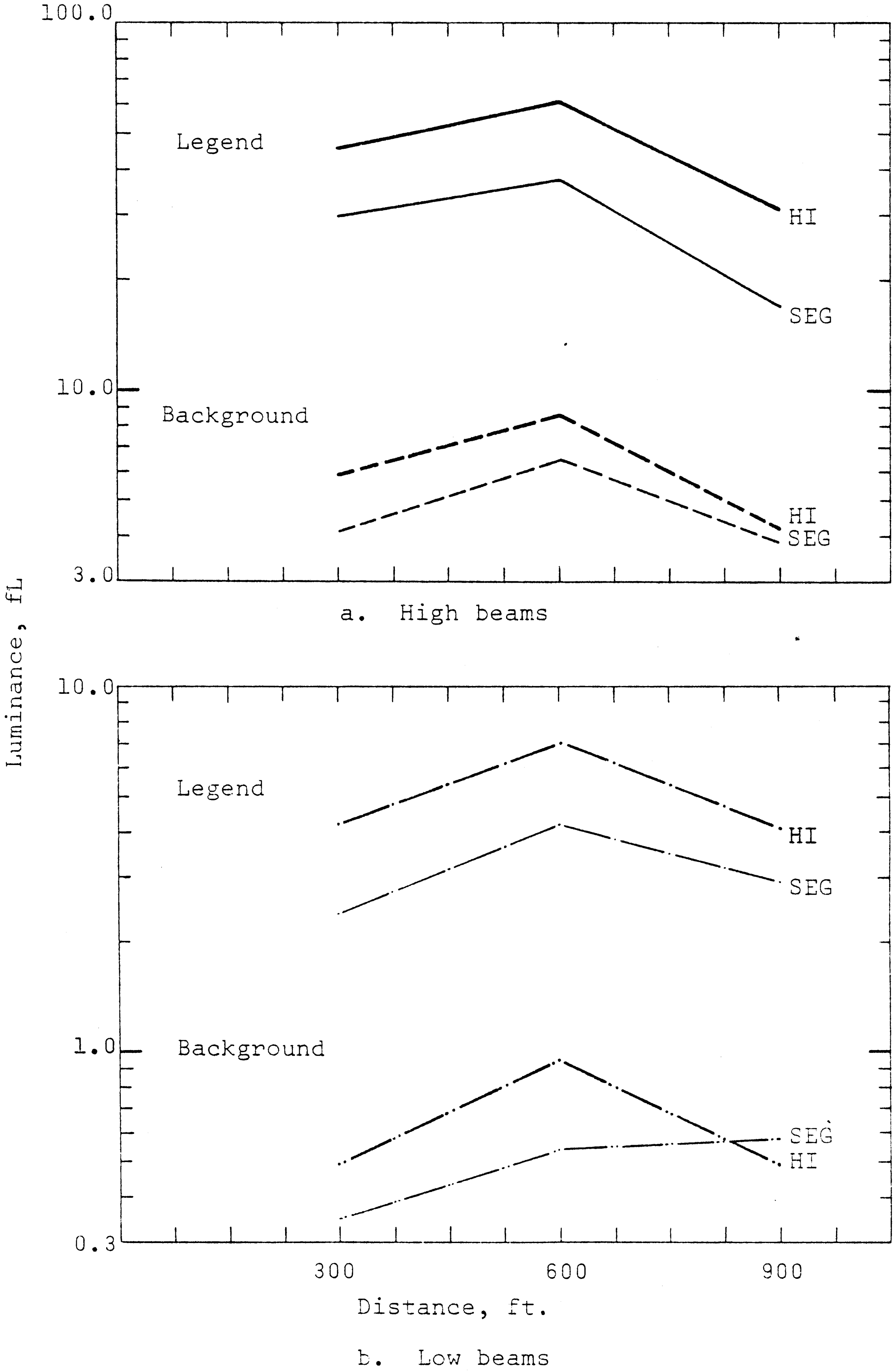


Figure 5. Luminance versus distance — ground-mounted signs.

