Comparison of Effectiveness Ratings–Roadway Lighting

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● THE seeing factor effectiveness of roadway lighting systems is now being measured using new instrumentation which facilitates proper evaluation of outdoor full-scale installations.

For comparison, computed ratings for the seeing effectiveness of roadway lighting systems are also presented. There is a substantially good correlation between measured and computed seeing factor ratings for roadway lighting.

During 1961 high-speed digital computers will be used for the prediction of seeing effectiveness ratings for representative roadway lighting systems. The method and data for computation have been developed and are described in previous papers including several presented to the Highway Research Board.

The measured data include comparison of systems of luminaires producing a cutoff-type candlepower distribution similar to that recommended by Christie (1), Rex (7), and de Boer (4).

The intense international, and cooperative, activity to produce visual seeing effectiveness ratings for roadway lighting is motivated by a general recognition of necessity. It is essential to provide all who represent the public, and those who desire to improve night-as-well-as-day-business activities with a basis for the proper evaluation of the humanitarian, traffic, and economic gains which good roadway lighting produces.

Knowledgeable estimates, appraisals, figures-of-merit, measurements, and ratings for the broad benefits of roadway lighting are essential. The extent by which these benefits are provided is contingent on how much seeing effectiveness is produced by the roadway lighting. Evaluation of the broad benefits will determine the extent of roadway lighting installed and the quantity and quality of seeing provided.

Hence, the evaluation of roadway lighting benefit may be expressed:

$$\frac{\text{BENEFIT RATINGS}}{\text{Humanitarian, Traffic, Economic}} \quad \text{Requires} \quad \frac{\text{SEEING RATING}}{\text{Visibility, Visual Comfort}}$$

Variations in the seeing factor effectiveness of different roadway lighting systems should be considered and factored into each evaluation of the broad benefits.

Ratings for the seeing effectiveness of roadway lighting are now being provided in terms of (a) relative visibility, and (b) relative visual comfort.

Availability of relative visibility and relative visual comfort ratings for the seeing effectiveness of roadway lighting presents a substantial simplification for all concerned.

In many countries, including the United States, evaluation of traffic and other broad benefits, as well as substantial installations of good roadway lighting, has been the direct result of engineering studies and technology applied to ratings for the visual seeing benefits of roadway lighting.

Rex (7) pointed up only a few of many economic evaluations for the aid which roadway lighting may provide for the benefit of the public and the night automotive industry:

1. Nighttime prosperity for the country and the community,
2. Aid to motor vehicle transportation industry,
3. Enhancement of social, recreational, and business activities,
4. Development of useful land areas,

5. Discouragement of criminal activities, and
6. Facilitating pleasant driving with less fear of accidents.

These humanitarian, traffic, and economic gains should be evaluated or rated.

If it is assumed that a benefit of $10,000 per mile per year is derived by the installation of lighting having seeing factor ratings of: relative visibility 9.5 (Appendix A),

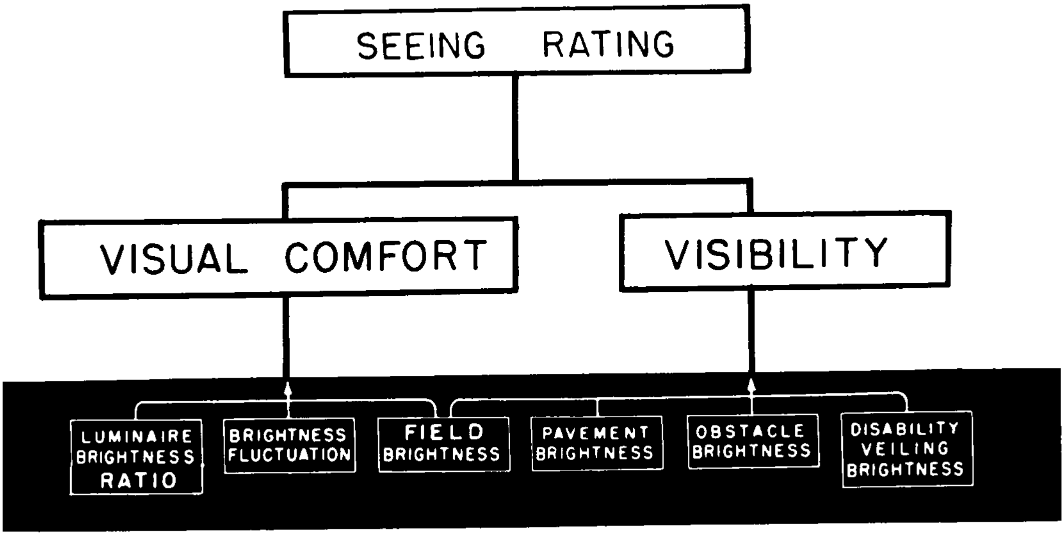


Figure 1.

and relative visual comfort 0.3, the relation may be expressed as follows:

$10,000 PER MILE PER YEAR (Benefit Rating)	Requires	VISIBILITY = 9.5 / VISUAL COMFORT = 0.3 (Seeing Rating)

Further simplification to a single rating in terms of relative seeing will develop from evaluation of the comparative general benefit produced by each of the major factors: (a) relative visual comfort, and (b) relative visibility.

SEEING TECHNOLOGY SPARKS NEW SURGE OF ENGINEERING INTEREST IN ROADWAY LIGHTING

A $1 million research evaluation of benefits of roadway lighting termed, "Warrants for Lighting Freeways," was recommended during 1959 (3). Progress on this project will be retarded if seeing factor effectiveness ratings for the lighting are not made available, rapidly.

The Highway Safety Study (3), prepared under the direction of Charles W. Prisk, presents an outline of numerous night driving problems, including vision, which will be substantially aided by roadway lighting providing high seeing factor effectiveness.

Everything possible must be done to facilitate evaluation of the benefits of roadway lighting. This endeavor should have the attention of all who represent the public and night-as-well-as-day-business and welfare activities. Included are economists, engineers, and scientists for whom the improvement of the public welfare is an underlying thought and impelling force.

