Some Factors Influencing the Night Visibility Of Roadway Obstacles

By D. M. FINCH

INTEREST IN the night-visibility of the roadway scene is wide spread and has been the subject of numerous research efforts[1] of which this paper is only a small segment. We at the University of California have been working in various phases of this field continuously on an organized basis since 1919. This report covers one phase having to do with street lighting and its evaluation in terms of the visibility of objects under specified conditions of observation. The work included in this paper has been partially sponsored by the Illuminating Engineering Research Institute in a grant made to the University of California in 1952. This paper is a summary of the accomplishments made during the period of the grant (August 1952 to August 1955) and of the concurrent work done by graduate students with University support.

There are many factors that influence the night-visibility of roadway obstacles. We will probably never run out of combinations of variables to investigate. With such a situation confronting us it was decided to use the time tested procedure of isolating the parameters, holding as many as possible constant and then determining the effect of variations of a single quantity. One quantity that seems to be a key to the entire problem is the roadway brightness as seen by a vehicle operator. The effect of roadway brightness patterns on the visibility of typical roadway obstacles is the principal subject to be reported upon in this investigation.

As usual in research, several side-lights have developed as a result of the main activity. We have had to develop special instrumentation for both brightness measurements and visibility measurements. Also, we have had to re-open the question of size, shape and characteristics of obstacles, *i.e.*, whether to use a pedestrian, a box, a dog or cat, or an automobile as a typical target. Some data on various targets and a recommendation for standardization of targets is included. It would be very helpful in future work to have standardized targets used by most investigators.

The scope of this project is as mentioned above and the work has resulted in improvements to a previously reported "Instrument for the Evaluation of Night Visibility on Highways"[2] and data on the visibility of objects viewed against two roadway brightness patterns; (a) a very uniform roadway brightness, and (b) a very non-uniform roadway brightness. The balance of the paper will be a discussion of the technique of night-visibility measurements, a review of our outdoor street lighting laboratory and the results of some visibility measurements.

A Technique for Night-Visibility Measurements

Visibility is a rather indeterminant and intangible thing with subjective attributes that have to be perceived and interpreted by a brain before they become real. Thus if something is in a certain location but is invisible, it is below the threshold of perception; but if it is visible, it is above the threshold of perception. The perception threshold is the only satisfactory measuring point on the visibility scale because only at this point can an observer indicate with certainty (on a statistical basis) whether or not an object is visible. The problem is to reduce a supra-threshold visual scene to a perception threshold scene and then use the magnitude of the reduction system as an index of the supra-threshold visibility.

There are four parameters that can be used to reduce a visual scene to threshold, *viz,* size, time, brightness and contrast. All have been used effectively in visual threshold measurements for special purposes by various research investigators.[3] We have selected contrast as the control variable to use in our method since it seems to more nearly simulate roadway situations wherein the objects are generally large (greater than one minute of arc), time is substantial (greater than 0.01 second), and the average brightnesses are low and therefore

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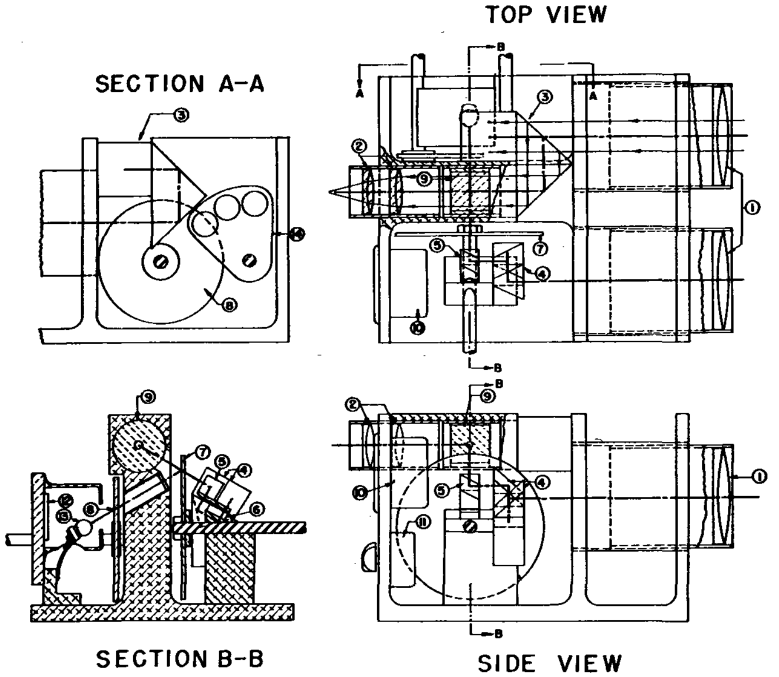


Figure 1. Details of visibility meter.

1. **Objective Lens—coated achromat 180 mm focal length.**
2. **Eyepiece Lens—coated achromat 122 mm focal length.**
3. **Binocular Prism 7 x 50.**

4-6. Right Angle Prism.

7. **Variable Transmittance Mirror (partial aluminum coating) — visibility index control.**
8. **Variable Density Wedge — background brightness control.**
9. **Object Mirror.**
10. **Ammeter — 100 milliamps.**
11. **Background Brightness Potentiometer.**
12. **Photocell-Round 1-inch dia., A-5.**
13. **Veiling Glare Source — 2.2-volt bulb.**
14. **Color Selector.**

should not be changed because one should maintain a constant adaptation level. Perception of most critical objects on the roadway at night is first by means of contrast and later the objects are resolved by means of critical detail (acuity).

The ground rules that we have established for our contrast-threshold instrument are as follows:[2]

1. The eye adaptation should be constant at the average value for the central field of the roadway.
2. Only a small central portion of the total field should be varied to determine the contrast- threshold (Visibility Index).
3. A change in the contrast in the central area should not change the average brightness of the field of view.
4. The total field of view should be large enough to include all glare sources normally within a driver's field of view.
5. A means for measuring the average brightness of the field should be included in the device.

