Retroreflectivity Requirements for Pavement Markings

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Subjective evaluations by 59 observers and quantitative measurements of in-place roadway markings were made in order to determine minimum field luminance and retroreflectivity levels for pavement markings. A minimum luminance value was also determined for the same observers through subjective evaluations and quantitative measurements under controlled and repeatable laboratory conditions. For the field test, more than 90 percent of the subjects rated a marking retroreflectance of 93 mcd/m²/lx as adequate or more than adequate for night conditions. More than 98 percent of the subjects rated all locations having a marking luminance of 3.84 cd/m² or greater as adequate or more than adequate, corresponding to a measured retroreflectivity of 94 mcd/m²/lx. For the laboratory study, more than 90 percent of the subjects rated the simulated markings with a luminance of 0.38 cd/m² as adequate or more than adequate. Subjects used in this research represented a relatively young population, and the study was conducted under ideal field conditions. It is likely that an older driver, operating in a real-world driving situation, would require a retroreflectivity value higher than 93 mcd/m²/lx.

The nighttime accident rate is more than three times the daytime rate when computed on a mileage basis. Factors contributing to this statistic may include use of alcohol or other drugs and driver fatigue. However, the information required by drivers is visual in nature, and the poor visual conditions at night may be considered a major contributing factor. The driver depends on roadway markings for much of the information required for guidance during nighttime driving.

Little work has been reported in the literature concerning the relationship between retroreflectivity and driver perception of roadway marking adequacy (*1–5*). There is no widely accepted minimum adequate retroreflectivity value in the United States.

In this research, subjective evaluations by 59 observers and quantitative measurements of in-place roadway markings were made in order to determine minimum field luminance and retroreflectivity levels for pavement markings. A minimum luminance value was also determined for the same 59 observers through subjective evaluations and quantitative measurements under controlled and repeatable laboratory conditions, and an equation was developed to express the relationship between the field and laboratory luminance subjective evaluations.

FIELD INVESTIGATION

The field experiment provided objective measurements of the retroreflectivity and luminance of existing roadway markings and subjective evaluations of the adequacy of the markings. The initial step in the field investigation was to establish an observation course, with a broad range of marking retroreflectivity values, that could be traversed in approximately 40 min at a safe and comfortable night speed. Each marking on the observation course met the following criteria:

1. Each marking location was on a straight section of roadway on a uniform grade.
2. The minimum length of each marking location was 200 ft.
3. There was no supplemental lighting near the location.

A number of suitable locations were chosen, and retroreflectivity readings were made at 15-ft intervals on each with a Mirolux 12 Retroreflectometer. Average retroreflectivity readings for the locations were used to determine the final observation route, which included 20 observation locations spaced over a distance of approximately 20 mi.

Retroreflectivity measurements were easily made with a Mirolux 12 Retroreflectometer during daylight hours. Luminance measurements were made at night using a Gamma Scientific Telephotometer Model 2000 mounted at eye level between the driver and passenger positions in the front seat of a 1980, 4-door, Plymouth Volare. Luminance measurements could not be made from a moving vehicle, and traffic prevented stopping on the roadway for the necessary amount of time required to make a stationary measurement. For safety reasons the vehicle was parked on the roadway shoulder while measurements were recorded at viewing distances of 50, 75, and 100 ft. Of the 20 marking locations on the observation route, 11 were considered to have suitable shoulder conditions for safe parking and for obtaining luminance measurements. A study was conducted in a dark parking lot to relate the measurement made from an actual driving position to the measurements made from the roadway shoulder.

Subjective evaluations of each location on the test route were made at night. Paid observers were secured through posted and verbal advertisements, and the only criterion was that each observer have a valid driver's license. A total of 59 observers, 43 male and 16 female, ranging in age from 19 to 47 with an average age of 24.5 years, were included in the study. Eight of the observers took part in a pilot study.

