such a service. It should be pointed out that surface-based advisories are nearly as effective as airborne services, are much less expensive, and can be analyzed with the methods described in this paper.

ACKNOWLEDGMENTS

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Road Surface Reflectance Measurements in Ontario

W. JUNG, A. KAZAKOV, and A. I. TITISHOV

ABSTRACT

A photometer for measuring surface reflectance matrices of dry pavements was developed at the University of Toronto and has been used to measure the light reflectance properties of many pavements in Ontario. The laboratory measurements were carried out on 6-in. diameter samples, and statistical deviations were carefully studied to determine the feasibility of classifying the pavements in accordance with Committee International de l'Eclairage (CIE) and (more recent) Illumination Engineering Society (IES) practice and to establish a reliable sampling procedure. The measured pavement types were classified on the basis of their reflectance parameters (Q0, S1, S2) established as average values from reflectance matrices of at least three samples. These parameters were found to be dependent on aggregate polishing and stone brightness, and on accumulated traffic load. The influence on the light reflectance of the viewing angle α being different from the standard 1 degree was also studied, and it was found that all parameters tend to decrease with increasing angle α. The findings indicate that reflection properties can be measured with fair accuracy and confidence, but that significant fluctuations of the reflectance properties can occur on a given pavement. The IES or CIE proposal for four specularity classifications under dry conditions can be recommended; however, the brightness parameter, Q0, was found to be of greater significance in lighting than originally anticipated and more accurate values should be established as discussed in this paper.

The Illumination Engineering Society (IES) has recommended the luminance method of lighting design for expressways and freeways (1), and there are some efforts to introduce even more advanced design methods based on luminance contrast or visibility index. All of these computer-based design methods require information on light reflectance properties of pavement surfaces for computational input of data.

Sponsored by the governments of Ontario and Canada, the University of Toronto has built a photometer for the measurement of road surface reflectance matrices based on the concepts originally developed by the Committee International de l'Eclairage (CIE) (2). The Ontario system features an automated control of positioning, reading and recording, and a conveniently small sample size [6 to 8 in., (150 to 200 mm)] obtained from normal pavement cores, although at least three samples are needed to classify a pavement type (3).

The pavement reflectance photometer has been used to measure the reflectance coefficients of more than 400 samples from different experimental pavements in Ontario. The results have been processed to determine pavement types by composition and age and to classify them with regard to brightness and specularity classes. The parameters of light reflectance were studied with regard to their statistical variations from:

- The measurement procedures,
- Close-range or local changes of surface features, and
- Long-range fluctuations along or across lanes.

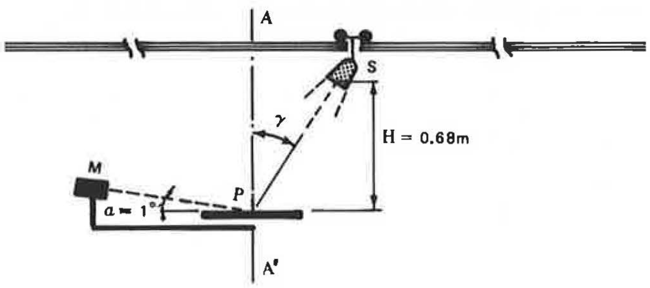

FIGURE 1 Principle of experimental setup for measurement of the reflection properties of road surfaces.

The influence of changes in viewing angle (usually set to 1 degree) on the reflectance matrix was also investigated.

REFLECTANCE MATRIX

The basic principle of road surface reflectance measurement in a laboratory is shown in Figure 1. The sample is placed horizontally on a rotating table, centered at P, and is illuminated from various positions determined by the angle γ. A photometer, M, measures the reflected light or luminance from a constant angle $\alpha = 1$ degree. The table with the rigidly fixed photometer and the sample rotate around the axis A-A', so that the projections of the light beam axis S-P and the viewing axis M-P form successive increments of a rotating angle β varying from zero to 180 degrees. The luminous intensity, I, of the lamp, S, pointing toward P is kept constant by tight voltage control. The lamp moves along a rail with constant height, H, above the sample (P).

The corresponding road geometry is shown in Figure 2. In the CIE system, the influence of the angle δ is neglected ($\delta = 0$), and the angle α is fixed to 1 degree. The laboratory measurements are automatically processed, and a matrix of reduced luminance coefficients, $R(\beta, \tan \gamma)$, is calcu-