The instrument that has evolved from designs and field tests covering the past several years is shown in Figs. 1 and 2. This design is our latest attempt to provide an optical path having a central field area of approximately two degrees wherein the contrast can be varied by decreasing the field brightness and simultaneously adding an equal amount of veiling brightness. A discussion of this principle and the equations for compliance have been given in a prior report.[2] The major problem in fulfilling the design requirements has been in the development of a variable density neutral filter and optical system that will allow exactly as much light flux to be added in the form of veiling glare as

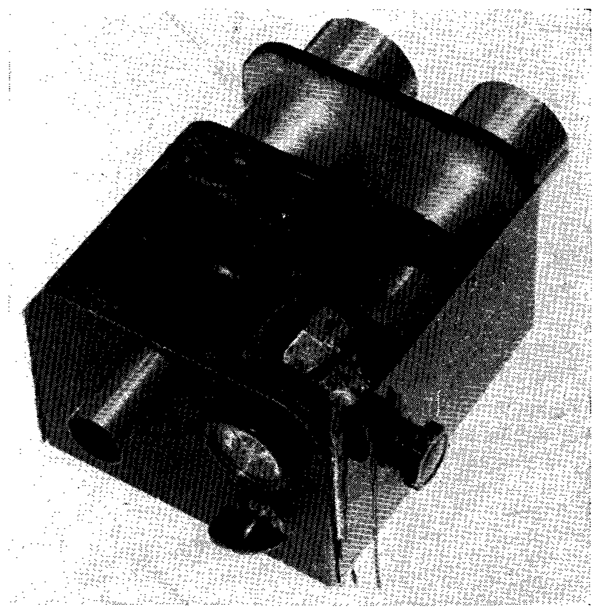


Figure 2. Photograph of visibility meter.

is subtracted from the central path. This is a necessary condition to maintain the average brightness at a constant level while changing the contrast.

The design shown in Figs. 1 and 2 incorporates a circular wedge made by depositing aluminum on a plane glass surface with a special evaporation technique so that the transmission varies approximately linearly with angular position. For a partial coating of metal on glass made by evaporating the

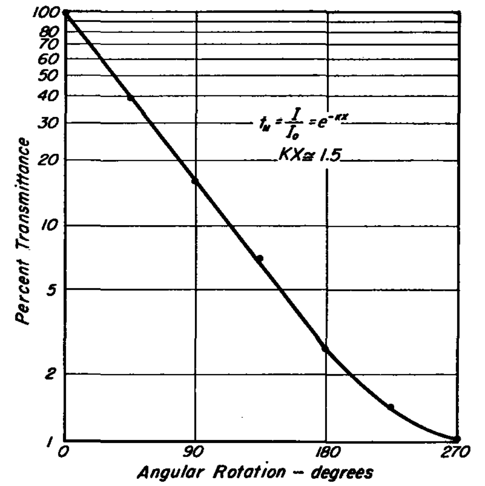


Figure 3. Per cent transmittance *vs* angular rotation of mirror using direct drive.

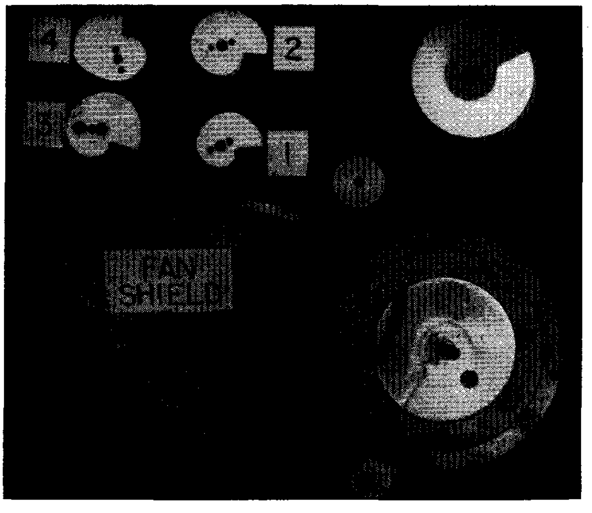


Figure 4. Variable transmittance partial mirror. Mirror in upper right. Drive cams and progressively closing fan type shield on left. Drive plate and holder in lower right.

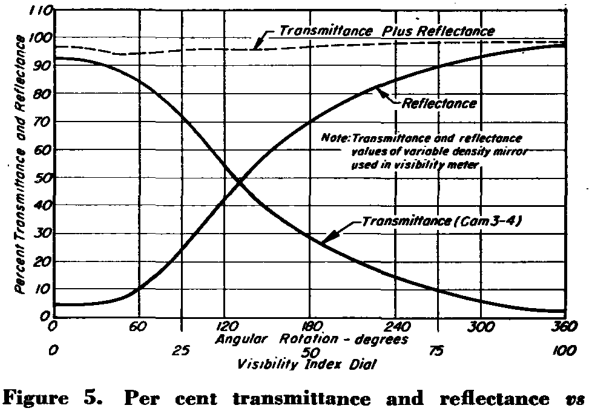


Figure 5. Per cent transmittance and reflectance *vs* angular rotation and visibility index dial — for glass mirror.

metal onto the glass under vacuum, the transmission was found to vary approximately exponentially with thickness, $t = e^{-kx}$, where:

t = transmittance
e = base for natural logarithms
k = absorptance (constant of material)
x = thickness

This phenomenon has been known to apply to many non-scattering transmitting materials (Beer's Law) but it was not evident in the literature whether it could be applied to metal films of only a few atoms in thickness.