Progress depends on cooperative efforts, which are being extended to an international activity, directed toward understanding and appreciation of the efficiency of roadway lighting in producing good seeing conditions. Accomplishment of the six objectives previously listed is contingent on the seeing provided. Hence knowledgeable estimates, appraisals, measurements, figures-of-merit, or ratings are essential for both: the degree by which one or more of the broad objectives are accomplished; and, how much seeing effectiveness is produced by the roadway lighting being evaluated. This is a simple, straightforward approach to the problem which can only be answered by engineering evaluation based on known technologies.

The rapidly increasing worldwide engineering interest in, and attention to, roadway lighting may in large part be attributed to the technology which has provided seeing factor ratings as a base for rating the other benefits.

The two seeing factor ratings, relative visual comfort and relative visibility, combine to replace the six sub-factors in seeing, shown in Figure 1.

1. Luminaire brightness ratios are being computed. The computations are backed up by measurements. Luminaire brightness is mitigated by luminaire cutoff which is explained later in this paper.

2. The important dynamic effect of brightness fluctuation, was discussed by Forbes (2). Evaluation of the effect of fluctuation on visual comfort will develop along with methods of improving this sub-factor.

3. The brightness of the driver's visual field is subject to evaluation using the Fry-Pritchard instrumentation.

4. The predominate pavement brightness factor is readily being measured. Computations are available based on previous measurements.

5. Obstacle brightness and size vary over a wide range. An abstract target of 1-ft diameter and 8 percent reflectance is generally accepted as suitable criteria for relative visibility measurements.

6. The highly significant disability veiling brightness sub-factor is now being measured as well as computed. The loss of visibility now includes compensation for the effect of dynamic fluctuation.

Relative rating scales or numbers for these seeing factors are obviously much better than word descriptions. Opinion appraisals may range from excellent to poor for the same roadway lighting system when installed in different communities or viewed by different observers. Interchangeability and communication from one portion of the world to another are also highly advantageous.

Now that ratings for roadway lighting systems can be readily provided in terms of relative visibility and relative visual comfort, the engineer can transmit to others the seeing effectiveness which he has in mind; thus avoiding the confusion and complex mental interpolations with respect to seeing factor benefit when only sub-factors—or worse yet—when only foot-candle data are used as criteria. Sufficient foot-candles of light are necessary to obtain the seeing on which benefit depends; the requirement varies over a wide range. This is well known among highway as well as illuminating engineers.

Fowle and Kaercher (6) include data showing that the ratio of average foot-candles required per foot-lambert average pavement brightness varies over a range of 2:1 for 17 different roadway lighting systems. Therefore, to obtain the predominant visibility factor, such as an average pavement brightness of 0.6 foot-lambert, may require average foot-candles ranging from less than 1.8 to more than 3.0. The system brightness computations providing the ratios shown in Figure 2 were all based on the same pavement reflection data.

Comparison or rating roadway lighting systems on the basis of foot-candles should be limited to the rare instances in which circumstances and conditions are identical, as follows:

1. Control and proportioning of the luminaire candlepower distribution extending along, across, and above the roadway;

2. System geometry including luminaire spacing, mounting height, and overhang; and

3. Pavement surface characteristics in reflecting all angles of incident light from the luminaire toward an approaching driver.

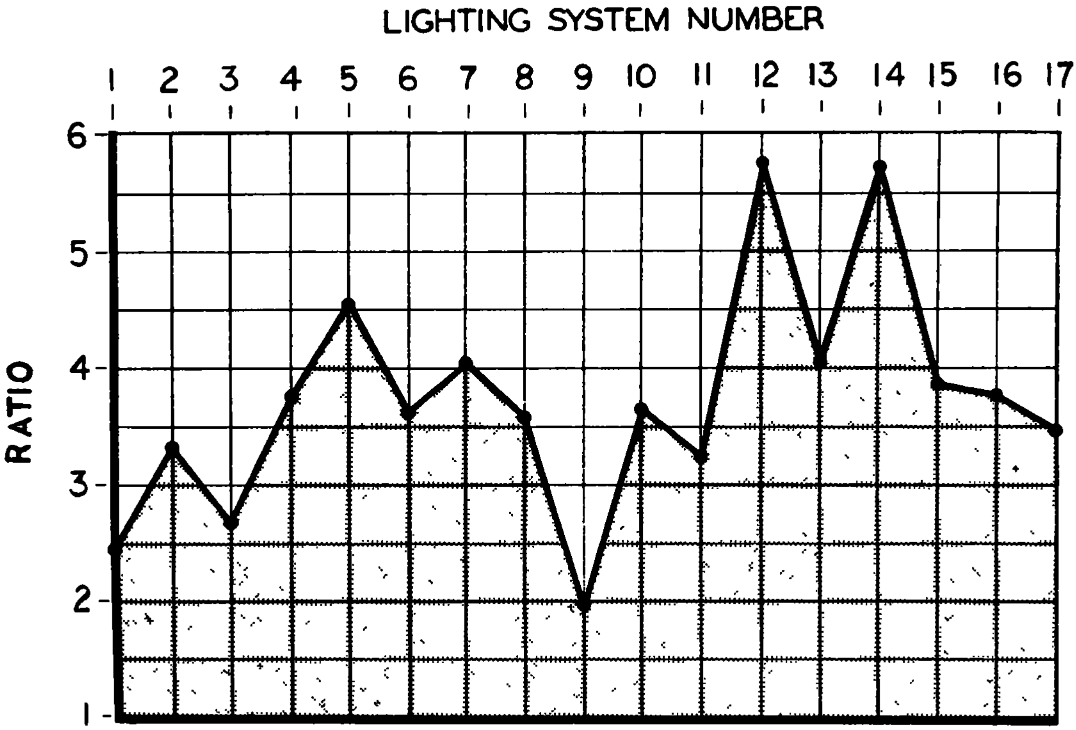


Figure 2. Average foot-candles per average foot-lambert. Pavement brightness computed for medium reflective pavement by A.W. Fowle and R.L. Kaercher.