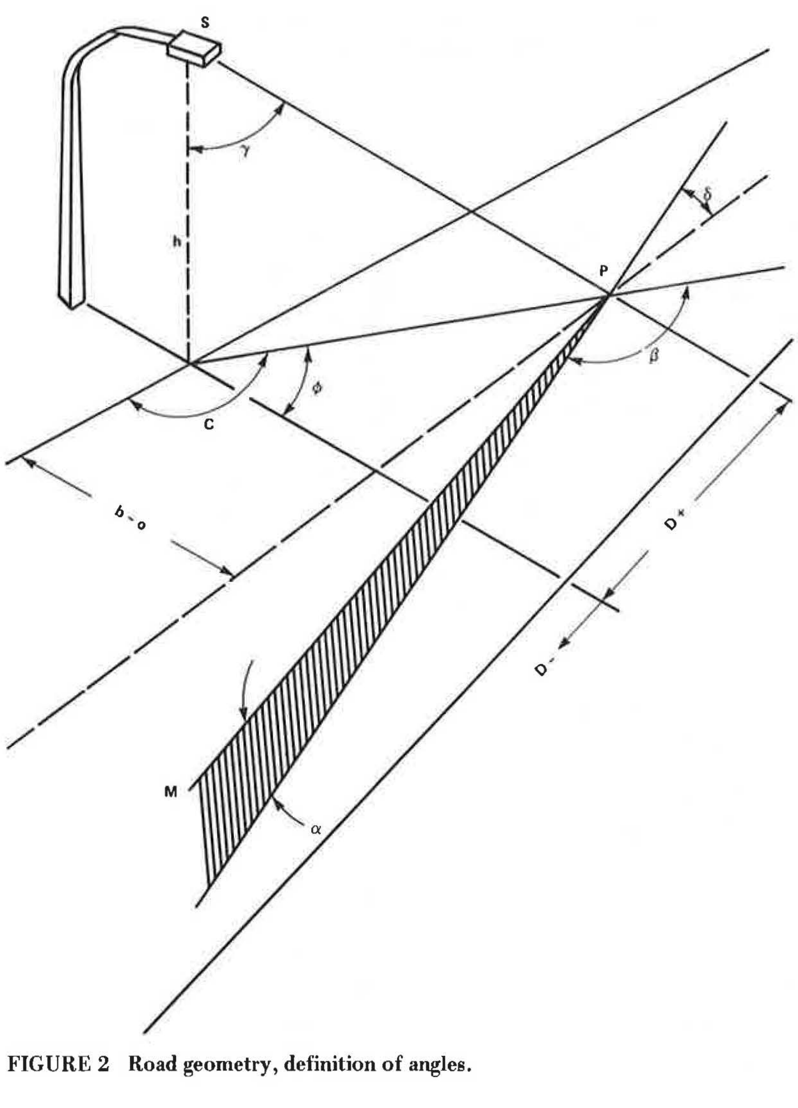

FIGURE 2 Road geometry, definition of angles.

lated and printed. Each coefficient, R, is calculated by the following relationship:

$$R = L\ H^2/I \qquad (1)$$

where

- L = luminance measured at P, in cd/m^2,
- H = height of lamp above the sample surface, in meters (0.68 m), and
- I = luminous intensity of the lamp, in lumens.

Note that the coefficient R, is reduced by a factor cos $^3\gamma$ applied to the normal luminance coefficient, q, ranging from zero to $1/\pi$ for a perfect white diffusor. Figure 3 shows an example of a matrix printout with R-values multiplied by 100,000. The CIE reflectance parameters, Q0, S1, and S2 for this particular matrix are also given in the figure. The modified values are calculated from improved values of R(0,0) and R(0,2) based on averages or nonlinear regression analysis. The parameters are defined as follows:

- S1 = R(0,2)/R(0,0),
- S2 = Q0/R(0,0), and
- Q0 = average luminance coefficient as defined by the IES Roadway Lighting Committee (2).

All normal measurements of the matrix values, R, were carried out on samples of 150 mm (6 in.) diameter, on a centrally located field-of-view of 65 mm by 115 mm.

CLASSIFICATION CRITERIA

The aforementioned quantities (Q0, S1, and S2) are generally recognized as a set of parameters that essentially describe the reflection characteristics of a pavement for roadway lighting design. Here, Q0 is a measure for the overall brightness of the pavement as it appears to the viewer, whereas S1 and S2 describe the degree of specularity. Traditionally, these parameters are used to classify pavements for the purpose of lighting design. Specularity classes are defined by selected standard values and boundaries of S1 or S2. Systems of four or eight standard reflectance tables (i.e., matrices as shown in Figure 3) have been proposed for dry pavements (1-6). Table 1 contains the parameter values for the R-series (4) and N-series (5) of standard reflectance tables. The R-series of standard tables has been approved by IES (1).

Although Table 1 contains standard values for Q0, the overall brightness can change independently from the degree of specularity. If Q0 differs from the standard value, all reflectance coefficients, R, in

DATE: MARCH 15/83
IDENTIFICATION: 14-1 Open Grade Mix, 67% coarse aggregate, 5.8% asphalt, Hwy. 401 test section

tan GAMMA ↓ BETA ——>

tan GAMMA	0	2	5	10	15	20	25	30	35	40
0	2713	2760	2760	2742	2713	2760	2713	2754	2807	2760
.25	3319	3325	3325	3307	3325	3272	3230	3230	3183	3125
.5	3789	3731	3778	3731	3601	3495	3325	3183	3089	2895
.75	4078	4160	4078	3842	3654	3401	3025	2801	2477	2277
1	4219	4248	4160	3748	3325	2836	2430	2130	1834	1647
1.25	4295	4213	4078	3554	2807	2242	1787	1506	1302	1137
1.5	4342	4219	3936	3089	2283	1675	1289	1039	885	785
1.75	4172	4060	3554	2560	1754	1256	913	757	653	560
2	4031	3842	3213	2130	1292	878	673	540	461	419
2.5	3654	3460	2471	1278	732	492	384	315	263	254
3	3325	2989	1830	790	437	277	243	219	194	183
3.5	3042	2424	1275	489	266	214	170	151	154	151
4	2789	2101	927	329	203	148	124	144	129	118
4.5	2477	1706	672	249	153	112	99.1	86.5	106	100
5	2336	1463	492	194	114	90.1	84.6	75.1	76.5	84.0
5.5	2164	1162	376	154	95.0	80.8	73.2	64.4	64.4	63.0
6	2024	950	282	117	83.5	67.7	68.5	63.0	58.6	
6.5	1904	751	236	97.4	74.5	60.6	58.0	57.8		
7	1745	629	204	84.6	65.3	60.9	55.0	54.5		
7.5	1725	550	175	73.2	64.2	56.2	47.9			
8	1557	456	141	65.3	55.5	52.5	50.2			
8.5	1517	386	126	66.1	53.9	45.4	48.3			
9	1401	351	102	61.9	48.8	45.5				
9.5	1330	309	101	56.2	48.7	47.9				
10	1231	263	85.6	59.2	47.3	44.6				
10.5	1241	253	78.0	56.3	47.8	47.8				
11	1136	201	75.8	50.1	44.6	42.3				
11.5	1090	197	73.3	52.6	43.7					
12	1076	194	65.8	49.3	42.8					