To check the effect of metal thickness on transmission a disc was set up in our evaporation coating chamber and arranged to rotate under a semi-circular shield at a uniform rate while the rate of deposition of metal was applied at a constant rate. A plot of the transmittance *vs* angular position on semi-log paper gives a straight line over 180 degrees of rotation as shown in Fig. 3 which indicates that the transmittance varies exponentially with metal thickness.

In order to obtain a circular filter in which the transmittance varies linearly with angular position it is necessary to deposit the metal coating at a non-uniform rate. The foregoing work indicated that the drive for the disc should be logarithmic since $\log t = -kx \log e$ which is a straight line function. A cam drive was subsequently arranged to operate a fan type of shield as shown in Fig. 4. This development permits the useful angular range of the filter to be extended to include approximately 320 degrees as shown in Fig. 5. The actual curve is not linear but it is much better than an exponential curve because small changes in angular rotation give about the same change in transmittance over the useful length of the scale.

The design requirements indicate that the total flux in the controlled contrast optical path should remain constant. This is now achieved by utilizing the transmitted flux for the object and its background and the reflected flux from the same area on the filter for the veiling brightness flux. See Section B-B, Fig. 1. The partial mirror has the desired property that the transmitted plus reflected flux equals a constant. See Fig. 5.

The instrument as now constructed is shown schematically in Fig. 1 and photographically in Fig. 2. The total field of view is approximately 15 degrees and the central field of view is two degrees. These limitations are imposed by the physical dimensions of the available optical parts and will be changed in future models to give a total field of view of approximately 30 degrees with a central field of two degrees. The field of view should be large enough to include all of the principal brightnesses (glare sources and peripheral brightness patterns). The existing meter with which the data of this report were obtained does not have a large enough field to include the glare effect of the lighting units. Thus the visibility indices refer to the conditions without glare.

The instrument is calibrated both as an average brightness meter and as a visibility meter.

Brightness Calibration

To determine the average brightness the Visibility Index dial is set at 100 (minimum transmittance) and the Veiling Brightness source is adjusted for color (current and color filter) and brightness (variable density wedge in veiling brightness optical path) until the central field of view is visually balanced in brightness with the total field of view. It is only necessary to make this setting for the approximate average brightness so that the adaptation level is known and is not changed while varying the contrast. Our instrument has been calibrated by balancing the central field against known brightness sources over the range of 0.01 to 5.0 ft-L. See Fig. 6.

Visibility Measurements

The instrument will permit any object in the central field of view to be reduced to its contrast threshold. This is done by adding veiling brightness to both object and its background at the same time that the actual brightnesses of the object and its background are reduced.

The above is accomplished by rotating the variable transmittance partial mirror until by visual observation the object is at its contrast threshold. The dial has been calibrated so that the setting of the partial mirror is a measure of the supra-threshold contrast since it indicates the amount of veiling brightness necessary to reduce the actual contrast to threshold conditions. The setting of the partial mirror for threshold contrast is used to obtain the "Visibility Index." Refer to the following section on calibration.

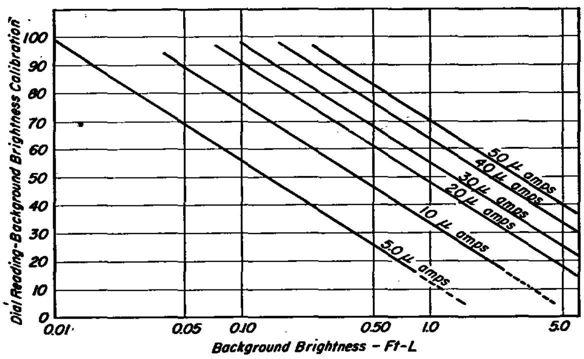


Figure 6. Background brightness dial calibration for visibility meter.

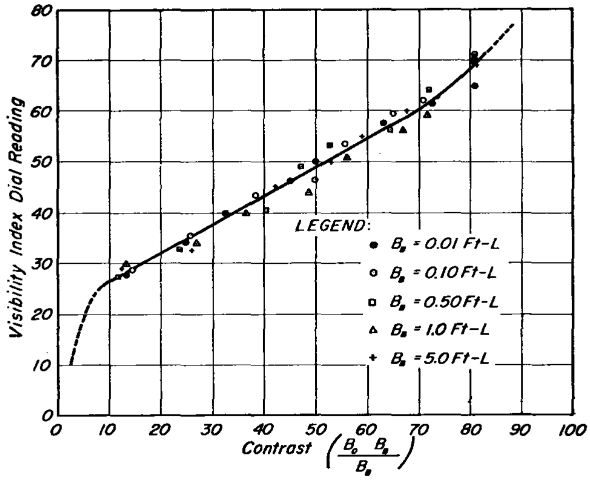


Figure 7. Visibility Index dial calibration for visibility meter.

The Visibility Index is a measure of the supra-threshold contrast of the object as seen against its own immediate background. The concept of the "visibility index" can also be explained in terms of the calibration procedure.

Calibration as Contrast-Threshold Meter

A series of matte gray discs 3¼ inches in diameter having reflectances from 11 to 80 per cent were mounted in the center of a matte white field with a reflectance of 80 per cent located approximately 10 feet ahead of the instrument. The visibility meter was sighted at the test field so that the gray disc was in the center of the central field of view. The illumination on the test field was varied to give background brightnesses from 0.015 to 5.0 ft-L. The brightness of each gray disc was measured and checked by calculation. Thus the actual contrast in the field of view was accurately known.

The visibility index dial was then rotated to the position of minimum transmission and the brightness of the veiling glare source was adjusted to the same average brightness as the surrounding. The visibility index dial was then rotated until the contrast of the gray disc on its background was visually observed to be at the contrast threshold. The dial reading was recorded and many repeat runs were made for each contrast and background brightness level. The results are shown plotted in Fig. 7 and indicate that there is no observable effect of background brightness. This is advantageous because then one calibration curve can suffice for all background brightnesses within the calibration range.