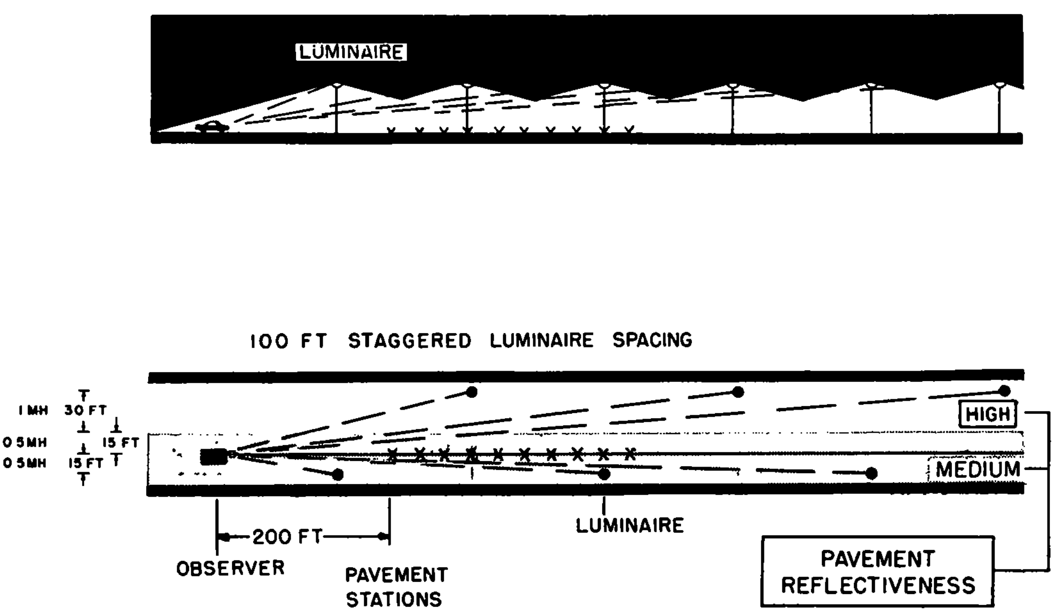


Figure 3.

Figure 4.

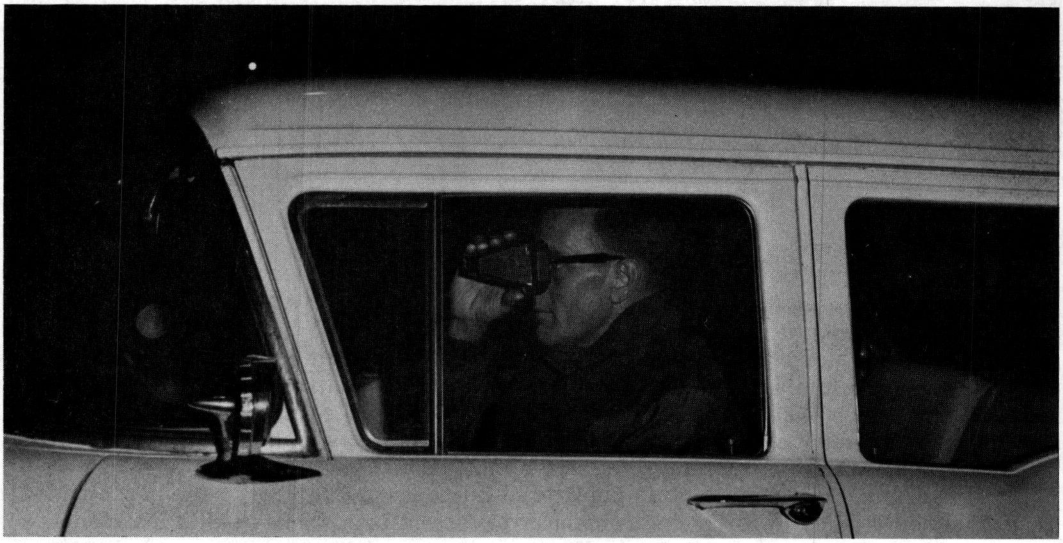


Figure 5.

STAGGERED LUMINAIRE SYSTEM RATINGS

Blackwell (9) described the staggered roadway lighting system on which his outdoor full-scale measurements were made along the 0.5 MH LRL (longitudinal roadway line) at 15-ft transverse distance from the luminaires (Fig. 3). Instead of designating the pavement surface as concrete and asphalt, the author prefers to designate the pavement surface as having high or medium reflectiveness. It is well known that the reflection characteristics of asphalt pavement can be made favorable by top surface treatment such as rolling-on a white or light gray aggregate. Also aging and traffic use may favorably affect the specular pavement reflection characteristics for roadway lighting.

The 5-yr-old asphalt pavement surface shown in Figures 3 and 4 is of medium reflectiveness.

In Figure 4 the 1-ft diameter, 8 percent diffuse reflectance disc is at 180-ft distance. This abstract target has been widely used as visibility criteria. It is similar to the black dog used in the studies by Blackwell et al. (9). The Blackwell data will soon be published in an I.E.S. paper in terms of his supra-threshold-visibility as well as pavement brightness factors. This photo was made through the windshield of the test car from the driver's eye position.

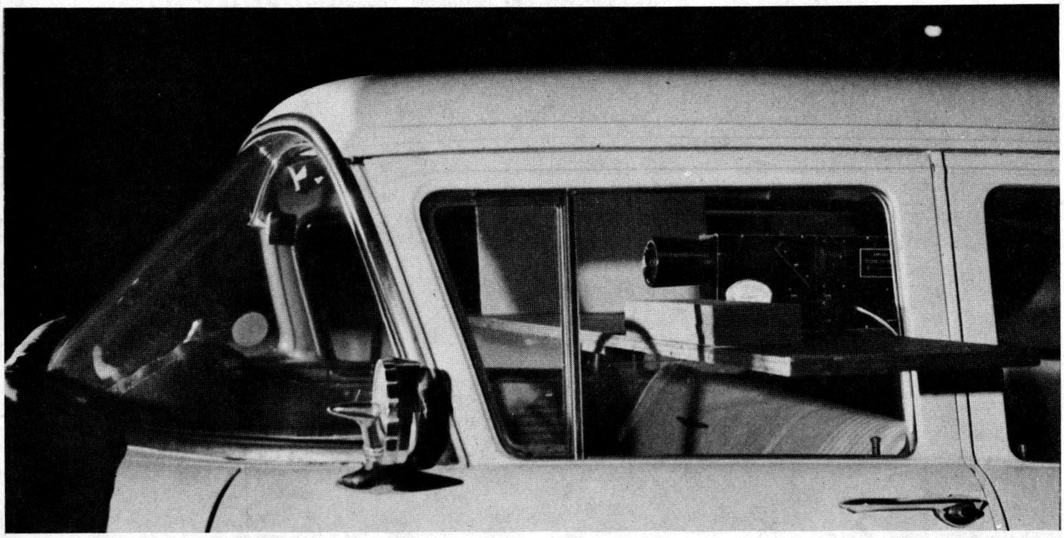


Figure 6.