tan GAMMA	45	60	75	90	105	120	135	150	165	180
0	2760	2848	2654	2789	2636	2807	2754	2760	2742	2742
.25	3072	2901	2795	2648	2471	2383	2318	2224	2177	2242
.5	2795	2430	2148	1954	1820	1759	1711	1679	1650	1620
.75	2163	1783	1556	1398	1298	1217	1208	1208	1209	1203
1	1481	1195	1005	944	861	845	837	859	650	856
1.25	996	795	719	677	653	625	653	621	645	645
1.5	713	577	525	484	475	478	456	494	484	503
1.75	522	422	393	367	360	374	376	380	386	398
2	375	324	310	291	287	301	301	304	319	324
2.5	235	221	208	210	210	212	202	224	216	230
3	189	165	148	158	149	163	164	174	183	189
3.5	135	120	112	119	119	112	131	132	141	139
4	106	99.1	86.8	90.3	94.9	98.3	99.1	119	127	121
4.5	84.6	76.6	78.8	80.2	84.6	89.6	93.4	94.1	100	106
5	76.6	68.2	63.3	72.9	70.8	78.8	79.3	69.4	91.6	95.3

X 100000

Qo= .0737384
S/1= 1.48577
S/2= 2.7178
R(0,0)= .0271316
R(0,2)= .0403113

MODIFIED VALUES:

S/1= 1.46331
S/2= 2.66294
R(0,0)= .0276906
R(0,2)= .0405197

FIGURE 3 Typical printout of a light reflectance matrix.

TABLE 1 Parameter Values of Standard Surfaces, "R" and "N" Classification

	R Series				N Series			
Parameter	R1	R2	R3	R4	N1	N2	N3	N4
Q0	0.10	0.07	0.07	0.08	0.10	0.07	0.07	0.08
S1	0.25	0.58	1.11	1.55	0.18	0.41	0.88	1.61
S2	1.53	1.80	2.38	3.03	1.30	1.48	1.98	2.84

the standard reflectance table must be increased or decreased proportionally.

The Erbay Atlas (5) contains 240 measured or calculated matrices, carefully numbered and identified, with an even spread of plotted points of log(S1) versus log(S2), which can be used for refined classification work. The pavement types measured in Ontario have been classified in terms of R and N classes, and also with regard to the closest matrix table contained in the Erbay Atlas.

The classification of dry pavement surfaces into a system of four specularity classes, R or N, leads to root-mean-square (rms) errors of no greater than about 5 percent in luminance and 9 percent in uniformity, when design calculations are compared (6) using an accurate matrix versus the closest standard table.

STATISTICAL VARIATIONS IN MEASURING PAVEMENT REFLECTANCE

Several studies were undertaken to determine statistical variations and confidence limits (95 percent) for matrix and parameter measurements on a pavement type. The first study was on the repeatability of measurements on the same core sample to establish the accuracy of the instrument in conjunction with the procedure of placing and leveling the sample. In this instance, it was found that the standard deviation of all parameters being measured was no greater than 2 percent.

More important were the efforts to determine the influence of texture randomness and small sample size. It was found that sufficient confidence could be established for all reflectance parameters if averages are formed from three samples taken from the same pavement. The term "same pavement" has to be understood in three ways:

1. Including only very local variations of the surface on the same sample and its immediate vicinity,
2. Including not only local variations but also variations farther along the same wheelpath, and
3. Including variations over the whole surface of a test section.

If variations of the first kind (Item 1) are much smaller than variations of the second kind (Item 2), then the small sample size in conjunction with texture randomness is generally acceptable.

The first study was carried out on a worn HL-1 type pavement of relatively uniform quality. The 95 percent confidence limit for averages from three samples were found to be as follows:

	Local (%)	Whole Wheelpath (%)
Q0	3	11
S1	4.5	11.5
S2	3.5	5

For the specularity parameters, S1 and S2, the results have been plotted in Figures 4 and 5 in the form of ellipses among the plotted points from the Erbay Atlas (4). The 95 percent confidence limit for local variation (Figure 4) is consistent with the density of the Atlas points, whereas the 95 percent confidence limit for the whole wheelpath variation (Figure 5) extends beyond several plotted Atlas points. Similar studies were carried out for other types of pavements, always showing localized variations as being substantially smaller than overall variations. The results of these studies are summarized in Table 2.

Thus, averages from three core samples of 150 mm (6 in.) diameter can be regarded as equivalent to measurements of one larger sample used by earlier CIE research. However, overall variations over long stretches of pavements may be much larger than indicated by the 95 percent confidence level for the whole wheelpath quoted previously. Such surface texture variations may be caused by

1. Inconsistencies in mixture compaction;
2. Differences in pavement wear, polishing, and aggregate loss; and
3. Contamination of pavement surface.