Conversion Units: 1 ft = 0.3048 meter
1 fL = 3.426 cd/m^2

Table 7

Contrast Ratios

Distance, ft.	High Beams		Low Beams	
	HI	SEG	HI	SEG
		Overhead Signs		
300	8.3	7.2	7.0	4.3
600	5.1	4.4	5.6	4.1
900	3.8	3.6	4.3	2.8
Average	5.7	5.1	5.6	4.1
		Ground-Mounted Signs		
300	7.8	7.0	9.1	8.0
600	7.1	5.9	7.5	7.8
900	7.0	4.4	8.6	4.9
Average	7.3	5.8	8.4	6.9

1 ft. = 0.3048 meter.

The average contrast ratio is greater for the high intensity signs than for the seibulite SEG signs. Only the average contrast ratio for the seibulite SEG overhead sign under low beams fell below the suggested required minimum of 5 to 1.

Conclusion on Luminance Readings

It was concluded that for the legend luminance the high intensity sheeting was significantly brighter than the seibulite SEG. The difference in brightness was greater for the ground-mounted than the overhead signs. The high intensity sheeting was generally brighter than the seibulite SEG in background luminance, but was not significantly brighter except for the ground-mounted signs under high beams. Therefore, it was concluded that there was no significant difference in the background luminances of the two sheetings, except for the ground-mounted signs under high beams. The luminance readings and the difference in luminance readings for the two sheetings were generally greater for the ground-mounted signs because under the headlamp alignment standards (SAE specifications) the light beam is aimed to the lower right side of the roadway.

The contrast ratios also favored the high intensity sheeting in that those for the high intensity signs were greater than those for the corresponding SEG signs.

COST ANALYSIS

As mentioned in the introduction, the cost of materials used on highway signs is an especially important consideration because of the large quantities purchased. The prices of seibulite super engineering grade and scotchlite high intensity grade sheetings are $1.755/ft.^{2} ($0.163/m^2) and $2.297/ft.^{2} ($0.213/m^2), respectively; thus, the former costs 23.6% less than the latter. However, a cost analysis should consider the expected service life and brightness of the materials as well as the purchase price. Consequently, a comparison of the cost/lumen/year of useful life was made using the following equation from reference 7.

$$C = \frac{PC}{\frac{B_n + B_o}{2} \times PF}, \qquad (1)$$

where

C = cost/lu./yr. of useful life;

PC = purchase cost of sheeting per ft.^{2} (0.93 m^2);

B_n = average luminance of new material;

B_o = minimum average luminance of material at the end of its useful life — (from Table 1, B_o = 35.7% B_n, for seibulite SEG white;

B_o = 36.7% B_n for seibulite SEG green; 80% B_n for HI; and

PF = effective performance life (manufacturer's warranty) equals 10 years for both sheetings.

A straight-line linear reduction in luminance over the useful life of the sheeting is assumed. The cost savings, S, was calculated by using the following equation:

$$S = \frac{C_{SEG} - C_{HI}}{C_{SEG}} \times 100\%, \qquad (2)$$

where

S = percent savings by using high intensity;

SEG = seibulite SEG; and

HI = high intensity.

Two sets of luminance readings (taken under both high and low beam headlights) for the overhead and ground-mounted signs were used in the calculations: one set consisted of luminance readings taken at 600 ft. (182.9 m), and the other of the readings averaged over 300, 600, and 900 ft. (91.5, 182.9, and 274.3 m). The average luminance, cost per lumen per year of useful life, and cost savings are presented in Table 8, where it can be noted that the high intensity reflective sheeting consistently provides a cost savings. Therefore, it is concluded that the high intensity sheeting is more cost-effective than the seibulite SEG over the useful life of the sheeting.

DURABILITY

As mentioned in the Objective and Scope section of this report, durability, an important consideration in an evaluation of reflective sheeting, was not addressed. Accelerated weathering tests of the reflective sheetings were incomplete at the writing of this report. However, it is noted that the high intensity green reflective sheeting failed before 500 hours in the weatherometer due to delamination. Delamination of high intensity sheeting has also been noted in the field. The 3M company claims that delamination problems have been solved in the modified high intensity sheeting by improving the integrity of the top film. All of the sheeting tested had heat-activated adhesives.