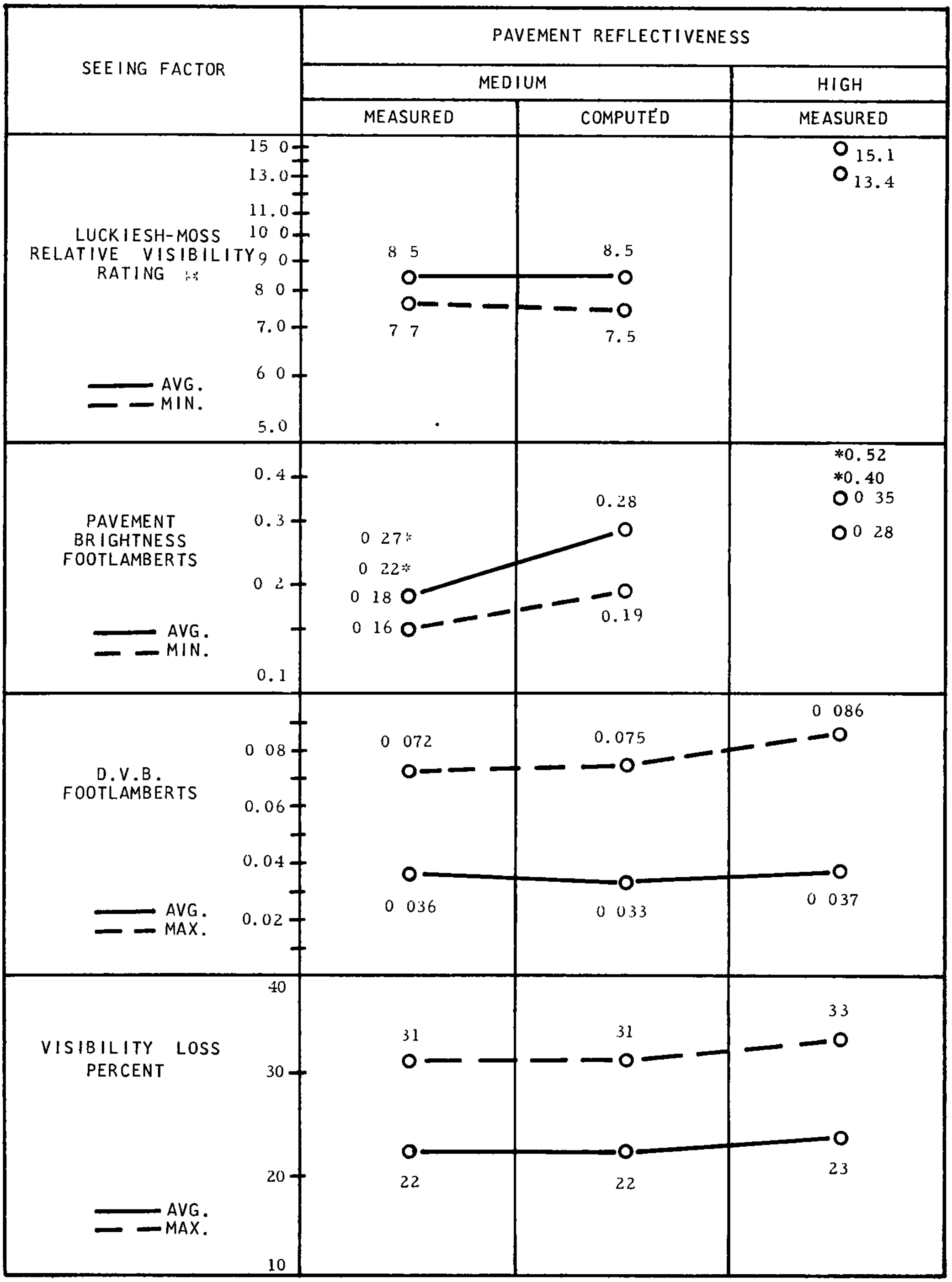
The eye-level position of an average, typical observer is used for the instrument as shown in Figure 5. In present-day autos the eye-level is 4 ft above the pavement. The average seat position is also used.

The Luckiesh-Moss Visibility Meter, shielded as shown in Figure 5 to eliminate the light from the luminaires, is being used to measure relative visibility. The Luckiesh-Moss relative Visibility Meter ratings, measured and computed, for medium reflectiveness pavement are lower than when the pavement has high reflectiveness. The new numerical scale for this meter is shown in Appendix A.

The observer's eye position was duplicated in mounting the lens of the new Pritchard Telephotometer (Fig. 6) for measurement of pavement brightness. This instrument has the additional advantage of physical scale meter readings rather than photometric balance which requires skill and experience.

The measured pavement brightness data (Fig. 7) are based on 6-min angle aperture. Thus, the pavement background at 200 ft may be contrasted with the mid-portion of the 1-ft diameter target as measured in the visibility meter tests. The Pritchard meter lens aperture is particularly desirable when there are large variations in the brightness of the pavement. The system pavement brightness is appreciably higher on the high reflectiveness pavement surface.

Figure 8 shows the instrument supplemented by a new lens developed by Fry and Pritchard (7). This now makes possible measurement of DVB (disability veiling brightness) of roadway lighting system luminaires. The brightness of the pavement is shielded from lens view. Incidentally, this is another example of new instrumentation developed by research sponsored by the Illuminating Engineering Research Institute.



* Meter Scale Reading
**Contrast Rating Per Appendix A

Figure 7. 100-ft staggered spacing—filament 15,000 lumen semi-cutoff.