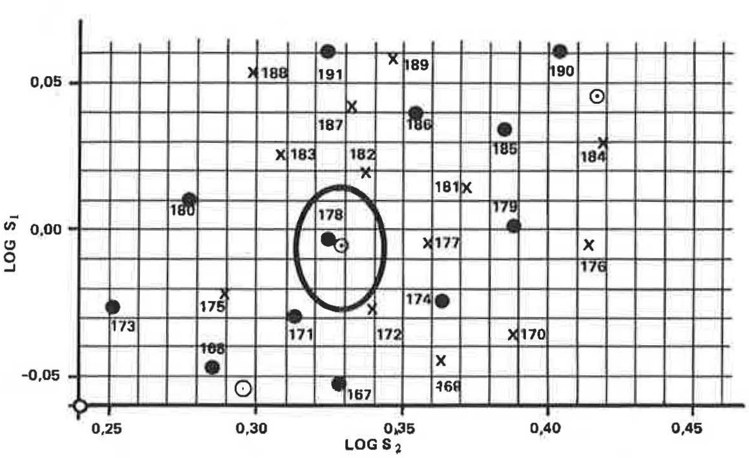

FIGURE 4 95 percent confidence limit of specularity parameters S1 and S2 for local variation.

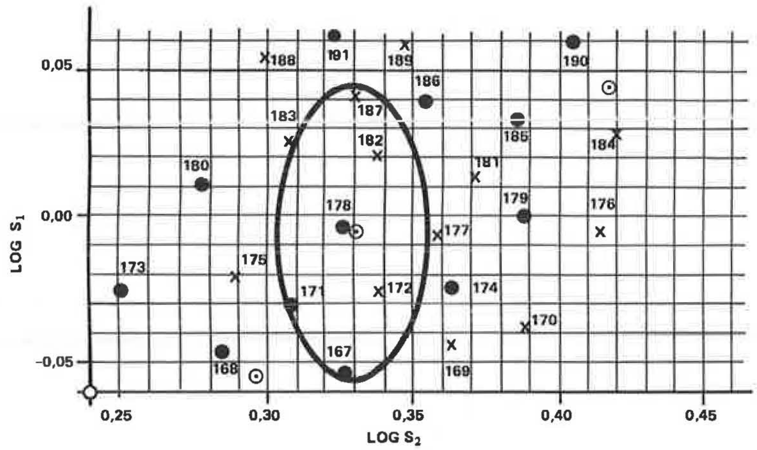

FIGURE 5 95 percent confidence limit of parameters S1 and S2 for variations along the wheelpath of a longer stretch pavement.

TABLE 2 Statistical Variations for Various Levels of Measurements

Level of Measurement	Parameter	Std. Deviation
Measurements repeated on the same sample with repositioning	Q0 S1 S2	2 2 2
Measurements on adjacent viewing areas close to same sample	Q0 S1 S2	2 9 4
Measurements along the wheelpath of the same test section	Q0 S1 S2	6% 20% 6%
Measurements over the whole road section including outside the wheelpath	Q0 S1 S2	2-15%) 4-56%)[a] 3-23%)

Note: The values in Table 2 have been established based on selected sections of Hwy 401, Toronto Bypass.

[a]Total Range Encountered.

LIGHT REFLECTANCE MEASUREMENTS OF ONTARIO PAVEMENTS

The reflectance matrix photometer used for the measurements on 36 different types of pavements in Ontario is shown in Figure 6. More than 400 core samples were processed, including those for a more rigorous statistical investigation of test sections, and the matrices of all samples were printed as shown in Figure 3 and are kept on file. The reflectance parameters of each pavement type (averages of at least three measurements) are given in Tables 3-5, indicating location, pavement types, and composition. The last three columns of these tables contain the specularity classes in terms of R and N number, and the number of the nearest Erbay Atlas matrix table (5).

Several figures have been prepared to assist interpretation of the results presented in Tables 3-5. Figures 7 and 8 represent plots of log(S1) versus log(S2), similar to plots found in Calculation and Measurement of Luminance and Illuminance in Road Lighting (2) and the Erbay Atlas (5). The figures show that for all Ontario test sections the plots are within the boundaries of the Erbay Atlas "cloud" indicated by the dashed lines. Further, Figure 7 reveals a relationship between S1 and the type of coarse aggregate, ranging from hard traprock and igneous stone to limestone. S1 values are grouped as follows:

Coarse Aggregate	Range of Log(S1)
Igneous or traprock	-0.29 to -0.17
Limestone	-0.10 to -0.06
Blend of the two	-0.23 to -0.08

This grouping can be explained by different resistance to polishing under traffic load.

Figures 9 and 10 represent plots of log(S1) versus Q0, similar to Table 9c in Theoretical Basis of Road Lighting Design (4). In general, these diagrams show a wide scattering of Q0 values, indicating large variations in brightness. More specifically,

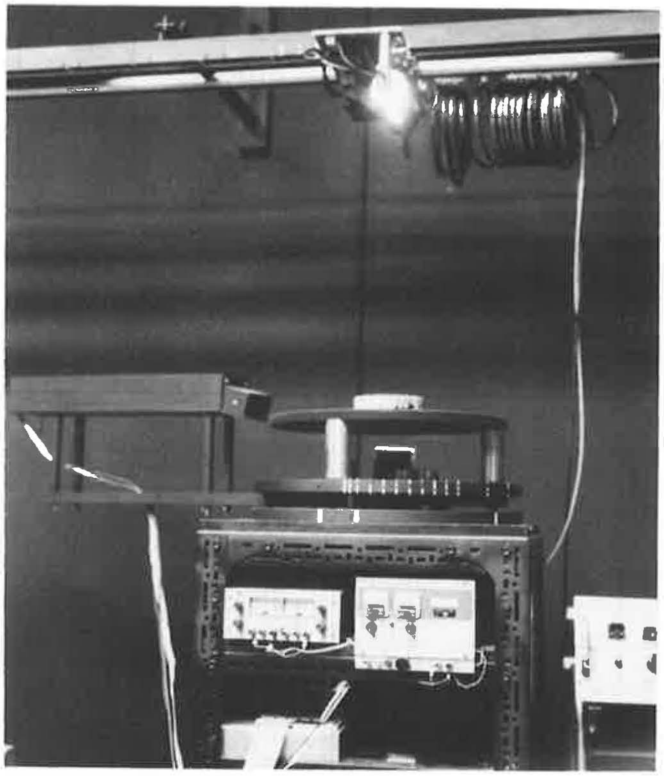

FIGURE 6 Photograph of equipment—the reflectance matrix photometer.