A *visibility index* number has the following meaning: It is a number equal to the contrast of an equivalent gray disc on a uniform background and indicates that the object has a supra-threshold visibility equivalent to the gray disc; the physical conditions of size, reflectance and brightness for the calibration disc being as previously described. The parameters of time, motion, color and critical detail are excluded and are not evaluated by the instrument. Thus a visibility index dial reading of 30 indicates that the scene has the same supra-threshold visibility as a gray disc on a gray background having a contrast of −16 per cent (a Visibility Index of 16) whereas a Visibility Index dial reading of 70 indicates the same visibility as a disc having a contrast of −82 per cent and therefore a visibility index of 82. (See Fig. 7.) The calibration curve is a function of the transmission characteristics of the partial mirror but the visibility index is independent of the mirror transmittance by virtue of the calibration procedure.

Figure 8. Daytime scene of outdoor Street Lighting Laboratory at University of California Engineering Field Station, Richmond, Calif.

Street Lighting Laboratory

A section of roadway within the area of the Engineering Field Station of the University of California at Richmond, California has been assigned for experimental street lighting studies. The area is 55 x 450 feet and is graded and paved with a blacktop macadam surface. See Fig. 8. A row of poles 35 feet high on 50-ft centers has been erected along each side. Mast arms, power, circuits and controls have been developed to permit almost any combination of lighting equipment to be operated. A layout of the roadway and pole location is shown in Fig. 9.

Two basic lighting situations have been under investigation as the first phase of our research: (1) wherein pavement brightness is approximately uniform and (2) in which the pavement brightness is markedly non-uniform. Several combinations of modified luminaires have been used to secure these patterns but none of the patterns have been obtained with standard commercial street lighting luminaires. The uniform patterns have varied in brightness ratio from 4:1 to 1.1:1 and the non-uniform patterns have had ratios of 12:1 to 36:1 over the test area. Two typical pavement brightness patterns are shown in Fig. 10. The illumination and brightness data for these conditions are shown in the iso-lux and iso-brightness diagrams in Progress Report No. 2 I.E.S. Research Project No. 37.[4]

Preliminary Results of Visibility Measurements

Several sets of test data have been reported in previous test reports rendered to the I.E.S. Research Fund.[4] The results to be presented here are a summary of previous work.

Among the problems that arise in connection with visibility measurements is the matter of target design and location. It has become apparent that the type of target is extremely important and can influence the results to an appreciable degree. For

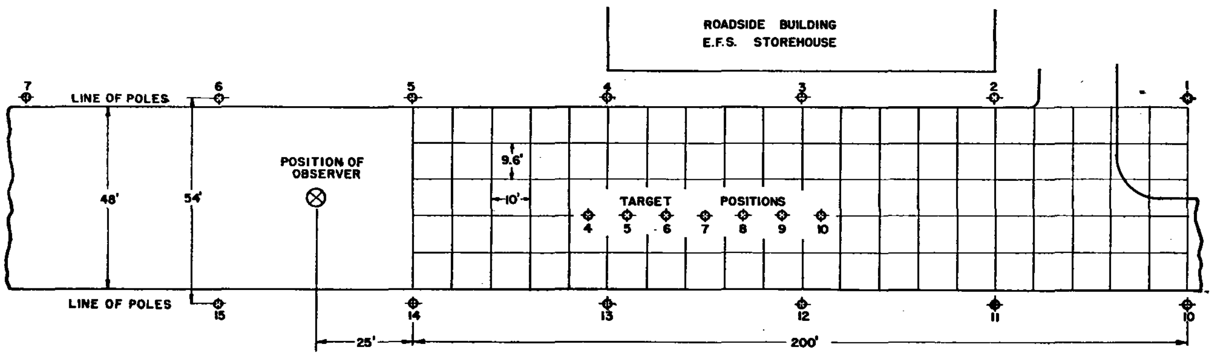


Figure 9. Plan view, street lighting test area.

instance, if a small round disc one foot in diameter is used as a target as in several research investigations by others[5] one may find many locations on a lighted roadway with either uniform or non-uniform brightness where the target brightness will equal the background brightness and the visibility will be very low. If one changes the plane surface to one having multiple plane segments, the number of low visibility target positions on the roadway will be reduced. If one uses a larger target or a tall narrow target to simulate a pedestrian still different visibility indices will result. It is desirable from a research point of view to reduce the number of targets and to have them representative of field conditions and at the same time each should present a reasonably difficult visual task so that differences in the lighting systems will show up in the measurements.

All roadway lighting systems now in current use are directional in principle and practically all roadway obstacles are three dimensional in form, therefore the target should take these conditions into account. These considerations suggest a three dimensional target so that brightness variations will occur within its boundaries but each patch of brightness on the target must be of sufficient size to be observed as an area for contrast discrimination. At roadway sight distances of 75 to 500 feet the target therefore should have a minimum dimension of approximately 6 in. for any segment and should have at least three vertical planes with approximately equal projected dimensions. This would result in a target with a minimum projected width or height of approximately 18 inches. Due to the overhead mounting of most luminaires it is also important to consider the downward directed component of light and therefore to have some surfaces on the target oriented in non-vertical planes to reveal this characteristic of the lighting system. Examples of the above effects are demonstrated in the photographs of Fig. 11 to 13. Note that in Fig. 11a the pavement brightness is approximately uniform and the targets are seen against very nearly the same background brightness. At this position and for the target surface reflectance of 10 per cent, the vertical faces have a very low brightness whereas the inclined faces on the multi-plane target (octagonal-section) all have higher brightnesses. These differences result in variations in the visibility index as will be discussed later. In this case the plane disc has the higher over-all contrast and therefore has a higher visibility index than the octagonal-section target. (See Table I.)