Since the manufacturing processes for seibulite super engineering grade and engineering grade are essentially the same (except that SEG has smaller, more uniform glass beads),[2] it is likely that the two sheetings may be similarly durable. Therefore, experiences with seibulite engineering grade are discussed.

Table 8

Cost Analysis

	Silver/White		Green	
	HI	SEG	HI	SEG
Ground-Mounted Signs				
Distance = 600 feet:				
Luminance high beams (ft.-l)	61.13	38.13	8.66	6.48
C (¢/lm./yr.)	0.418	0.678	2.95	3.96
S (%)	38.3		25.5	
Luminance low beams (ft.-l)	7.04	4.19	0.94	0.54
C (¢/lm./yr.)	3.63	6.17	27.2	47.5
S (%)	41.5		42.7	
Distance = average of 300, 600, and 900 feet:				
Luminance high beams (ft.-l)	46.21	28.58	6.34	4.91
C (¢/lm./yr.)	0.552	0.905	4.03	5.23
S (%)	39.0		22.9	
Luminance low beams (ft.-l)	5.18	3.28	0.633	0.49
C (¢/lm./yr.)	4.93	7.89	40.3	52.4
S (%)	37.5		23.1	
Overhead Signs				
Distance = 600 feet:				
Luminance high beams (ft.-l)	29.82	20.13	5.87	4.60
C (¢/lm./yr.)	0.856	1.28	4.35	5.58
S (%)	33.1		22.0	
Luminance low beams (ft.-l)	0.96	0.69	0.168	0.166
C (¢/lm./yr.)	26.59	37.49	151.92	154.7
S (%)	29.1		1.8	
Distance = average of 300, 600, and 900 feet:				
Luminance high beams (ft.-l)	22.35	16.34	4.50	3.66
C (¢/lm./yr.)	1.14	1.58	5.67	7.02
S (%)	27.8		19.2	
Luminance low beams (ft.-l)	0.88	0.63	0.158	0.157
C (¢/lm./yr.)	29.0	41.1	161.5	163.5
S (%)	29.4		1.2	

1 ft. = 0.3048 meter.

1 fL = 3.426 cd/m^2.

The Department has encountered a rapid deterioration in brightness, or graying, of the engineering grade sheeting. The breakdown appears to be in the coating under the glass beads. The North Carolina DOT has experienced graying or streaking with engineering grade white and yellow, with an accompanying loss in reflectivity, as soon as 2 months after installation under road conditions. In considering seibulite SEG sheeting, the Georgia DOT removed the super engineering grade sheeting from its bid list after white and yellow sheeting turned gray and failed the weatherometer tests. The problem of graying and streaking is apparently confined to pressure-sensitive adhesive sheeting. The aforementioned problems warrant consideration, especially since pressure-sensitive adhesives are used extensively in the regional sign shops.

It is important that durability be examined in the testing of a reflective sheeting for proven performance. One effective technique for exposing a variety of sheetings to the environment to evaluate their durability is to use an outdoor exposure deck with sign racks. In this manner, several reflective sheetings can be evaluated as new types are developed and existing types are modified.

CONCLUSIONS

Table 9 summarizes the results of the comparative analysis of the initial brightness of scotchlite brand high intensity grade and seibulite super engineering grade reflective sheetings and of the cost analysis. In this table the reflective sheeting receiving the highest rating for each comparison is shown. Except for the luminance readings of the background on the overhead signs, the high intensity sheeting rated higher than the seibulite SEG for subjective evaluations, luminance readings, and costs.

The discussion presented on durability indicates that caution should be observed in considering use of the seibulite SEG sheeting.

Table 9

Comparative Analysis Summary

Method of Comparison	Preferred Materials	
Subjective evaluation	Overhead Signs: HI	Ground-Mounted Signs: HI
Luminance readings (for both beams)	Overhead Signs: White/Silver HI; Green HI/SEG	Ground-Mounted Signs: White/Silver HI; Green HI
Cost analysis	White/Silver: HI	Green: HI

RECOMMENDATIONS

Based on the results of this comparative analysis of high intensity and seibulite super engineering grade reflective sheetings, it is recommended that the Department continue to use the high intensity grade sheeting where maximum brightness is desired. The SEG sheeting does not appear to be a viable substitute.