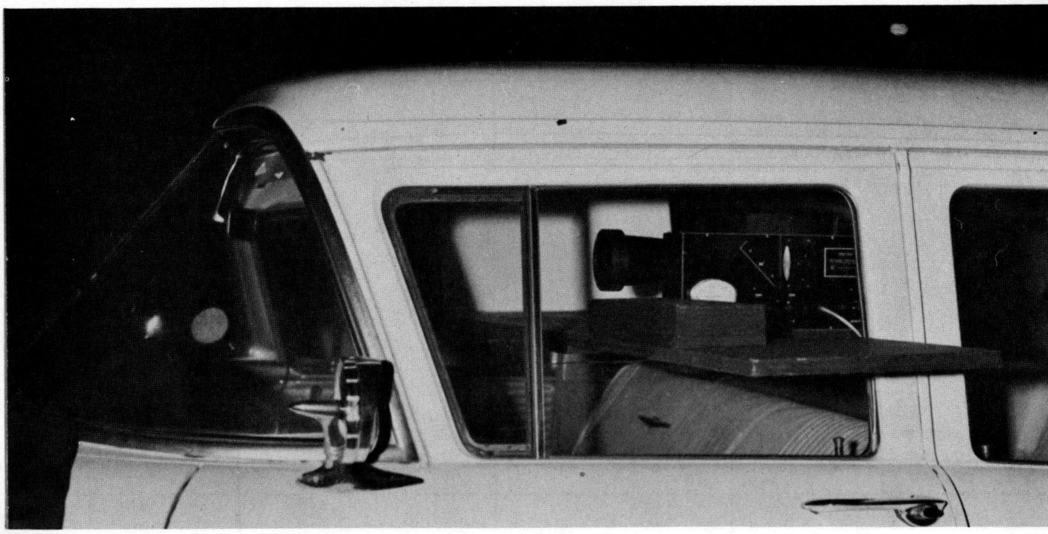


Figure 8.

Obviously, this Pritchard meter may be supplemented by an electrical recorder mounted in an automobile which may be driven along the road to obtain a graphical record of the DVB, pavement brightness, and variations or fluctuations thereof under roadway lighting.

As shown in Figure 7, the measured and computed DVB is fairly consistent for the staggered roadway lighting system. Under the dynamics of actual driving conditions, the maximum DVB may be highly important because it is indicative of the range of fluctuation to which the driver's eyes are subjected. As explained in previous papers, (12, 13, 14, 15) there are correlations showing the percent loss of visibility resulting from disability veiling brightness. This percent loss has been applied to the Luckiesh-Moss Visibility Meter ratings.

Figure 9.

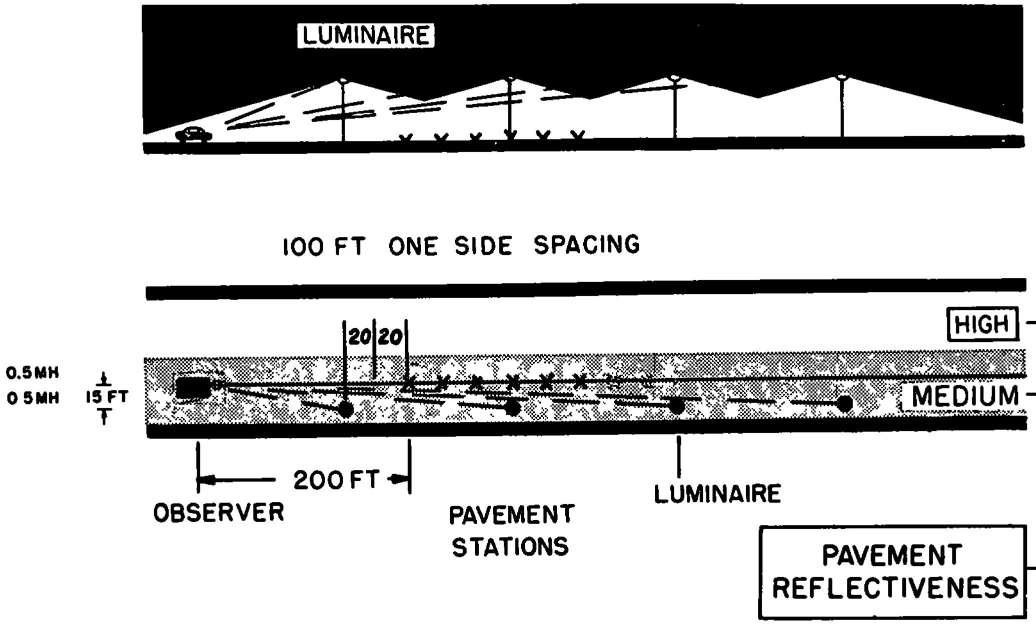


Figure 10.