TABLE 3 Reflectance Parameters of Highway 7 Test Sections (Lindsay)

LOCATION, TYPE AND MIX COMPOSITION (%)					REFLECTANCE PARAMETERS			SPECULARITY CLASSES		NEAREST ERBAY TABLE
SECT. No.	PAVEMENT	AGE (YRS)	COARSE AGGREG.	FINE AGGREG.	Q0	S1	S2	R	N	Number
1	O.G.	5	58 MR	35 MRS*	0.0744	0.6623	1.9457	2	3(2)	149
2	O.G.	5	61 LS	35 MRS*	0.1019	0.8814	2.0171	2	3	164
3	O.G.	5	61 MR&LS	35 MRS*	0.0887	0.7805	1.9875	2	3	157
4	O.G.	5	58 MR&LS	35 MRS*	0.0947	0.8289	2.0058	2	3	165
5	O.G.	5	58 LS	35 LSS	0.1125	0.8586	1.9732	2	3	164
6	O.G.	5	59 LS	35 LSS	0.0821	0.5911	1.8119	2	2(3)	136
7	D.F.C.	5	54 LS	45 S	0.1135	0.9804	2.0997	2	3	178
8	D.F.C.	5	52 LS	45 BLEND	0.1146	0.8899	2.0375	2	3	167
9	D.F.C.	5	52 LS	45 BLEND	0.1066	0.9608	2.1192	2(3)	3	178
10	D.F.C.	5	55 LS	45 MRS	0.1061	0.7990	2.0396	2	3	157
11	D.F.C	5	52 MR	45 MRS	0.0791	0.6376	1.9476	2	3(2)	143
12	D.F.C.	5	53 MR	45 LSS	0.0858	0.5425	1.8352	2	2	127
13	D.F.C.	5	52 BLEND	45 LSS	0.0969	0.6877	1.9254	2	3	149
14	D.F.C.	5	52 LS	45 LSS	0.1155	0.9660	2.0436	2	3	171
15	HL-3	5	45 LS	55 S	0.1242	1.1288	2.3490	3	3	186
16	DELUGRIP	5	60 BLEND	35 MRS	0.0858	0.5988	1.9103	2	2(3)	140
17	HL-1	5	45 TR	55 S	0.0879	0.5193	1.8068	2	2	125

LEGEND:
* -- WASHED
O.G. -- OPEN GRADE
D.F.C. -- DENSE FRICTION COARSE
MR -- MAPLE RIDGE
LS -- BEAMISH (BROWN) LIMESTONE
TR -- HAVELOCK TRAPROCK
MRS -- MAPLE RIDGE SCREENINGS
LSS -- LIMESTONE SCREENINGS
S -- ORMELL SAND