The modified high intensity grade sheeting was not being distributed in the Commonwealth of Virginia because the Virginia Department of Highways and Transportation's specifications for reflective sheeting, in particular those for encapsulated lens sheeting, are based on Federal Specification L-S-300B,[11] which was superseded by Federal Specification L-S-300C in 1979. The modified high intensity sheeting was manufactured to satisfy the new specifications,as well as to improve the product line. Therefore, it is recommended that the Virginia Department of Highways and Transportation adopt Federal Specification L-S-300C to ensure receipt of the modified high intensity sheeting.

Further, it is recommended that a standard evaluation procedure that includes outdoor exposure to weathering be developed for evaluating new and modified reflective sheetings.

ACKNOWLEDGEMENTS

The author expresses sincere appreciation to J. D. Shelor, R. N. Robertson, B. T. Williams, and C. Janowski for their efforts in collecting field data. Appreciation is also due R. N. Robertson for advice given during the study.

Appreciation is due D. I. Bower and the Traffic Section of the Salem District of the Virginia Department of Highways and Transportation for their assistance in fabricating, refurbishing, and installing the signs and for furnishing traffic control during the collection of data.

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APPENDIX

RESULTS OF THE SUBJECTIVE EVALUATIONS

TRAFFIC RESEARCH ADVISORY COMMITTEE

Comparative Evaluation of Reflective Sheeting — Results June 1, 1[illegible]

Weather — Rain Number of Observers = 12

This evaluation requires six trips through the study site: two trips to evaluate the overhead signs (part 1) and four trips for the ground-mounted signs (part 2). Please feel free to make additional comments on your observations.

Part 1. Overhead Sign Evaluation

Three overhead signs are present at the study site. Please focus your attention on the Left and Center signs. Check the appropriate answer for the questions below for low and high beam conditions.

1. Is there a difference in the brightness for the two signs?

Low beam	High beam	
3 (25%)	3 (25%)	no difference
5 (42%)	7 (58%)	the left sign is slightly brighter
4 (33%)	2 (17%)	the left sign is much brighter
____	____	the center sign is slightly brighter
____	____	the center sign is much brighter

2. Is there a difference in the uniformity in brightness for the two signs?

Low beam	High beam	
4 (33%)	4 (33%)	no difference
8 (67%)	8 (67%)	the left sign is slightly more uniform
____	____	the left sign is much more uniform
____	____	the center sign is slightly more uniform
____	____	the center sign is much more uniform

3. Is there a difference in the legibility of the two signs?

Low beam	High beam	
4 (33%)	5 (42%)	no difference
8 (67%)	6 (50%)	the left sign is slightly more legible
____	1 (8%)	the left sign is much more legible
____	____	the center sign is slightly more legible
____	____	the center sign is much more legible

4. Which sign do you prefer?

3 (25%) no preference 9 (75%) left sign ____ center sign

5. Which signs have sufficient brightness to gain the attention of the motoring public?

11 (92%) Both signs 1 (8%) Left sign only ____ Center sign only ____ Neither sign

Comments The left sign is slightly too much brighter in target value.
The left sign is slightly more uniform and legible.
The left sign is preferred but both signs are acceptable.

Part II. Ground-Mounted Sign Evaluation - Center Lane

Three ground-mounted signs with the same message are present on the right shoulder. The ground-mounted signs are identified as first, second and third signs (i.e. as you approach the signs, you will arrive at the first sign first the second sign second, and the third sign last).

Rank the ground-mounted signs with respect to the following variables for high and low beam conditions. If there is no difference, rank the signs equally. Ranking scale: 1 2 3

		SEG First sign			HI Second sign			HI/SEG Third sign		
	Ranking	1	2	3	1	2	3	1	2	3
6. Brightness	(low beam)	3	6	3	8	2	2	1	6	5
	(high beam)	6	4	1	4	5	2	1	3	7
7. Uniformity of Brightness	(low beam)	4	2	5	8	1	2	1	3	7
	(high beam)	7	2	2	4	5	2	1	3	7
8. Legibility	(low beam)	3	6	3	7	4	1	0	5	7
	(high beam)	5	4	2	3	7	1	0	5	6
9. Overall preference		1	9	2	8	3	1	0	6	6
			(75%)			(67%)			(50%)	

10. Check the signs that are of sufficient brightness to gain the attention of the motoring public.

11(92%) first sign 12(100%) second sign 8(67%) third sign

Comments

Note: The third sign was mounted in alignment with the exit taper instead of the through roadway.