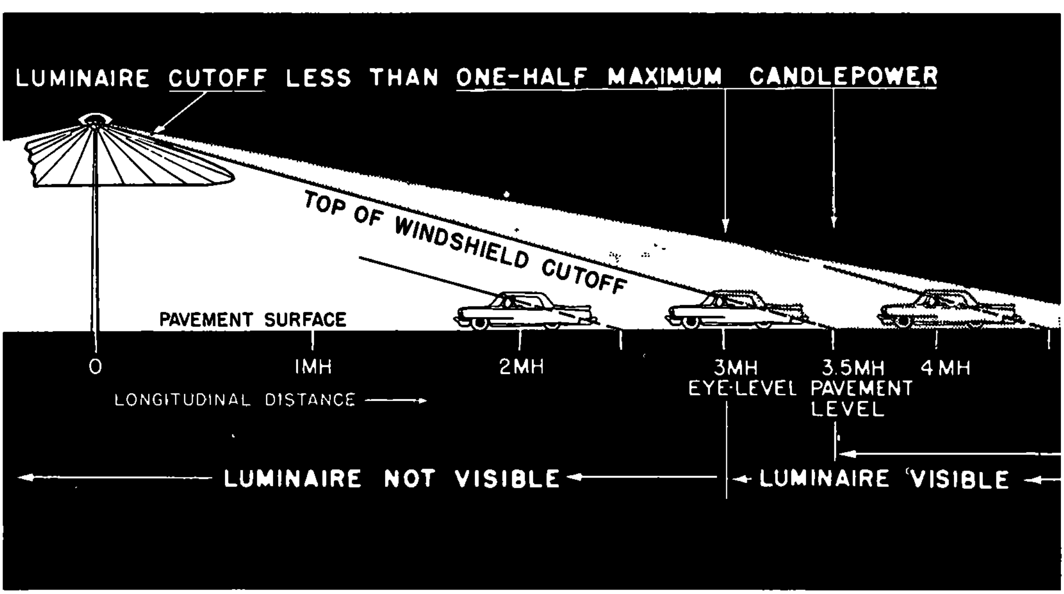
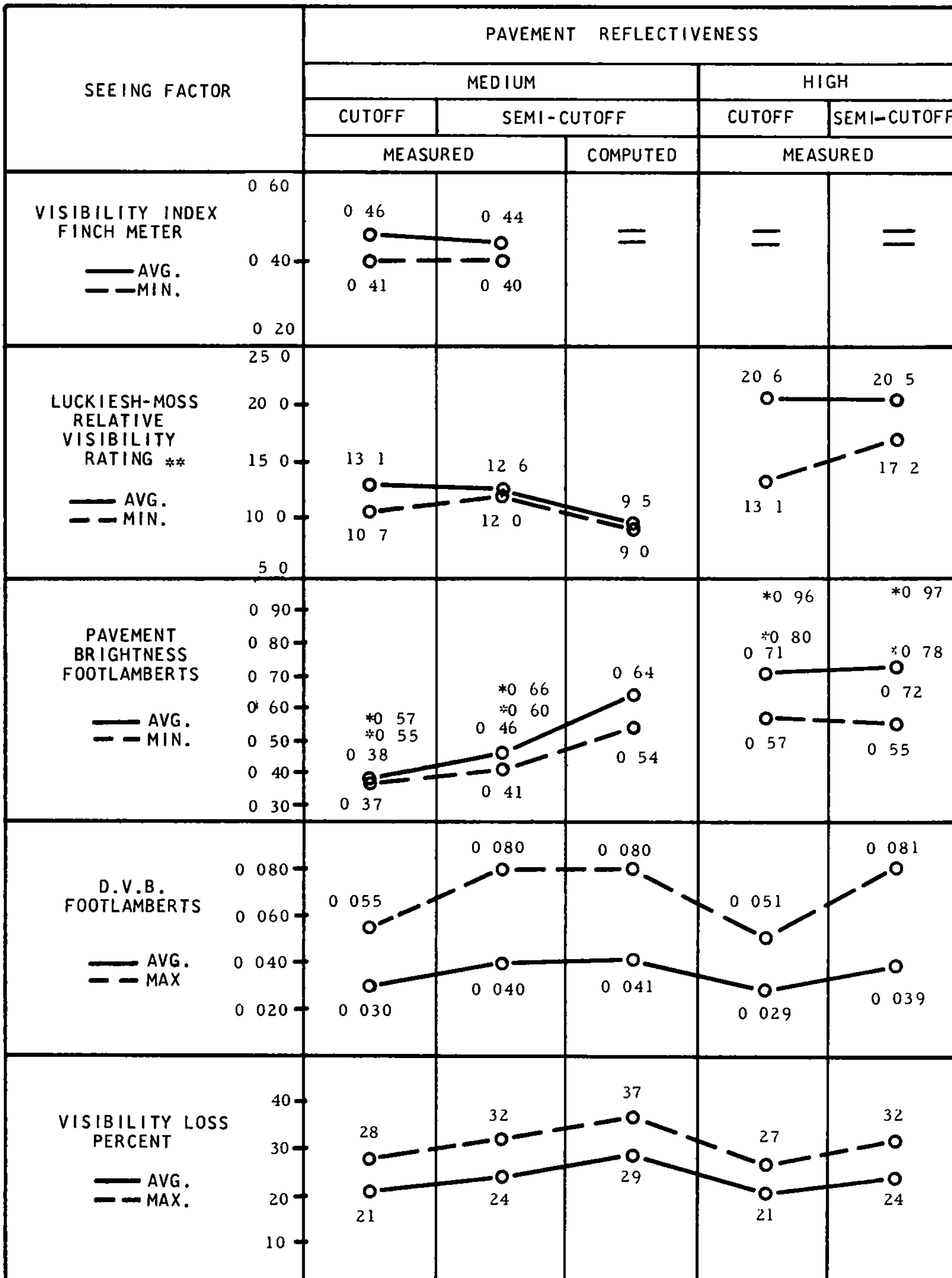


Figure 11.

ONE-SIDE LUMINAIRE SYSTEM RATINGS

Comparison of measured data for systems having 100-ft, one-side luminaire spacing is also of interest. For both high and medium reflectiveness pavement, the measurements are along the 0.5 MH longitudinal roadway line and driver path (Figs. 9 and 10).

In this system arrangement and driver path an additional comparison is provided in



*PRITCHARD METER READING
** CONTRAST SCALE AS PER APPENDIX A

Figure 12. 100-ft one side spacing—mercury 20,000 lumen.

the measurements of systems comprising cutoff luminaire candlepower distributions versus semi-cutoff candlepower distribution.

Cutoff of Luminaire Candlepower Distribution

The seeing effectiveness of most roadway lighting systems may be significantly improved by cutoff of the luminaire candlepower distribution (Fig. 11). The benefits of cutoff of candlepower distributions are most significant when the angle of cutoff is coordinated with the average top-of-auto windshield cutoff as shown on the right-hand side of Figure 11.

Under average automobile and driver conditions, the luminaire is cut off from view by the top of auto windshield at a longitudinal eye-level distance of 3 MH, three times the mounting height of the luminaire. This windshield cutoff intercepts the pavement at a longitudinal distance of 3.5 MH. It is expedient to use the 3.5 MH or pavement level expression of longitudinal distance. The pavement distance of 3.5 MH corresponds to the average demarcation or cutoff distance at which a luminaire is no longer visible to an approaching driver because of the protection provided by the automobile.

Coordinate cutoff control of the luminaire candlepower proportioning is shown at the left-hand side of Figure 11. The candlepower extending to the 3.5 MH distance is restricted to less than one-half the maximum candlepower. This means that the adverse effect of candlepower impinging on the driver's eyes is considerably less than that which would result if the maximum candlepower were elevated to coincide with, or extend above the 3.5 MH cutoff line. Obviously the sharp control of candlepower above the cutoff which extends to distances beyond 3.5 MH is also highly desirable.

The 3.5 MH one-half maximum candlepower cutoff is quite similar to that shown by Christie (1). It is also similar to that shown by de Boer (4).