The three-dimensional effect is further emphasized in Fig. 13b where the same two targets are viewed against a non-uniform pavement brightness pattern. In this case the vertical planes are very dark and the background brightness is low so the contrast is very poor but the inclined planes on the left side of the octagonal-section of this target develop considerable brightness and thereby raise the over-all contrast of this target well above threshold. The visibility indices shown in Table I reflect this situation. For this visual situation the octagonal-section target has a moderately high visibility index whereas the plane disc reads zero.

TABLE I — Visibility Measurements Using Uniform and Non-Uniform Pavement Brightness. (Glare effect of luminaires is excluded — field of instrument does not include the light sources)

	Uniform Pavement Illumination (1.3:1 variation)		Non-Uniform Pavement Illumination (19:1 variation)		
Object Position (See Fig. 7)	Pavement Brightness = 0.20 ftL. Br. Ratio = 4:1 in test area		Pavement Brightness = 0.35 ft-L. max. 0.03 ft-L. min. Br. Ratio = 12:1 in test area		Direct or Silhouette Seeing
	Type of Object		Type of Object		
	Circular Disc	Octagonal Sec.	Circular Disc	Octagonal Sec.	
	Vis. Index	Vis. Index	Vis. Index	Vis. Index	
4	39				Silhouette
4		28.5			Silhouette
4			0		———
4				0	
5	39				Silhouette
5		31			Silhouette
5			10		¼ Silhouette
5				15	¼ Silhouette
6	39				Silhouette
6		34			Silhouette
6			30		¾ Silhouette
6				32.5	¾ Silhouette
7	39				Silhouette
7		42.5			Silhouette
7			45		Silhouette
7				51	Silhouette
8	40				Silhouette
8		48			Silhouette
8			45		Silhouette
8				51	Silhouette
9	43.5				Silhouette
9		43.5			Silhouette
9			41		½ Silhouette
9				51	½ Silhouette and Direct
10	39				Silhouette
10		40			Silhouette
10			0		———
10				44	Direct

The target designs that we have used for these studies are shown in Fig. 14. At a recent meeting of the advisory committee for this project (May 1956) the effect of target shape and size was discussed and the conflicting requirements were reviewed. It was proposed that the targets should be

Figure 10a. Uniform roadway brightness pattern. No targets. 4:1 brightness ratio within target area.

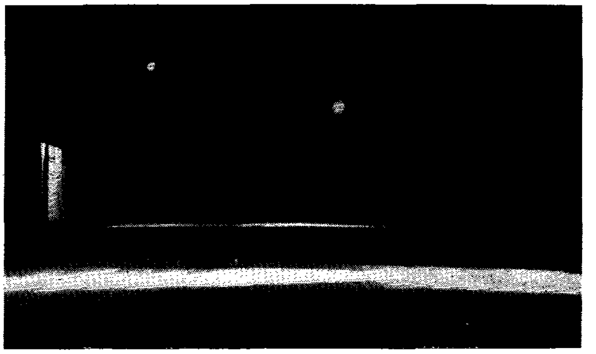


Figure 10b. Non-uniform roadway brightness pattern. No targets. 12:1 brightness ratio within target area.

Figure 11a. Uniform roadway brightness pattern. Targets at Position 4.

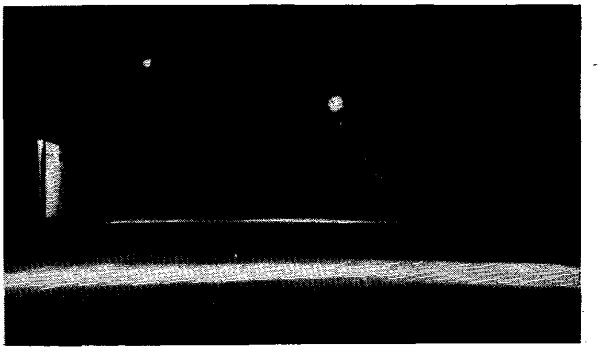


Figure 11b. Non-uniform roadway brightness pattern. Targets at Position 4. (Pinpoint of light indicates target position.)

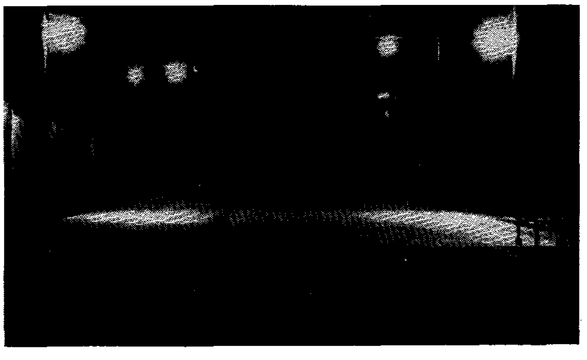


Figure 12a. Uniform roadway brightness pattern. Targets at Position 8.

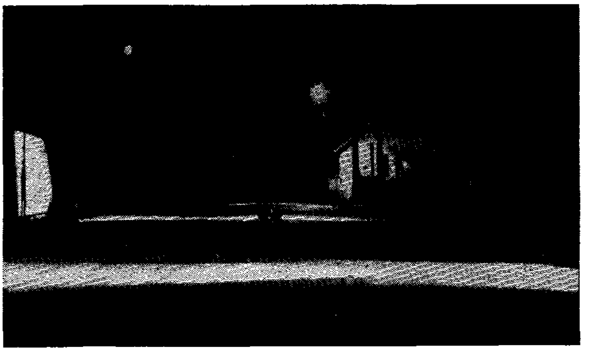


Figure 12b. Non-uniform roadway brightness pattern. Targets at Position 8.