The observers met at a designated location at an assigned time in groups of three. Each observer was given a set of written instructions, a statement of informed consent, and a clipboard with a recording form. A pencil and a penlight were attached to the clipboard by strings. The observers were given tape-recorded instructions in addition to the written version in order to ensure consistency and understanding. The in-

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structions gave the purpose of a roadway marking, a description of observation locations, and an explanation of the method of recording responses. A selected evaluation response of (a) less than adequate, (b) adequate, or (c) more than adequate was based on the results of a pilot study for eight observers. Observers were informed that they should remain silent during the testing, wear glasses or contact lenses if they normally did so to drive, and record their evaluations promptly. It was emphasized that there were no right or wrong answers, only the observer's personal opinion. At the end of the instruction period each observer was asked if he or she had procedural questions, which were answered, but no questions pertaining to the adequacy of roadway markings were allowed. The observers were instructed in how to fill out the observation recording forms and how to use the penlight, which was used to enable observers to see to record information at night. The bulb was covered with red translucent plastic to minimize any effect on the observer's night vision.

The same driver was used for all observers, and vehicle speed was a safe, comfortable speed for roadway conditions as determined by the driver and within posted speed limits. No attempt was made to drive at a constant speed because the observer route was on public roadways and other traffic was present. Opposing traffic was infrequent and random and no vehicles were closely followed. Low-beam headlights were used at all times. The beginning of each observation location was announced approximately 300 ft in advance. An observation trip typically lasted 35 to 40 min, and all trips were made on clear, cold, dry nights.

After being instructed, the observers were seated in the front right, rear left, and rear right passenger seats of the test vehicle. This seating arrangement had proved satisfactory during the pilot study. Observers were initially shown one of the reflective markings used to mark the beginning of observation locations in order to acquaint them with what they would be looking for on the observation course. The test vehicle was stopped approximately 100 ft short of the example reflective marking, and the observers were informed that this was representative of what they would see to indicate the beginning and ending of each observation location. Observers were also informed of the distance to the example marking to better familiarize them with the length of an observation location and the distance from the location at which advance notice would be given on the course. The driver then proceeded while the observers evaluated each location by circling on the recording form the proper category best describing their perception of marking adequacy.

LABORATORY INVESTIGATION

The laboratory experiment was designed to evaluate simulated roadway markings of varied luminance. A dark tunnel, 16-ft long by 4-ft wide by 8½-ft high, was constructed of heavy black cloth and hung from the ceiling in a large laboratory room. Inside the tunnel at one end was a 3-ft by 6-ft platform 2-ft 6-in. above the floor, which supported a simulated roadway surface on which strips of roadway marking tape could be placed.

At the opposite end of the tunnel was an observation booth constructed of plywood and heavy black cloth. The booth had a 2-in. high by 4-in. wide closable viewing window through which the simulated roadway surface and markings could be observed. The observation booth was approximately 6-ft long by 4-ft wide by 8½ ft high with a table below the observation window. An adjustable height chair was provided for the observer in order to adjust the eye height of all individuals to the same level. The geometry of the tunnel was designed to simulate a roadway edge line marking as viewed by a driver from a distance of 50 to 75 ft.

In order to vary the luminance of the markings, a lighting system was mounted on the outside vertical plywood surface of the observation booth inside the dark tunnel. A shielded reflector-floodlight was mounted on each side and below the observation window. The intensity of the light output of the reflector-flood lamps was controlled by means of a precision rheostat and monitored by a digital multimeter. Because the reflective properties of each roadway marking were constant, a change in incident light intensity resulted in a proportional change in the luminance of the marking.

Test markings, 6-ft long by 1-in. wide, were cut from 3M Company's Stamark 5730 White and 5731 Yellow roadway marking tape. Background colors were gray and black to simulate portland cement concrete and asphalt concrete roadway surfaces.

Because the relationship between an observer's perception of roadway marking adequacy in the laboratory and in the field was unknown, the range of laboratory luminances was from one that was barely visible to the human eye, 0.01 cd/m^2 to an obviously high luminance, 3.00 cd/m^2. The lower luminance value was based on several individuals' judgment of the level at which they could barely see the markings, while the upper luminance value was the maximum that could be produced by the lighting system in the tunnel.

The luminance values for the simulated markings were measured using the Gamma Scientific telephotometer in the observer booth. The optical head was directed through the window toward the marking, the same orientation as the observer's eye during an observation. Luminance values were measured at three locations along the simulated roadway marking and averaged. Once the luminance values at the limiting conditions were fixed, a number of luminance conditions within the range were selected and both the luminance and voltage producing the condition were recorded so that each value could be reproduced later.