TABLE 4 Reflectance Parameters of Highway 401 Test Sections

LOCATION, TYPE AND MIX COMPOSITION (%)						REFLECTANCE PARAMETERS			SPECULARITY CLASSES		NEAREST ERBAY TABLE
SECT. No.	PAV'T	AGE (YRS)	COARSE AGGREG.	FINE AGGREG.	LANE	Q0	S1	S2	R	N	Number
1	HL-1	8	45 TR	41 NS	DRIVING	0.0875	1.0553	2.4168	3	3	197
				14 LS	CENTRE	0.0845	1.1937	2.5148	3	3	195
					PASSING	0.0919	0.7013	2.1601	3(2)	3	148
2	HL-1	8	45 TR	41 NS	DRIVING	0.0962	1.3114	2.7968	4(3)	4(3)	200
				14 TRS	CENTRE	0.0888	1.3491	2.6985	3	4(3)	202
					PASSING	0.0818	0.6646	2.0795	2	3(2)	145
3	HL-1	8	45 TR	55 TRS	DRIVING	0.0696	0.7532	2.2817	3	3	156
					CENTRE	0.0714	0.7863	2.2428	3	3	160
					PASSING	0.0708	0.5868	2.0908	2	2(3)	137
4	HL-1	8	55 TR	34 NS	DRIVING	0.0775	1.1883	2.6601	3	3	195
				11 LS	CENTRE	0.0738	0.9037	2.2916	3	3	169
					PASSING	0.0748	0.6203	2.0066	2	3(2)	145
5	HL-1	8	60 TR	28 NS	DRIVING	0.0774	0.8829	2.2766	3	3	169
				10 LS	CENTRE	0.0749	0.9179	2.3568	3	3	174
					PASSING	0.0745	0.4992	1.9236	2	2	118
6	HL-1	8	60 TR	38 TRS	DRIVING	0.0656	1.4944	2.7842	4(3)	4	207
					CENTRE	0.0632	1.5247	2.6752	3	4	212
					PASSING	0.0620	1.2059	2.4144	3	3	194
7	MODI-	8	45 LS	55 SLS	DRIVING	0.0774	0.6631	2.4803	3	3(2)	151
	FIED				CENTRE	0.0704	0.7604	2.4639	3	3	160
	HL-1				PASSING	0.0654	0.5974	2.1512	3(2)	2(3)	137
8	MODI-	8	50 SL	38 NS	DRIVING	0.0841	1.9061	3.3580	4	4	225
	FIED			12 LS	CENTRE	0.0798	1.6745	3.0357	4	4	215
	HL-1				PASSING	0.0736	1.6503	2.8793	4	4	216
9	MODI-	8	45 BF	55 BFS	DRIVING	0.0812	0.6129	2.0031	2	3(2)	140
	FIED				CENTRE	0.0737	0.5665	1.9588	2	2	134
	HL-1				PASSING	0.0788	0.5290	1.8862	2	2	125
10	MODI-	8	40 BF	45 NS	DRIVING	0.0934	1.1418	2.7321	3	3	192
	FIED			15 LS	CENTRE	0.0866	1.0565	2.5498	3	3	184
	HL-1				PASSING	0.0866	0.7446	2.1071	2	3	153
11	SAND	8	14 TR	84 TRS	DRIVING	0.0673	1.4215	2.9109	4	4	204
	MIX				CENTRE	0.0655	1.2502	2.7779	4	3	198
					PASSING	0.0614	1.1994	2.7355	3(4)	3	192
12	SAND	8	9 TR	89 TRS	DRIVING	0.0691	1.2944	2.8359	4	3(4)	200
					CENTRE	0.0659	1.1170	2.6160	3	3	190
					PASSING	0.0646	0.9624	2.3550	3	3	174
13	OPEN	8	67 TR	33 TRS	DRIVING	0.0674	1.4182	2.8718	4	4	204
	GRADE				CENTRE	0.0669	1.5510	2.9015	4	4	211
					PASSING	0.0656	1.1693	2.5874	3	3	190
14	OPEN	8	67 TR	31 TRS	DRIVING	0.0646	1.4286	2.7329	3(4)	4	207
	GRADE				CENTRE	0.0624	1.3612	2.6552	3	4(3)	202
					PASSING	0.0611	1.0972	2.3352	3	3	186
15	OPEN	8	30 TR	70 TRS	DRIVING	0.0750	1.7050	3.2041	4	4	215
	GRADE				CENTRE	0.0686	1.5377	2.8701	4	4	211
					PASSING	0.0655	1.0616	2.5457	3	3	184
16	OPEN	8	30 TR	68 TRS	DRIVING	0.0673	1.2342	2.8069	4(3)	3	198
	GRADE				CENTRE	0.0613	1.1412	2.5527	3	3	190
					PASSING	0.0611	0.9703	2.4239	3	3	179
17	MASTIC	8	70 LS	19 SLS	DRIVING	0.0629	1.4552	2.6720	3	4	207
					CENTRE	0.0647	1.3673	2.5713	3	4(3)	202
					PASSING	0.0658	1.2484	2.5214	3	3	197
1 & 19	HL-1	8	45 TR	41 NS	DRIVING	0.0817	1.8504	3.1227	4	4	224
					CENTRE	0.0752	1.6846	2.9403	4	4	216
					PASSING	0.0743	1.3179	2.6698	3	4(3)	202
18	OPEN	1/2			DRIVING	0.0610	0.6555	2.0780	2	3	145
	GRADE				CENTRE	0.0613	0.6234	2.0760	2	3(2)	145
					PASSING	0.0618	0.7702	2.0627	2	3	157

LEGEND: COARSE AGGREGATE
TR -- TRAPROCK
SL -- STEEL SLAG
BF -- BLAST FURNACE SLAG

FINE AGGREGATE
SLS -- STEEL SLAG SCREENINGS
LS -- LIMESTONE SCREENINGS
TRS -- TRAPROCK SCREENINGS
BFS -- BLAST FURNACE SCREENINGS
NS -- NATURAL SAND

TABLE 5 Reflectance Parameters of Concrete Samples from Highway 401

LOCATION, TYPE AND MIX COMPOSITION (%)					REFLECTANCE PARAMETERS			SPECULARITY CLASSES		NEAREST ERBAY TABLE
SECT. No.	PAVEMENT	AGE (YRS)	COARSE AGGREG.	FINE AGGREG.	Q0	S1	S2	R	N	Number
1, #2	even concrete polished	~15	LS	PRS	0.1235	1.294	2.676	3	3(4)	200
1, #3	even concrete gritty	~15	LS	PRS	0.1093	0.473	1.875	2	2	114
2, #2	concrete longitud'l grooving	~15	LS	PRS	0.1291	1.318	2.267	3	4(3)	201
2, #2	concrete lateral grooving	~15	LS	PRS	0.0945	0.906	2.249	3	3	169
3, #2	concrete longitud'l grooving	~15	LS	PRS	0.1244	1.333	2.461	3	4	202
3, #2	concrete lateral grooving	~15			0.0958	1.324	2.625	3	4	202
4, #2	concrete rough bridge deck	~15	LS	PRS	0.1206	1.264	2.092	2(3)	3(4)	196