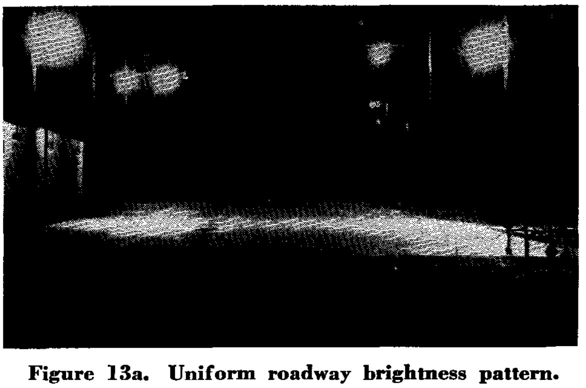


Figure 13a. Uniform roadway brightness pattern. Targets at Position 10.

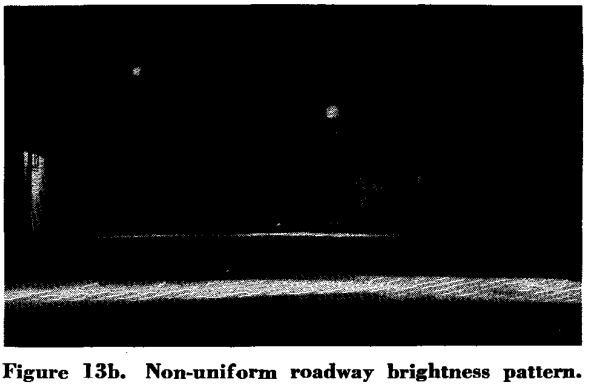


Figure 13b. Non-uniform roadway brightness pattern. Targets at Position 10.

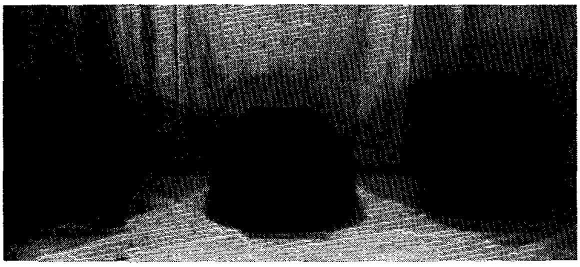
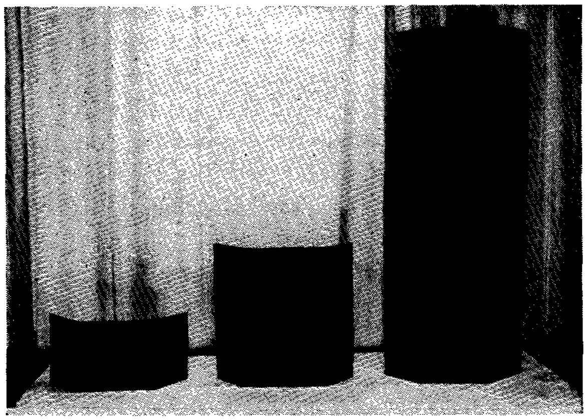


Figure 14. Roadway targets. (above) 18-inch plane disc, partial octagonal-section, full octagonal-section targets; (right) 3-sided vertical plane targets suggested by Illuminating Engineering Research Institute Committee.



standardized in cross-section but in a range of three heights. The proposed shape is a three sided section of a right rectangular prism with one normal and two 45-degree vertical planes each one foot wide and in three heights of 1, 2 and 5 feet. Photographs of sample targets conforming to these sizes and having 10 per cent reflectance are shown in Fig. 14.

Some preliminary studies on the proposed three-sided vertical plane targets indicate the need for inclined top surfaces to reveal the downward component characteristics of some lighting systems. Preliminary data also show that there may be a marked difference between the visibility of a short or a tall object under non-uniform pavement brightness conditions. These data are not complete and are not yet available in numerical form. They seem to indicate that as many as three targets may have to be used in a complete visibility evaluation to reveal different lighting characteristics. These three types of targets are: (1) a small plane diffusely reflecting surface (18 x 18 inches, square or round), (2) a small multi-plane object (three vertical planes with three 45-degree sloping planes — 18 x 18 inches) and (3) a tall multi-plane object (same as (2) except 18 x 60 inches). With three such objects each with a low reflectance (10 per cent) matte surface and placed at various locations within a representative roadway brightness pattern, visibility index measurements can be made which can then be used to make an over-all evaluation. The small plane target would simulate holes or cavities in the roadway and objects having completely diffuse reflectance properties to make them appear uniformly bright, the small multi-plane target would simulate most small obstacles above the roadway (boulders, boxes, small animals, etc.) and the tall- narrow, multi-plane target would simulate pedestrians and other larger targets. For example, in the experiments made upon the two pavement brightness patterns previously described we observed the following data for the round plane disc and the octagonal-section targets located at position Nos. 4 to 10 (70 to 130 ft) on the test roadway. See Fig. 9. Photographs of targets at positions 4, 8 and 10 for the uniform and non-uniform patterns are shown in Figs. 11 to 13. The visibility index numbers do not include any glare effect that may be present due to the light sources. The field of view of the present instrument is not large enough to include the light sources used for these measurements. These data bring out the following points:

(1) With the uniform pavement brightness lighting system developed especially for these tests the plane disc was always seen in silhouette (negative contrast) and had moderately high visibility indices that were nearly the same for all positions along a central line ahead of the observer.

(2) With the uniform pavement brightness lighting system the octagonal-section target revealed considerably greater variation in visibility due to the directional nature of the light. At some positions (No. 4 as an example) the direct light on the inclined planes caused their brightness to be higher than that of the vertical normal plane and thereby reduced the over-all contrast with the background. The resulting visibility index for the octagonal-section target was therefore lower than for the plane disc target at this location. At position No. 8 the octagonal-section target gave a somewhat higher visibility index than the plane disc because the average brightness of the disc was higher than the average brightness of the multi-plane target. This is caused by the directional reflectance characteristics of the target surfaces.

A logical conclusion would be that under this system of lighting which developed approximately uniform pavement brightness the target shape had only a small effect upon visibility, but it is apparent that the three-dimensional target provides more information about the visual conditions than does the plane disc target.