Subjective evaluations of marking adequacy for varying luminance conditions were made under controlled laboratory conditions for each of the 59 observers who participated in the field study. Nine of the observers took part in a pilot study. The observers were given written instructions similar to those used in the field study. Tape-recorded instructions, which were identical to the written instructions, were also played for each observer. The instructions gave the purpose of a roadway marking, a description of the testing procedure, and the method of recording an evaluation of (a) less than adequate, (b) adequate, or (c) more than adequate for each marking. Observers were informed that they would have 5 sec during which time the window of the observation booth would be open to make an observation and then approximately 20 sec to record their evaluation during which the window would be closed. They were given a clipboard with a recording form and provided a pencil and penlight. The

observers were instructed to promptly record their evaluation after each observation. Observers were permitted to ask procedural questions but none pertaining to the adequacy of roadway markings. After being instructed, the observer was seated on the adjustable height chair in the observer booth, and his or her eye level was adjusted to the predetermined elevation. The curtain door of the booth was closed, and laboratory lights were turned off. After completion of 20 observations, the laboratory lights were turned on, the evaluation recording form was collected, and the observer was paid for his or her services.

RESULTS

Figure 1 shows the percentage of observers rating each field location as adequate or more than adequate. The x-axis is nonlinear, and the values shown are the average retroreflectance values for each of the 20 individual locations. This histogram shows a well-defined break-point, with all locations having retroreflectance values greater than 93 mcd/m²/lx being rated as adequate or more than adequate by more than 90 percent of the observers. Location 12, with a retroreflectance value of 137 mcd/m²/lx, was rated as adequate or more than adequate by all observers, as were all locations with values of 180 or greater.

Figure 2 is a graphic portrayal in which average retroreflectivity versus average subjective rating has been plotted for each field location. These ratings were produced by assigning numerical values of 1, 2, and 3 to the subjective ratings of less than adequate, adequate, or more than adequate, respectively, and then using the numerical values to calculate an average value for each of the 20 field locations. Regression analysis on the data gives the following logarithmic equation:

$$Y = 0.641 \ln(X) - 1.018 \quad (1)$$

where X is the retroreflectance (mcd/m²/lx) and Y is the average subjective rating. The resultant curve has a coefficient of determination of 0.89 and a standard error of estimate of 0.19. The lack of fit in the critical region of 100 mcd/m²/lx is readily apparent. When Equation 1 is used to calculate the

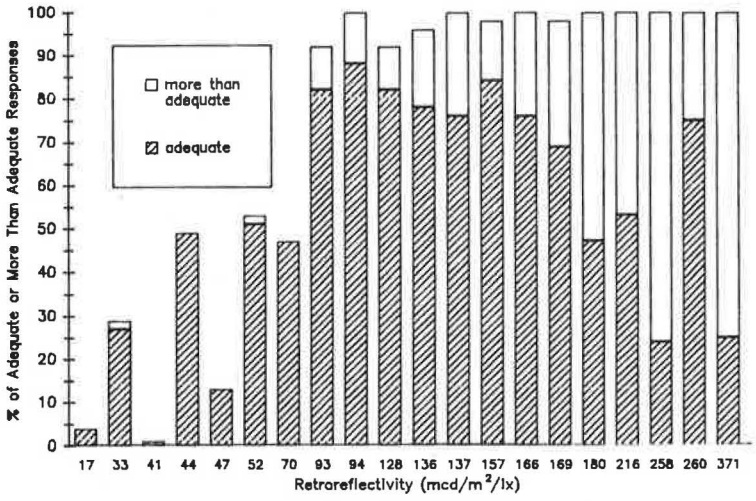

FIGURE 1 Field study retroreflectivity subjective evaluation.