LEGEND: LS -- LIMESTONE
PRS -- PIT-RUN SAND

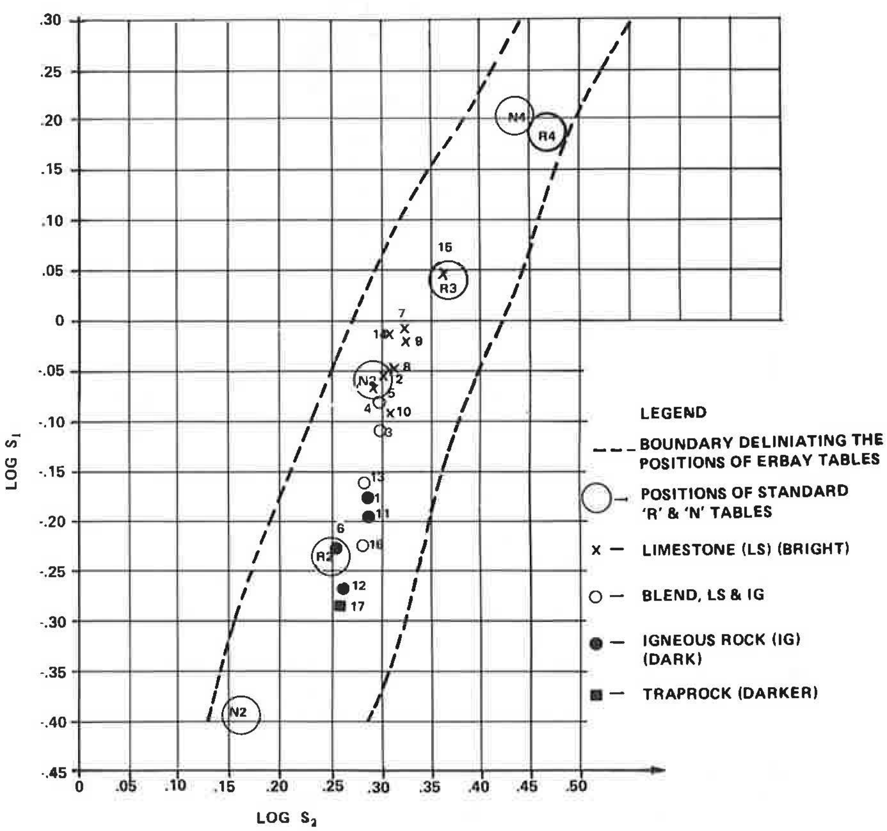

FIGURE 7 Specularity plot of Lindsay section.

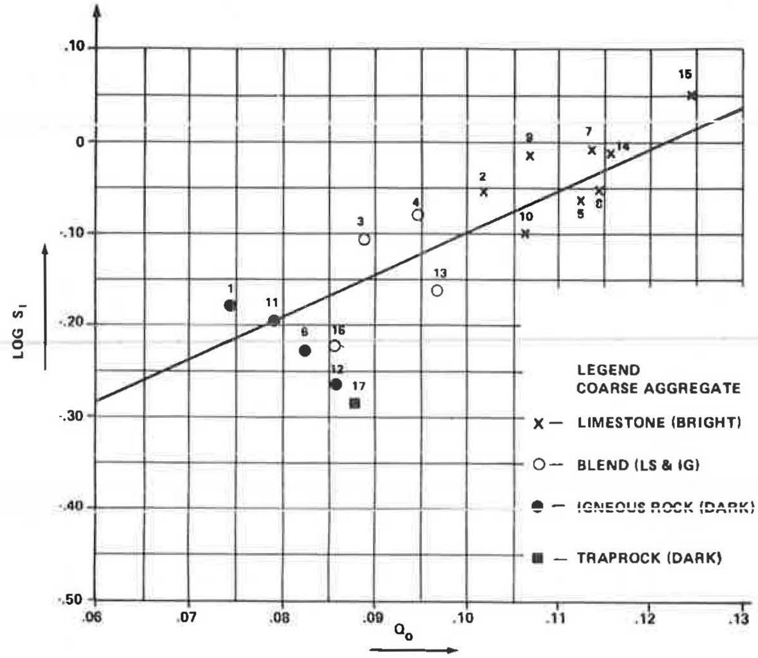

FIGURE 8 Specularity plot of Highway 40 test sections.

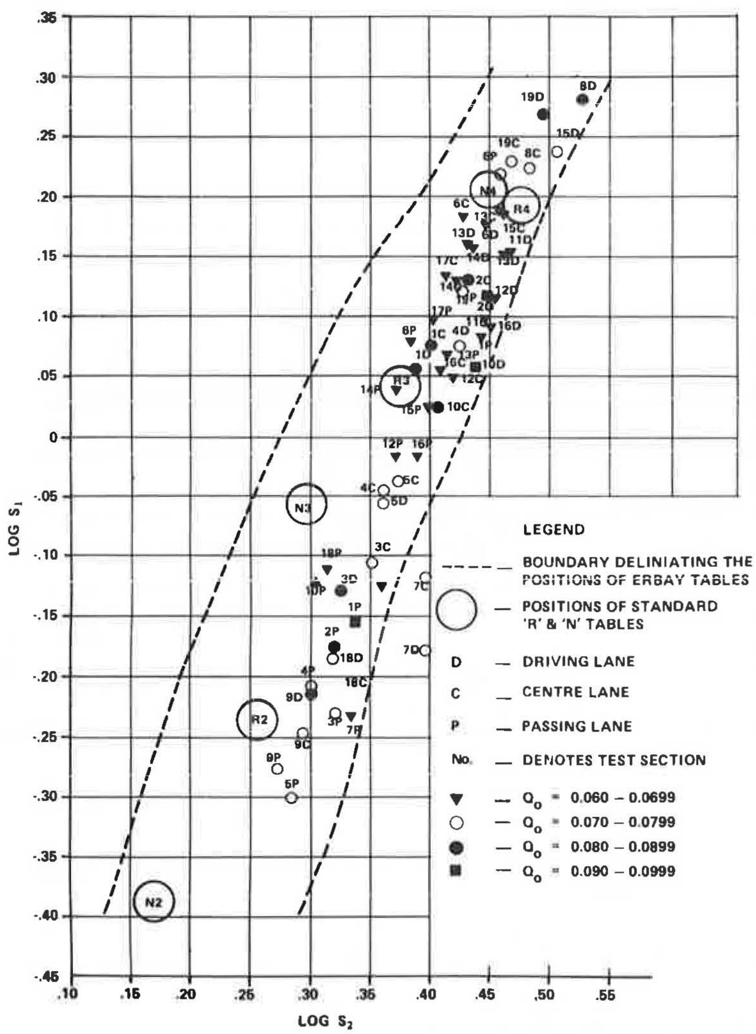

FIGURE 9 Brightness–number specularity diagram of Lindsay test sections.