The second sign is preferred from both the left and center lanes.

The first sign is ranked second.

Part III. Ground-Mounted Sign Evaluation - Left Lane

Part III is similar to Part II except that the evaluation is made from the left lane.

Rank the ground-mounted signs with respect to the following variables for high and low beam conditions. If there is no difference, rank the signs equally. Ranking scale: 1 2 3

		SEG First sign 1	2	3	HI Second sign 1	2	3	HI/SEG Third sign 1	2	3
11. Target value	(low beam)	2	6	2	8	3	0	0	5	6
	(high beam)									
12. Uniformity of brightness	(low beam)	5	2	2	7	1	1	0	2	7
	(high beam)	5	2	2	5	3	1	0	2	7
13. Legibility	(low beam)	5	4	1	6	3	2	0	3	7
	(high beam)	4	5	1	5	5	1	0	3	7
14. Overall preference		3	5	2	6	3	1	0	4	6
			50%			(60%)				

15. Check the signs that are of sufficient brightness to gain the attention of the motoring public.

10(91%) first sign 11(100%) second sign 6(55%) third sign

Comments (See Part II.)

Your title ____________________

Thank You for Participating in the Evaluation

SALEM DISTRICT EMPLOYEES

Comparative Evaluation of Reflective Sheeting — Results July 27, 1981

Weather — Partly cloudy No. of Observers = 18

This evaluation requires three trips through the study site: one trip to evaluate the overhead signs (part 1) and two trips for the ground-mounted (part 2). Please feel free to make additional comments on your observations.

Part 1. Overhead Sign Evaluation

Note: Left sign — high intensity
Center sign — Seibulite SEG

Three overhead signs are present at the study site. Please focus your attention on the Left and Center signs. Check the appropriate answer for the questions below for low and high beam conditions.

1. Is there a difference in the target value for the two signs?

Low beam	High beam	
3 (17%)	1 (6%)	no difference
8 (44%)	11 (61.1%)	the left sign is slightly brighter
3 (17%)	3 (17%)	the left sign is much brighter
3 (17%)	3 (17%)	the center sign is slightly brighter
1 (6%)		the center sign is much brighter

2. Is there a difference in the uniformity in brightness for the two signs?

Low beam	High beam	
13 (72%)	8 (44%)	no difference
3 (17%)	5 (28%)	the left sign is slightly more uniform
1 (6%)	4 (22%)	the left sign is much more uniform
	1 (6%)	the center sign is slightly more uniform
1 (6%)		the center sign is much more uniform

3. Is there a difference in the legibility of the two signs?

Low beam	High beam	
6 (33%)	5 (28%)	no difference
7 (39%)	10 (56%)	the left sign is slightly more legible
3 (17%)	2 (11%)	the left sign is much more legible
2 (11%)	1 (6%)	the center sign is slightly more legible
		the center sign is much more legible

4. Which sign do you prefer?

4 (22%) no preference 13(72%) left sign 1(6%) center sign

5. Which signs have sufficient brightness to gain the attention of the motoring public?

11(61%) Both signs 5(28%) Left sign only 1(6%) Center sign only ____ Neither sign

Comments: There is a reversal in ratings between low and high beam. The left sign is brighter at greater distances; there is no difference close up. (Noted by 3 observers.)

There is a hot spot in the center of the center sign.

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Part II. Ground-Mounted Sign Evaluation - Center Lane

Three ground-mounted signs with the same message are present on the right shoulder. The ground-mounted signs are identified as first, second and third signs (i.e. as you approach the signs, you will arrive at the first sign first the second sign second, and the third sign last).