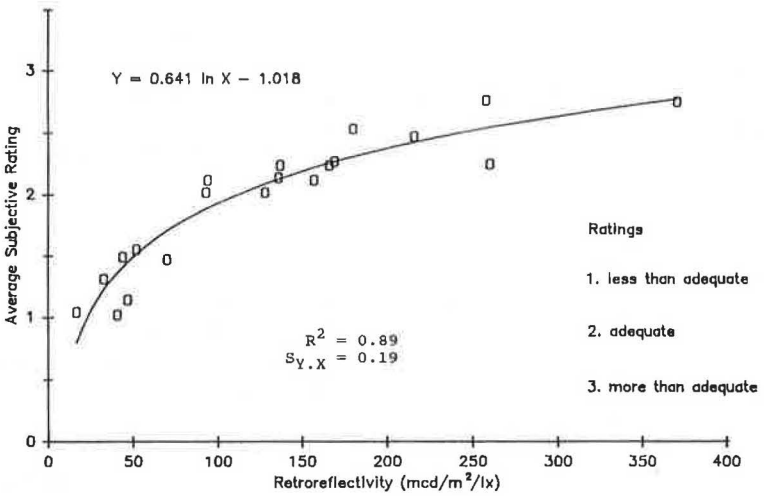

FIGURE 2 Average subjective rating of field retroreflectivity.

retroreflectance corresponding to an average subjective rating of 2, the result is 111 mcd/m²/lx.

Figure 3 shows the percentage of observers rating each field location as adequate or more than adequate. The x-axis is nonlinear, and the values shown are the average luminance values for each location. This histogram shows a definite break-point, with all locations having luminance values greater than 3.84 cd/m² being rated as adequate or more than adequate by 98 percent or more of the observers.

Figure 4 is a graphic portrayal in which average luminance versus average subjective rating has been plotted. Again, these ratings were produced by assigning the numerical values of 1, 2, and 3 to the subjective ratings of less than adequate, adequate, or more than adequate, respectively, and using the numerical values to calculate an average value for each of the 11 field locations for which luminance was measured. Regression analysis on the data gives the following logarithmic equation:

$$Y = 0.50 \ln(X) + 1.22 \quad (2)$$

where X is the luminance (cd/m²). The resultant curve has a coefficient of determination of 0.92 and a standard error of estimate of 0.14. When Equation 2 is used to calculate the luminance corresponding to an average subjective rating of 2, the result is 4.7 cd/m².

Figure 5 shows the percentage of observers who rated each laboratory simulation as adequate or more than adequate. Again, the x-axis is nonlinear, and the values shown are the average luminance values for each simulation. This histogram shows break-points at luminances of 0.11 and 0.38 cd/m². Starting at the 0.11 cd/m² luminance value, all values were rated adequate or more than adequate by more than 75 percent of the observers. Beginning with the 0.38 cd/m² value, more than 90 percent of the observers rated the simulations adequate or more than adequate. From a luminance value of 0.45 cd/m² onward all observers rated simulations as adequate or more than adequate except for the 0.75 cd/m² simulation, which was rated as adequate or more than adequate by 98 percent of the observers. From 1.52 cd/m² onward most observers rated markings as more than adequate.

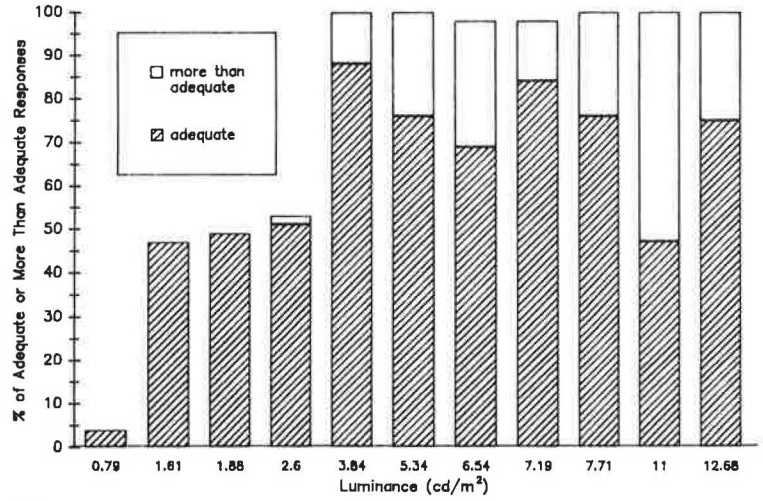

FIGURE 3 Field study luminance subjective evaluation.