(3) The non-uniform roadway brightness pattern was next developed upon the same area of the experimental roadway. The same targets were placed in the same locations as for the uniform brightness pattern tests. The variation in brightness was such that for certain locations the targets were seen against a very low background brightness and at other positions against a much higher background brightness. The average roadway brightness for the non-uniform pattern was approximately the same as for the uniform pattern.

The visibility index numbers for both the plane disc and the octagonal-section target are given in Table I. Note that in many of the positions the targets are seen partly in silhouette (negative contrast) and partly by direct lighting (positive contrast).

Within the non-uniform pattern both the plane disc and the octagonal-section vary in visibility from zero to moderately high values. There are more locations where the plane disc target has low visibility than for the three-dimensional target (see position Nos. 4 and 10).

The three-dimensional target more nearly approximates roadway seeing conditions for small objects under the non-uniform brightness patterns. Such patterns are only developen by highly directional lighting systems and three-dimensional targets can give an indication of such directionality in many instances that would not be demonstrated by a plane target.

Another set of field data is being analyzed at present in which a different uniform brightness pattern has been employed which has closer spacing of sources with more downlighting. Also a greater observation distance has been used. Although the final calculations are not now available the results appear to check those reported herein and the same conclusions regarding target visibility are emerging. There seems to be the need for more than one type of target.

Summary and Conclusions

The principle of operation of the contrast-threshold visibility instrument described in this report has been successfully demonstrated. It is believed that within the design limitations that are given, the meter can be used to obtain reliable visibility evaluations. The numerical number used to evaluate a specific situation is termed the Visibility Index.

The visibility indices are given for several types of targets (plane, two-dimensional and multi-plane, three-dimensional) for two experimental roadway lighting systems which develop uniform and non-uniform pavement brightness patterns. The system developing the uniform pavement brightness has a large number of sources and is less directional than the system developing the non-uniform pattern.

The directional effect of the lighting is evident when a three-dimensional target is used under either the uniform or the non-uniform system. Much greater variations in visibility were observed with the non-uniform brightness pattern than with the uniform pattern.

For extremely non-uniform patterns and small targets it is possible to lose the target in the dark area between the bright patches. The plane disc targets are lost more frequently than the multi-plane targets.

For uniform patterns that are developed with relatively few sources having appreciable directional distributions it has been observed that a plane disc target may disappear (drop below threshold) at somes test locations even though the background brightness is relatively high. This is due to the direct light on the front of the target which develops a uniform target brightness approximately equal to the background. Such an effect does not usually occur for multi-plane targets because the target brightness is never uniform. (It might occur with high reflectance objects.)

Tall thin targets simulating a pedestrian are now being evaluated. The preliminary data indicate that for both uniform and non-uniform pavement brightness patterns the visibility indices do not vary nearly as much as for the shorter targets when the target is moved from place to place within the test area. This is due to the fact that some part of the target develops a supra-threshold contrast with its background at almost every roadway position even though the over-all contrast of the target may be lowered because a portion of the target is at threshold contrast.

The role of roadway brightness pattern and target size and shape in the night visibility of roadway obstacles is demonstrated for two conditions which may be considered the extremes of engineering practice.

It is apparent that the final pavement brightness pattern is important, but also the lighting system used to obtain this pattern is equally significant.

No one target seems to be adequate for a complete field evaluation of visual conditions. Probably a minimum of three targets should be used for visibility measurements: (1) a small plane area, (2) a small multi-plane surface, and (3) a tall multi-plane surface. These should cover most critical seeing situations and permit a fair appraisal to be made for static visual conditions.

References

1. Richards, Oscar W.: "Vision at Levels of Night Road Illumination," *Highway Research Board, Bulletin 56*, Night Visibility 1952. Contains extensive bibliography.
2. Finch, D. M., and Simmons, A. E.: "An Instrument for the Evaluation of Night Visibility on Highways," ILLUMINATING ENGINEERING, p. 517 (October 1953).
3. Cottrell, C. L.: "Measurement of Visibility," ILLUMINATING ENGINEERING, p. 95 (February 1951).
4. Finch, D. M.: Progress Report Nos. 1, 2, and 3, July 1954, September 1954 and September 1955, Illuminating Engineering Society Research Fund Project 37. I.E.S., New York. N. Y.
5. Reid, K., and Channon, H. E.: "Evaluation of Street Lighting," ILLUMINATING ENGINEERING (December 1939).

DISCUSSION

W. B. ELMER:* The new visibility meter is a most important and significant development giving promise when the wide field instrument is build of determining definitively the relative visibility of different lighting systems and luminaires.

This recent work with larger and three-dimensional targets is beginning to give significant night-time visibility data for the first time and makes former work with small flat targets relatively insignificant.

Page 127, Point 1 states that the uniform pavement brightness system gave moderately high visibility for all positions. If the target were of higher reflectance, it would be less visible. *Some reflectance values might make the targets generally invisible throughout,* under uniform pavement brightnesses. Some controlled non-uniformity could give better overall visibility.

No general conclusion that maximum uniformity of pavement brightness gives maximum visibility is warranted. It appears from theoretical considerations and test results to date that a street lighting system giving controlled non-uniformity will provide the greatest overall visibility.

K. M. REID and D. A. TOENJES:** The author reports interesting and ingenious improvements in the design and construction of his visibility meter. Undoubtedly it will prove to be valuable in field studies of the relative seeing effectiveness of various street lighting installations. Is it now in form suitable for use by other investigators? And are any plans under way toward manufacture of these meters?

The paper points out that the existing meter does not yet have a large enough visual field to include the glare effect of the street lighting units. Therefore, the visibility scale refers to conditions in which the street lighting luminaires are shielded from the field of view. The paper further states that the total field of view of the present instrument is about 15 degrees and the central field of view is 2 degrees, while with future models it is expected that the total field of view will be about 30 degrees, with the same central field. Are we correct that a total field of view of 30 degrees means 15 degrees displacement from the line of sight? Is this field of view circular in shape?