Figure 13.

However, current U.S. semi-cutoff candlepower luminaire distribution has maximum candlepower of the order of 3.0 MH or 72½ degrees instead of the 75 degrees or 3.5 MH distribution shown by Christie.

Figure 12 shows the improvement in relative visibility and variations in relative visibility and variations in sub-factors due to cutoff of luminaire candlepower distributions.

Note that the average pavement brightness in Figure 12 approximates the 0.6 footlambert recommended by Blackwell, de Boer, and Guth.

The Finch Visibility Meter (22) ratings for the relative visibility effectiveness of the roadway lighting system, also shown in Figure 12 are based on measurements made with a preproduction model of the meter developed by D.M. Finch of the University of California, Institute of Traffic and Transportation. Figure 13 shows this meter being used by Mr. Karl Freund who will have six meters in production during 1961. Since luminaires are visible in the 30-deg field of this visibility meter the percent visibility loss is not applied to visibility index ratings.

Typical of his interest in night motor vehicle transportation, de Boer has donated a set of the Landolt C rings for use in comparing the effectiveness of roadway lighting systems. These rings definitely aid comparative appraisals of the visual effectiveness of roadway lighting systems. They are especially useful, a step forward in appraisals by large groups of observers.

A portable version of Blackwell's Visual Task Evaluator (9, 7, 10) is also expected to be available during 1961 for use in evaluating the relative visibility effectiveness of roadway lighting systems.

SUMMARY

High priority by highway engineers is now being assigned to the evaluation of the broad benefits of roadway lighting. This stimulus of interest is directly attributable to the international engineering emphasis on seeing factor ratings. An even more important fact is that seeing ratings also provide a base which encourages evaluation of the humanitarian, traffic, and economic benefits by the many interested agencies. The night transportation benefits of roadway lighting are also susceptible to numerical evaluation. This progress will be aided by numerical ratings for the lighting provided in such simple terms as visual comfort and visibility.

In many countries throughout the world, action with respect to figures-of-merit for both the seeing and traffic benefits of roadway lighting is interrelated and gaining new impetus. Seeing ratings are internationally interchangeable and may be communicated from one portion of the world to another. Interchange of information and ratings aids human progress throughout the world.

Improvement of the public welfare is an underlying thought and impelling force for economists, engineers and scientists. Everyone gains by attention to, and more extensive use of, roadway lighting.

ACKNOWLEDGMENTS

The author gratefully acknowledges the counsel and assistance of his associates including HRB, ITE, and IES. In particular, appreciation is extended to the staff members of the Photometric Laboratory, Outdoor Lighting Department, General Electric Company, who made the night field measurements and laboratory calibrations. The author is grateful to Mr. J.B. de Boer, Mr. J.F.T. Heemskerck Veeckens, and Mr. F. Burghout for the international comparison of pavement brightness data shown in Appendix B. It is significant that in the interest of progress toward seeing factor ratings in the United States, Mr. Harold Wall, Superintendent, and Mr. P.L. Young of the City of Detroit Public Lighting Commission, compiled the computed and measured pavement brightness data shown in Appendix C.

Measurements reported for DVB include the author's calibration factor for the Fry-Pritchard lens-meter based on computed versus measured data.

Computed combined system DVB (13) is based on IES Handbook formula $\frac{31.4E}{\theta^2}$. Future computations will use the formula $\frac{31.4\ E}{\theta\ (\theta + 1.5)}$.

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Appendix A

TABLE FOR CONVERTING L-M METER RELATIVE VISIBILITY READINGS TO RELATIVE CONTRAST[a]

Relative Visibility	Relative Contrast	Relative Visibility	Relative Contrast	Relative Visibility	Relative Contrast
1.0	2.0	3.6	29	7.2	61
1.05	2.4	3.7	30	7.4	62
1.1	2.8	3.8	31	7.6	64
1.15	3.2	3.9	32	7.8	65
1.2	3.6	4.0	33	8.0	66
1.25	4.0	4.1	34	8.2	67
1.3	4.5	4.2	35	8.4	68
1.35	5.0	4.3	36	8.6	69
1.4	5.5	4.4	37	8.8	71
1.45	6.0	4.5	38	9.0	72
1.5	6.5	4.6	39	9.2	73
1.55	7.0	4.7	40	9.4	74
1.6	7.5	4.8	41	9.6	75
1.65	8.0	4.9	42	9.8	76
1.7	8.5	5.0	43	10.0	77
1.75	9.0	5.1	44	10.5	79
1.8	9.5	5.2	45	11	82
1.85	10.0	5.3	46	11.5	84
1.9	10.5	5.4	47	12	87
1.95	11.0	5.5	48	12.5	89
2.0	12.0	5.6	48	13	90
2.1	13.0	5.7	49	13.5	92
2.2	14.0	5.8	50	14	94
2.3	15.0	5.9	51	14.5	96
2.4	16.3	6.0	52	15	98
2.5	17.5	6.1	52	15.5	99
2.6	18.5	6.2	53	16	101
2.7	20	6.3	54	16.5	103
2.8	21	6.4	54	17	104
2.9	22	6.5	55	17.5	106
3.0	23	6.6	56	18	107
3.1	24	6.7	57	18.5	108
3.2	25	6.8	58	19	109
3.3	26	6.9	59	19.5	111
3.4	27	7.0	60	20	112
3.5	28	-	-	-	-

[a]The relative contrast scale is based on the absolute threshold contrast of a standard 4-min disc target under specific laboratory conditions. The actual threshold contrast is assigned a value of unity. The Relative Contrast Scale reading for a task at a given illumination level relates the visibility of that task to the supra-threshold contrast of the standard disc at the same illumination level.

For example, a reading of 4 on the Relative Contrast Scale for a given task means that, under the conditions of measurement, the task is equivalent in visibility to the standard disc target which is four times its threshold contrast. A reading of 10 means that the task is just as visible as the standard disc when it is ten times its threshold contrast.

This table is derived from the basic data of Figure 1, "Comparison of Visibility Measurement Systems," A.A. Eastman and S.K. Guth, Illuminating Engineering, Vol. LV, No. 3, March 1960, p. 176, and the threshold curves for a 4-min disc, from "Specification of Interior Illumination Levels," by H. Richard Blackwell, Illuminating Engineering, Vol. LIV, No. 6, June 1959, p. 317.