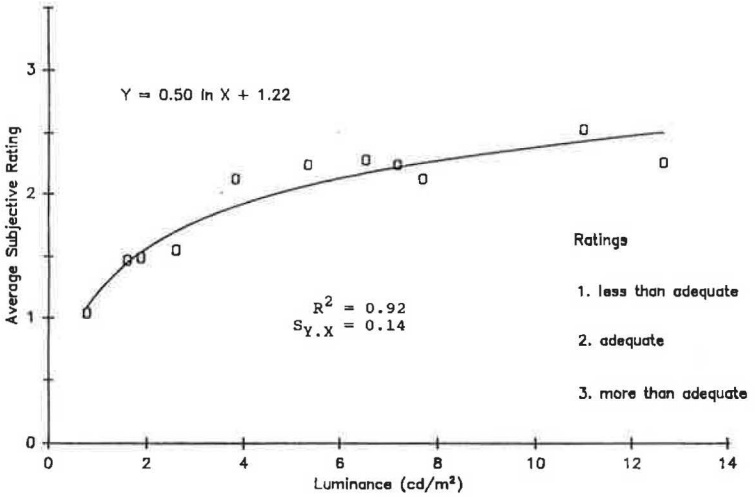

FIGURE 4 Average subjective rating of field luminance.

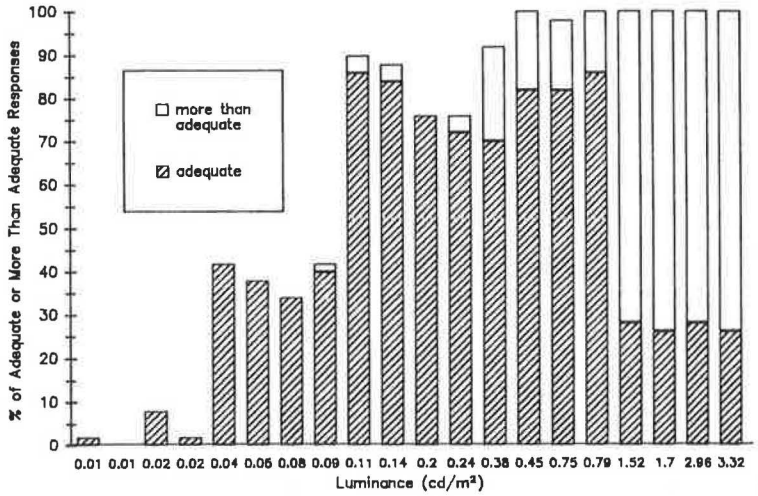

FIGURE 5 Laboratory luminance study subjective evaluation.

Figure 6 is a graphic portrayal in which laboratory luminance versus average subjective rating has been plotted. Regression analysis on the data gives the following logarithmic equation:

$$Y = 0.323 \ln(X) + 2.39 \quad (3)$$

The resultant curve has a coefficient of determination of 0.95 and a standard error estimate of 0.14. When Equation 3 is used to calculate the luminance corresponding to an average subjective rating of 2 in the laboratory setting, the result is 0.30 cd/m².

LABORATORY LUMINANCE VERSUS FIELD LUMINANCE

The relationships previously expressed in equations 2 and 3 were determined from 20 observations by each of 50 observers in the laboratory experiment and 11 observations by each of 51 observers in the field experiment. Letting X_1 represent field luminance and X_2 represent lab luminance the equations can be written as follows:

$$Y = 0.500 \ln(X_1) + 1.22 \quad (4)$$

$$Y_2 = 0.323 \ln(X_2) + 2.39 \quad (5)$$

Setting the average observer ratings Y_1 and Y_2 equal to each other and solving for X_1 results in Equation 6, which gives the relationship between the laboratory and field observations.

$$X_1 = 10.4 X_2^{0.65} \quad (6)$$

Thus, the relationship between subjective rating of the adequacy of roadway markings based on luminance in the field and luminance in the laboratory is the power curve expressed as Equation 6 and shown in Figure 7.

