Automated Facility for Measurement of Pavement Sample Reflectance Characteristics

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Design methods for roadway lighting based on the concept of luminance require information on the light-reflecting properties of pavement surfaces. To evaluate and classify typical pavement materials used in North America, an automated test facility was designed and built at the University of Toronto for the Ontario Ministry of Transportation and Communications. The reliability of the measurements has been assessed in terms of equipment stability and the measuring procedure followed. Results indicated that the measuring accuracy was not limited by the equipment but by the measurement procedure. An estimate of system accuracy based on the limited number of samples measured to date is included. Measurements of the variation of pavement characteristics with variation of angle of observation showed that the direction of traffic need not be identified with accuracy greater than ±5°. Measurements were also made on the effect of the sample size on the characteristics. Results indicated that, for samples with a particle size of about 3 mm, two 15-cm-diameter samples that yield four sets of data would provide reliable values for the relevant characteristics. A measuring program to assess a larger number of samples and a variety of surface textures is in progress.

Figure 1. Illuminance parameters.

Figure 2. Luminance parameters.

The point-by-point calculation of illuminance at a grid point P (Ep) is shown in Figure 1. Luminance is calculated from the corresponding illuminance value for the same grid point (P), but only that portion of the light that is reflected toward the driver's eyes is considered. As shown in Figure 2, the illuminance contribution (Ep) from each luminaire is multiplied by a coefficient q, which depends on the light-reflecting properties of the pavement surface. For each driver position, or each lane, the calculated luminance arrays are different (unlike illuminance arrays, which remain the same).

The luminance coefficient (q) is defined as the ratio between the luminance at point P and the horizontal illuminance at the same point (Ep). It is a function of four angles: α, β, γ, and δ, as shown in Figure 2. Thus,
L = q(α, β, γ, δ) x E_p

where q is the luminance coefficient \((\text{cd} / \text{m}^2) / \text{lxl})\), being a function of the angles α, β, γ, and δ for each particular pavement surface, and \(E_p\) is illuminance. In the metric system, the luminance coefficient [expressed as \((\text{cd} / \text{m}^2) / \text{lxl})\], has a maximum value for perfect white diffuser of \(q_{\text{max}} = 1/\pi = 0.318\).

At each grid point \(P_i\), values of luminance must be calculated for each luminaire and then added together. The luminance created by one luminaire at a given point (subscript \(i\)) according to Equation 1 is as follows:

\[ L = \sum_{i=1}^{n} q(\alpha_i, \beta_i, \gamma_i, \delta_i) E_p(\theta_i, \phi_i) \]

This is in accordance with Figure 2.

Adding the values for \(n\) luminaires, substituting for \(E_p\), neglecting the influence of \(\delta\), and setting \(\alpha = 1^\circ\), the following equation for luminance is obtained:

\[ L = \sum_{i=1}^{n} \frac{q(\alpha_i, \beta_i, \gamma_i)}{(\pi \cos^2 \gamma)} \left\{ \left[ (\sin \theta_i) \cos \gamma \right] / \left[ (\sin \theta_i) \cos \gamma \right] \right\} \]

In conjunction with the work that went into the CIE recommendations, standard reflectance tables have been established in the form of reduced coefficients: \(r = q \cos \gamma\) for \(\gamma = 1^\circ\). This combination of \(\cos \gamma\) and \(q\) simplifies the reflectance measurements. Also, the combination \(r = q \cos \gamma\) leads to tabulated values of \(r\), which decrease with an increase in \(\gamma\) or \(\tan \gamma\), whereas the pure reflectance function \(q\) alone increases tremendously for \(\gamma\) being equal to or close to zero (5).

The number \(n\) of luminaires to be taken into account should include a longitudinal distance of \(12 \times h\) or more beyond the point \(P_i\). Additional luminaires beyond this range contribute insignificant.

By substituting \(r = q \cos \gamma\), Equation 3 can be rewritten as follows:

\[ L = \sum_{i=1}^{n} \left\{ (q(\theta_i, \phi_i) / (\cos \gamma)) \right\} \]

**CLASSIFICATION OF ROAD SURFACES**

The results of measurements from a sample pertaining to a particular road surface are tabulated in terms of \(\tan \gamma\) and \(\beta\) and can be used as a design input after storage in a computer memory array. Figure 3 represents a typical array for a dark asphalt pavement surface. CIE-sponsored research in Europe has addressed the question of classifying such measurements into a manageable number of specularity classes. Usually there are four classes for dry pavements, although some suggestions go as far as eight in this category. More recently, there has been work done on four additional classes pertaining to wet pavement surfaces (6,7).

The most commonly known dry classes are designated RI, RII, RIII, and RIV, and an alternative system is known as N1, N2, N3, and N4—all proposed for European-type pavements (4,8). In the United States and Canada, the same or similar classes may apply, which will be subject to some research investigations. The example in Figure 3 is for RIII.

Classification of measured road surfaces is carried out by using certain parameters, which are \(Q_0\) (or \(q_0\)), \(S_1\), and \(S_2\), where \(Q_0\) or \(q_0\) equals an average luminance coefficient over a defined roadway ground area or space angle; \(S_1 = r(0,2)/r(0,0)\) (i.e., \(\beta = 0, \tan \gamma = 2\); and \(\beta = 0, \tan \gamma = 0\)) and \(S_2 = Q_0/r(0,0)\).