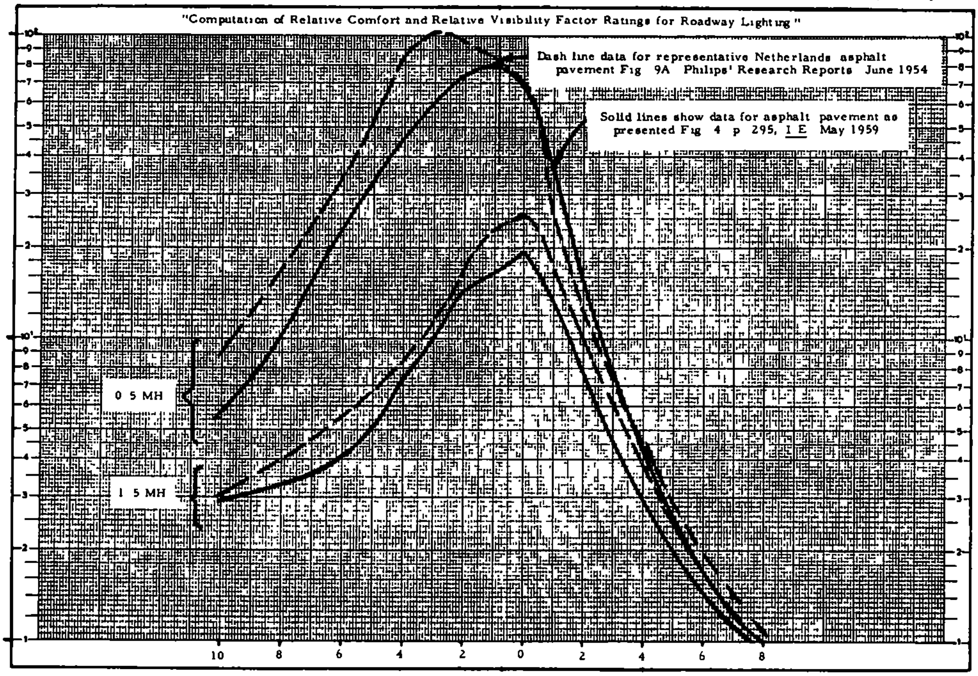
A.A. Eastman, April 3, 1961

Appendix B

COMPARISON OF PAVEMENT BRIGHTNESS PRODUCED PER 1000 CANDLEPOWER FROM SINGLE LUMINAIRE WHICH IS AT THE DRIVER'S LEFT

Prepared by J B deBoer F Burghout, and J F T Heemskerck Veeckens of the N V Philips Lighting Laboratory - May 3 1960 - for Charles Rex

I E May 1959 p 295



Longitudinal Distance From Luminaire In MH

COMPARISON OF PAVEMENT BRIGHTNESS PRODUCED PER 1000 CANDLEPOWER FROM SINGLE LUMINAIRE WHICH IS AT THE DRIVER'S RIGHT

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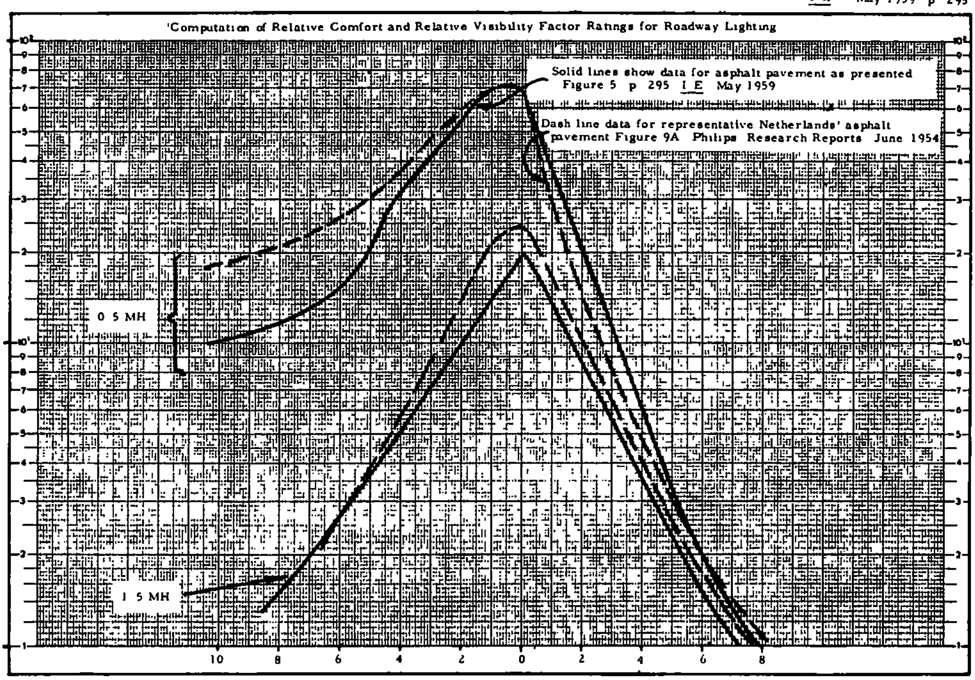

Longitudinal Distance From Luminaire In MH

Appendix C

Excerpts from Report to I. E. S. Roadway Lighting Committee
by H. F. Wall and P. L. Young, City of Detroit, Public Lighting Commission
May 23, 1961

Stations Along	Candlepower from Luminaire		PAVEMENT BRIGHTNESS		
			COMPUTED		MEASURED
			Reid-Chanon Bock-Rex Coefficients	J. B. deBoer Pavement 9A Coefficients	Pritchard Telephotometer 15 Minute Aperture
.5 MH LRL	'A'	'B'			
6	5520	4060	0.27 fL.	0.26 fL.	
7	7080	5334	0.33	0.33	
8	8330	6203	0.40	0.40	
9	7830	7289	0.44	0 47	
Avg			0 36	0.37 fL.	.39 fL.
1.0 MH LRL					
6	5610	5501	0.15 fL.	0.18 fL.	
7	8330	6526	0.19	0.22	
8	10374	7486	0.22	0.25	
9	9194	9522	0.24	0.28	
Avg			0.29 fL.	0.23 fL.	0.27 fL.