Rank the ground-mounted signs with respect to the following variables for high and low beam conditions. If there is no difference, rank the signs equally. Ranking scale: 1 2 3

		First sign (HI/SEG)			Second sign (SEG)			Third sign (HI)		
	Rankings	1	2	3	1	2	3	1	2	3
6. Target value	(low beam)	4	12	2	1	0	17	16	1	1
	(high beam)	9	8	1	2	1	15	10	7	1
7. Uniformity of Brightness	(low beam)	4	13	2	1	2	15	13	4	1
	(high beam)	12	5	1	1	4	13	7	9	2
8. Legibility	(low beam)	5	10	3	1	2	14	11	4	3
	(high beam)	11	5	2	2	5	11	7	8	3
9. Overall preference		6	11	1	0	0	18	13	4	1
			(61%)			(100%)			(72%)	

10. Check the signs that are of sufficient brightness to gain the attention of the motoring public.

16(89%) first sign   4(22%) second sign   17(94%) third sign

Comments : The third sign is preferred.

The first sign is more legible.

The third sign is too bright (difficult to read) (Noted by 4 observers.)

The second sign appears dull.

Part III. Ground-Mounted Sign Evaluation - Left Lane

Part III is similar to Part II except that the evaluation is made from the left lane.

Rank the ground-mounted signs with respect to the following variables for high and low beam conditions. If there is no difference, rank the signs equally. Ranking scale: 1 2 3

			First sign			Second sign			Third sign		
		Rankings	1	2	3	1	2	3	1	2	3
11.	Brightness	(low beam)	6	8	4	0	5	13	14	3	1
		(high beam)	6	9	3	1	3	14	12	5	1
12.	Uniformity of brightness	(low beam)	5	9	4	0	9	9	11	4	3
		(high beam)	6	9	3	1	7	10	9	8	1
13.	Legibility	(low beam)	6	7	5	0	7	11	12	5	1
		(high beam)	7	8	3	2	6	10	8	5	5
14.	Overall preference		7	7	4	0	7 (61%)	11	11	4 (61%)	3

15. Check the signs that are of sufficient brightness to gain the attention of the motoring public.

16(89%) first sign 6(33%) second sign 17(94%) third sign

Comments : (See Part II.)

Your title ____________________

Thank You for Participating in the Evaluation

December 14, 1981

23.7.60

MEMORANDUM

TO : Mr. Leo E. Busser III, Chairman, Research Council Administration Board

FROM : Howard Newlon, Jr.

SUBJECT: Comparative Analysis of Reflective Sheeting

The attached final report on the subject research requested by Messrs. Harold C. King and J. P. Mills, Jr. presents the results of a comparative analysis of 3M's scotchlite brand high intensity grade reflective sheeting and Mitsubishi's seibulite brand super engineering grade. The two types of sheeting were evaluated under road conditions.

A subjective evaluation, an analysis of luminance measurements, and a cost analysis were conducted. The 3M product was consistently rated higher than the Mitsubishi sheeting for all three considerations.

It is noted that the North Carolina DOT has experienced problems with seibulite engineering grade sheeting, which is fabricated by a process similar to that used for seibulite super engineeting grade sheeting. The sheeting has been noted to turn gray, streak and lose its reflectivity in a relatively short time. The Georgia DOT has removed seibulite super engineering grade sheeting from its bid list because of failure by graying in weatherometer tests. The Department's limited field experience with the seibulite engineering grade material has also revealed fading and loss of reflectivity. These problems appear confined to pressure-sensitive, adhesive seibulite reflective sheeting.

Based on the results of this research, it is concluded that seibulite super engineering grade reflective sheeting is not a viable alternative to high intensity grade reflective sheeting. It is recommended that:

1. the Department continue using high intensity reflective sheeting;

2. the Department adopt Federal Specification L-S-300C relative to reflective sheeting in lieu of Federal Specification L-S-300B, which it replaced in 1979; and

3. a standard evaluation procedure that includes an outdoor sign exposure deck for weathering be established for the evaluation of new and modified reflective sheetings.