The value \(Q_0\) can be understood as a parameter correlated to the average luminance of the pavement surface. The values \(S_1\) and, especially, \(S_2\) are parameters that indicate the degree of specularity. It is stipulated that surfaces with identical parameters are equivalent, with very little differ-

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**Figure 3. Standard reflection table R-III.**

- **Note:** Table of reflectance data: \(q \cos^2 \gamma \times 10^4\)
DESCRIPTION OF APPARATUS

The Ontario road reflectance matrix photometer is an instrument designed to measure \( r \)-values as a function of \( \beta \) and \( \tan \gamma \). The apparatus consists of four major subsystems, as shown in Figure 4 and described below:

1. A mechanical system with photoelectric sensors that position the light source and the sample in accordance with the specified range of parameters \( \beta \) and \( \gamma \) as defined in Figure 5, thereby maintaining a constant height of the source.

2. An optical detection system that is rigidly attached to the sample and maintains the constant viewing angle \( \alpha \) [see Figure 6 (note that scale is approximately 1:20)]. The core of this system is a 5x0.15-cm sector of a spherical lens of 35-cm focal length with a 1x0.5-mm iris located in the focal plane and an RCA 6217 photomultiplier tube, the cathode of which is located in the proximity of the focal plane. The dimensions of the lens sector define a field of view of approximately 5x8 cm while the focal plane iris defines the acceptance angle of 5' in the vertical and 10' in the horizontal planes.

3. An integrated data-acquisition and dedicated microcomputer system that stores the elements of the measured \( r \)-matrix, applies appropriate weighting factors, numerically integrates them, and evaluates the parameters \( S_1, S_2, \) and \( Q_0 \). The output is in the form of a printout of the \( r \)-matrix with the associated values of the three derived parameters. If desired, there is a provision for storing the output on an audio tape. This feature is about to be augmented by providing the option for storing the output on a magnetic disc.

4. A control module that uses the primary inputs from the photoelectric sensors of the mechanical subsystem and, in conjunction with the microcomputer, governs the operation of the other subsystems.

APPARATUS PERFORMANCE

The major performance parameters of the system are described in this section. The light source employed is a 400-W quartz halogen lamp moving on horizontal rails 60 cm above the sample level. The range of lamp movement is from directly above the sample to approximately 7 m away. With the integration time of about 15 ms, the signal-to-noise ratio provided by the detector employed (RCA 6217 photomultiplier) was about 10 dB for the weakest signal observed.

The choice of size of the field of view was dictated by the requirement that the equipment be designed to operate on circular samples of about 15 cm in diameter. The relative sizes of the field of view and the sample allow one to obtain two independent sets of measurements from one sample.

Experience has shown that the measurement cycle for one sample (two viewing fields), which includes mounting and alignment time, is about 1 h.

ASSESSMENT OF MEASUREMENT RELIABILITY

The reliability of measurements by the apparatus is affected by two phenomena:

1. Equipment stability and
2. Measurement procedure, such as mounting and alignment of the sample.
The particle size in the surfaces measured was of the order of 3 mm, and from the above data it is estimated that measurements performed on two 15-cm-diameter samples that yield four sets of data would provide reliable values for both the parameters \(Q_0\), \(S_1\), and \(S_2\) and the elements of the \(r\)-matrix. The accuracy of these measurements would be consistent with the accuracy of the equipment and the measuring procedure.

No results are available currently for surfaces with a larger particle size. It is expected that either a larger field of view may be required or a larger number of samples would be necessary to obtain reliable data. The latter option would be preferable due to the convenience of obtaining and handling smaller-sized samples.

### PILOT MEASUREMENTS FOR ONTARIO PAVEMENTS

The Lindsay, Ontario, test sections \(9\) were chosen to carry out pilot measurements on pavements of known composition. About 20 samples were measured from various sections, and each sample was measured at least three times in slightly changed angular position (+5°, 0°, and -5°). Comparing the results with the Erbay Atlas data in Figures 7a and b, it was found that, in terms of specularity \(S_1\), the surfaces range from \(S_1 = 0.4\%\) to \(S_1 = 1.4\%\) (i.e., from below the standard surface \(S_II\) to above \(S_{III}\)). The most specular surfaces contain at least 60 percent limestone coarse aggregates, and the least specular surfaces contain more than 70 percent igneous rocks. In the latter, the igneous stone projections feel gritty; in the former, the limestone projections feel smooth and polished. The surfaces were exposed to moderate traffic from summer 1978 to fall 1980.

The test sections had been skid tested by the old, nonstandard skid trailer in summer 1980. In Figure 8, the skid numbers \(S_N\) from these tests are plotted versus the specularity parameter \(S_1\).

There is a weak negative correlation \((-0.64)\) between the \(S_N\) taken at 80 km/h and the parameter \(S_1\). Stronger correlations may be expected between low-speed or "zero-speed" \(S_N\) and \(S_1\). In any case, it is certain that the degree of specularity of pavement surfaces is related to the degree of smoothness or polish of coarse aggregates.

### CONCLUSIONS

The Ontario road reflectance matrix photometer, as designed and tested to date, has provided measurement results that are well within the accuracy of existing design methods. The instrument provides reliable, rapid, and automatic measurements of pavement samples as small as 15 cm in diameter. Although the viewing angle \(\phi\) is fixed at 1° in the present apparatus, modifications are in progress to vary the range of \(\phi\).

The availability of this test facility with its rapid measuring time and small sample size should assist highway agencies in the acquisition of relevant data for modern highway lighting design by the luminance method.
Figure 8. Plot of SN versus specularity.


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REFERENCES


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