It will be interesting to compare the instrument's field of view with that of the motorist in the average passenger car. Our information on this point is not fully up to date, because it was obtained in 1951 from the Michigan State Highway Department and the U. S. Bureau of Public Roads, in connection with pavement reflectance measurements. However, the average age of automobiles on the road today in this country is about six years, so the windshield cut-off angles represented here are close to average for cars now in use. The vertical angles were about 12 degrees above horizontal, with reference to the average driver's eye position, and within the range of 13-22 degrees below horizontal, depending upon the size of the car. This gives a total vertical angle of 25 to 34 degrees. The horizontal angle, with reference to a line of sight directly ahead of the motorist, is about 58 degrees to the right and 23 degrees to the left, or a total of about 81 degrees. The driver's eye level is at an average of about 54 inches above the pavement. Thus it appears that a proposed later instrument with a total field of about 32 degrees would be reasonably well in line with the vertical angles that the motorist can see through a typical windshield. It is the vertical angle of cut-off that generally determines whether or not the street lighting luminaires are in the field of view.

We believe that a preferred instrument design, however, would be one in which the field of view, including the field of pickup of veiling glare, is substantially greater. Then, when measurements are made, as they preferably are, from the driver's seat in a car the cut-offs actually provided by the car serve to limit the field. Such a wide field would expand the flexibility of use of the instrument. It could then be used in measurements, not only for the average driver in the average car, but also for variations in car design and variations in position of the driver's eyes.

C. H. REX:* Professor Finch is certainly to be commended for his interest in roadway lighting and for his progress report on the difficult night work he has been conducting at Berkeley, Calif. It is hoped that his facilities and staff for the evaluation of roadway lighting principles, technique and effectiveness will be expanded considerably.

Much more needs to be done at a greatly accelerated pace, appropriate to the importance of lighting, in improving night travel conditions so that the multi-billion dollar motor vehicle transportation business will, in the future, be more efficiently kept open after dark.

The Technical Advisory Group of the Illuminating Engineering Research Institute has recommended an assessment appraisal of seeing under three conditions: (a) good roadway lighting, (b) poor roadway lighting, (c) no roadway lighting.

Numerical ratings for good roadway lighting should come first. The lighting should be representative of current recommended practice using modern luminaires and spacings comparable to Table V of the American Standard Practice.

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*Outdoor Lighting Dept., General Electric Co., Henderson, N. C.

As is known, such lighting generally provides pavement brightness uniformity equal or better than that designated as uniform by Professor Finch. The lighting by which Professor Finch produced non-uniform pavement brightness is certainly poor lighting.

As Professor Finch says, under uniform pavement brightness a plane disc target is usually seen in silhouette. He also says, "We will probably never run out of variables to investigate" and "One quantity that seems to be the key to the entire problem is the roadway brightness as seen by the vehicle operator."

So it is hoped further studies will indicate that three different obstacle brightness targets *will not* be necessary for the evaluation of the relative effectiveness of roadway lighting systems.

We are confident that simplification will result. His data probably indicate which facet of the three-dimensional target is resulting in the predominant contrast discernment at each representative roadway station. Or separate targets may be used for a series of complete relative visibility measurements with the purpose of weeding out those not essential for field testing.

We are looking forward to the availability and correlation of his new instrumentation.

D. M. FINCH:* The comments of these discussions are appreciated and bring out several points that either were not covered adequately in the paper or that cannot be answered as yet because of insufficient data.

Mr. Elmer draws his own conclusions from the data presented that a system giving controlled non-uniformity of pavement brightness would provide the greatest overall visibility. I believe that this is a premature conclusion, at least based upon the data of this paper. We have had as one of our objectives the identification and evaluation of some of the factors in the night-time roadway visibility problem. Pavement brightness and its distribution is certainly one of the important factors. Just how this factor should be controlled for best visual conditions is still far from being solved. Each particular roadway function such as continuous section, intersection, ramp, curve, etc., will probably have its own characteristics and specifications, insofar as roadway brightness is concerned.

The importance of target size and shape is beginning to be evident. Most targets are composites of many surfaces, reflectances and spectral distributions of flux. For our preliminary work we will have to reduce the number of variables to a minimum. Therefore, for some studies we may still wish to use small two-dimensional targets but for most cases we will probably wish to use small three-dimensional targets.

Messrs. Reid and Toenjes are correct in their interpretation of the field of view of the instrument. The present field is conical in shape with a total plane angle of approximately 15 degrees. Our present plans call for a modification to yield approximately 30 degrees total plane angle. A larger field is much to be desired but we have not solved the optical problems for a still larger field. We too have determined that a 25- to 35-degree field will be within the normal range of vertical angles encountered in motor vehicle visibility problems. This seems to be a practical compromise in design.

At the present time we do not have any plans to have the instruments manufactured although drawings are available for anyone who may wish to construct an instrument for his own use.

Mr. Rex has pointed to the increasing need for studies of roadway lighting. We firmly support his arguments in that it appears to us that roadway lighting is one of the most important, but so far least used, tools of the roadway designer in creating a safer and more efficient structure. The reason for its being least used is that it is probably least understood. We can do much to change this situation by research on the important quantities such as pavement brightness patterns, glare effects and reduction of conflicting and distracting visual areas in the field of view.

It may be that a uniform and simplified technique for roadway lighting evaluation will evolve in which it will not be necessary to use three or more targets. We have not yet reached that stage. Until we have most of the parameters isolated we will not be able to definitely say which target is more important. We are hopeful that continued support for the research will be forthcoming and that answers to some of the pressing problems will gradually evolve.

*Author.