If Equation 6 is used to convert the laboratory luminance value of 0.30 cd/m², the value corresponding to a subjective rating of 2, to a field luminance value, results in a field lu-

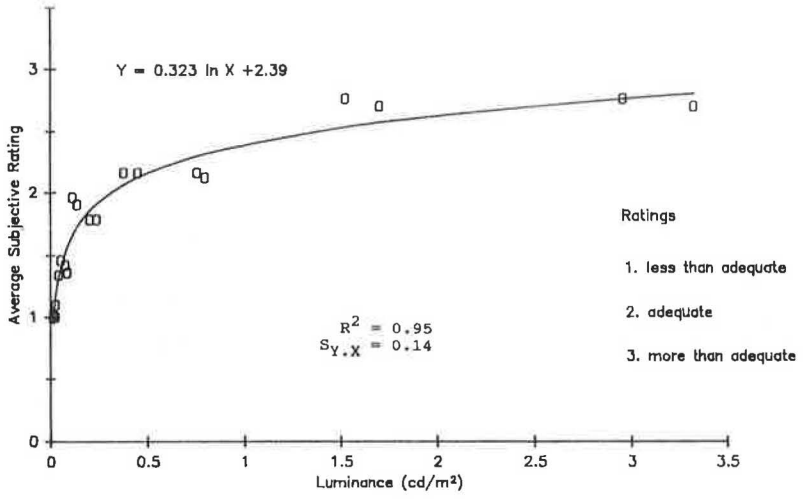

FIGURE 6 Average subjective rating of laboratory luminance.

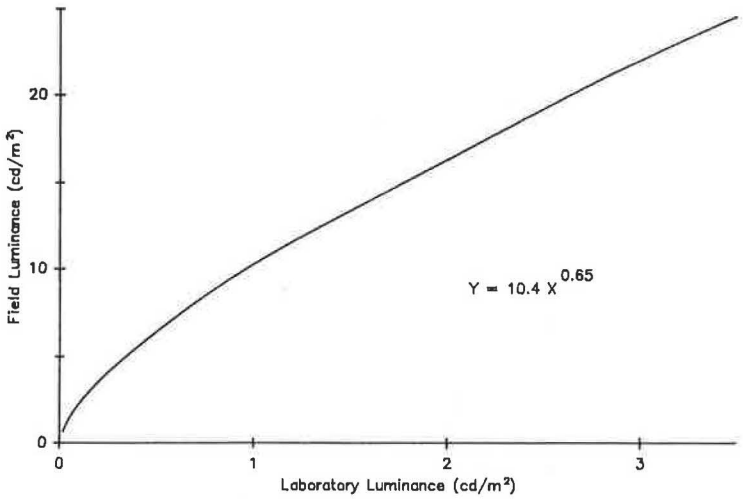

FIGURE 7 Field versus laboratory subjective rating.

minance of 4.76 cd/m². This relationship can also be observed in Figure 7 when for a subjective rating of 2 the value of laboratory luminance is approximately 0.3 cd/m² and that for the field luminance is approximately 4.7 cd/m². For this average subjective rating of 2.0 the field luminance to laboratory luminance ratio is 15.9. Equation 6 may be used to calculate additional "field factors" ranging from 13.2 at a laboratory luminance level of 0.5 cd/m² to 5.92 at a level of 5 cd/m².

SUMMARY

For the field test, more than 98 percent of the subjects rated all locations having a marking retroreflectivity of 93 mcd/m²/lx or greater as adequate or more than adequate. This retroreflectivity corresponds to an average luminance of 3.84 cd/m².

For the laboratory study, more than 90 percent of the subjects rated the simulated markings with a luminance of 0.38 cd/m² as adequate or more than adequate. The lowest luminance value to be rated as adequate or more than adequate by all observers was 0.45 cd/m². All values greater than 1.52 cd/m² were rated as more than adequate.

The relationship between the subjective evaluation of field luminance and the subjective evaluation of laboratory luminance can be expressed mathematically. The equation may be used to relate controlled laboratory study results to expected field results.

CONCLUSIONS

A roadway marking retroreflectivity value of 93 mcd/m²/lx may be considered as a minimum level for nighttime conditions on the basis of the field and laboratory evaluations and measurements reported in this study. However, it should not be considered as a recommended minimum value because the subjects used in this research represent a relatively young population and were aware that they were participating in a research study that was being carried out under "ideal" conditions in the field. It is likely that older drivers, operating in real-world situations, would require a higher value.

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