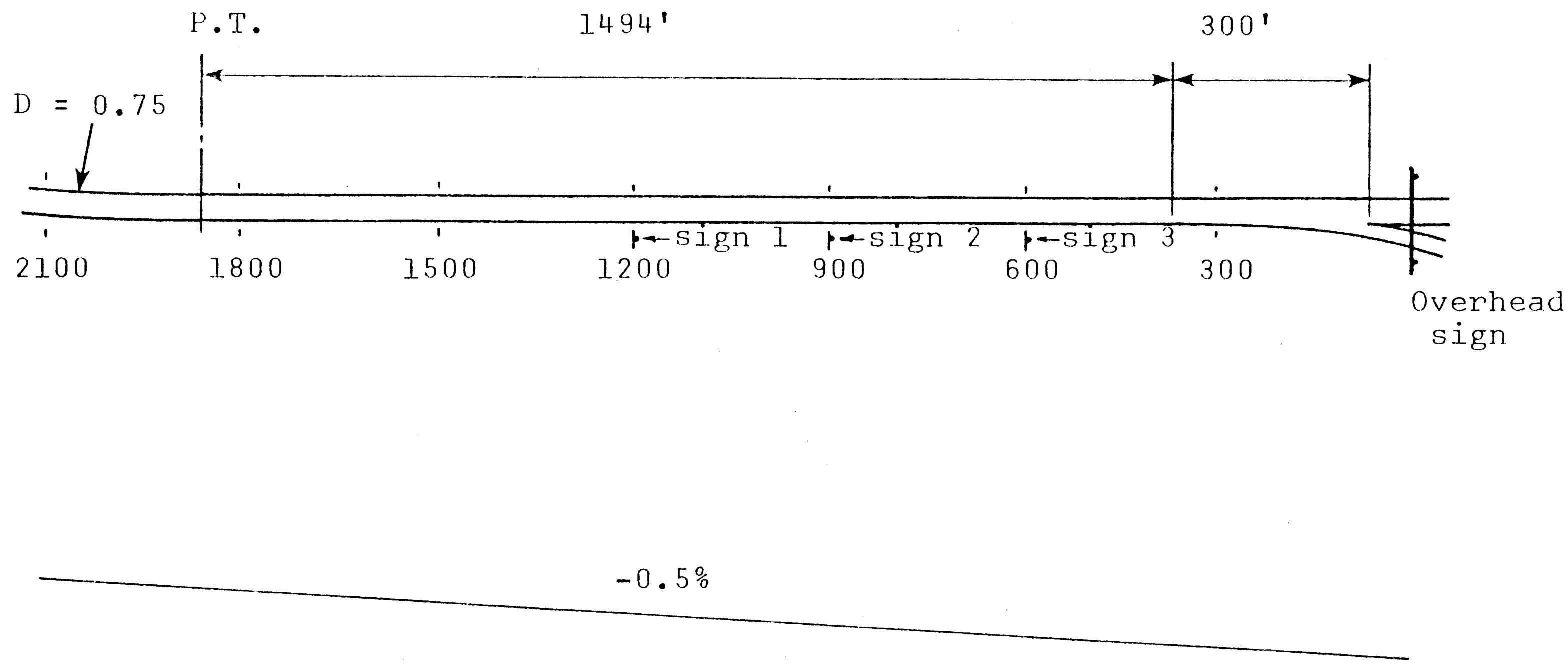
These recommendations have been reviewed by the Traffic Research Advisory Committee. Since recommendation no. 1 is a policy issue, it requires your consideration. Recommendation no. 2 is already being considered by the Traffic and Safety Division, and will be pursued through the specifications committee. A special task force under J. E. Galloway, Jr. has been established by the Traffic Research Advisory Committee to consider the feasibility of recommendation no. 3.

Respectfully submitted,

Howard Newlon, Jr., Director
Virginia Highway & Transportation
Research Council

BHCjr:jmv
Attachment

cc: Mr. P. F. Chamberlain, FHWA (4)
Dean J. E. Gibson
Dr. L. A. Hoel
Mr. O. K. Mabry
Mr. W. L. Brittle, Jr.
Mr. A. L. Thomas, Jr.
Mr. A. W. Coates, Jr.
Traffic Research Advisory Committee
Mr. R. N. Robertson
Mr. B. H. Cottrell, Jr.
Miss E. L. Knight



Distance from right travel lane

Sign 1 15.33 feet
Sign 2 15.83 feet
Sign 3 17.67 feet

1 Foot = 0.3048 meter

Figure 2. Study site at interchange of I-581 South with U. S. Rte. 101 West.