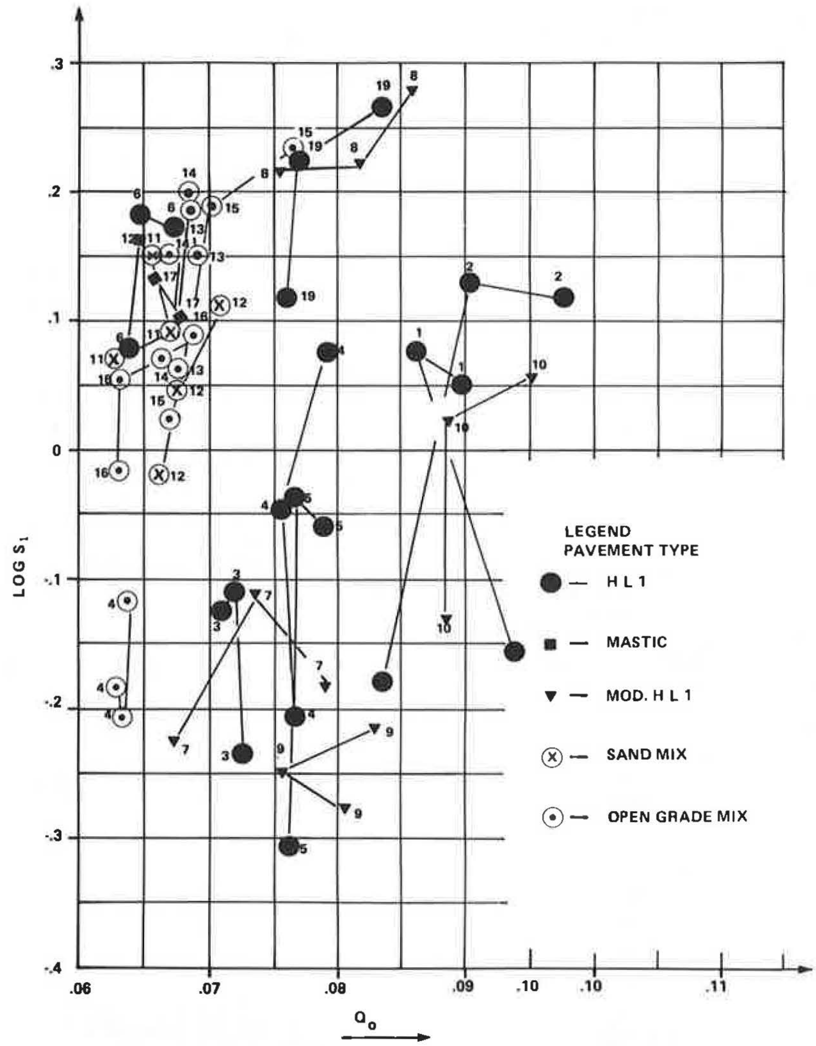

FIGURE 10 Brightness—specularity diagram for Highway 401 test sections.

Figure 9 (the Lindsay test site) reveals the following grouping in terms of coarse aggregates:

Coarse Aggregate	Range of Q0
Dark traprock	0.074 to 0.088
Blend of the two	0.086 to 0.097
Bright limestone	0.102 to 0.124

This grouping depends obviously on the brightness of aggregates and perhaps partly on a concurrent specularity increase.

Finally, with regard to Figure 10, representing the Highway 401 test site, there appears to be a narrow grouping of the open-grade mixes with traprock aggregate (and sand mixes combined). For these pavement types a narrow band of Q0 values exists between 0.061 to 0.069. Otherwise, the Highway 401 test sections show very large variations in brightness (Q0 = 0.06 to 0.10).

Some results from concrete samples that have been measured are given in Table 5. Much depending on the prevailing limestone coarse aggregate, the Q0 values are high, ranging from 0.109 to 0.129, including the longitudinally grooved textures. Note that only lateral grooving appears to reduce the Q0 value to about 0.095, without a significant change in specularity. From gritty to polished samples there is only a slight increase in Q0, but there is a major shift in specularity, from R2 to R3.

THE EFFECT OF ACCUMULATED TRAFFIC

With regard to the time of measurement, a shift can be observed from lower specularity classes to higher ones. A comparison between Table 3 and Table 4 indicates that the Lindsay/Highway 7 test sections have lower classes assigned to them, mainly R2 and N3, whereas most Highway 401 test sections exhibit higher classes, because of the substantially higher accumulated traffic since construction. Further, on Highway 401, a shift of specularity can also be observed when going from the driving lane to the outer passing lane. This shift is typically from Class 2 to 3 or from Class 3 to 4 for both R and N classifications. At the same time, there is also an increase in brightness of the asphalt pavements with time or traffic accumulation, which is reflected in a shift of Q0 values. An attempt has been made to quantify these shifts versus accumulated truck traffic load, which has been estimated at about 0.76 and 19 units of 10,000,000 tons (1000 kg) for the outer passing lane and the driving lane, respectively. The corresponding shift of parameters (i.e., the differences in Q0 and S1) are: (a) difference in Q0, 0.01 (approximately) and (b) difference in S1, 0.3 to 0.6 (range for many types).

REDUCED REFLECTANCE COEFFICIENT MATRIX

A representation of a reduced reflectance coefficient matrix is shown in Figure 1. The coefficient is a function of β and tan γ. Another representation is given in Figure 11, which shows visual images printed by a computer. The plastic plottings cover an area that corresponds to a roadway area measured in multiples of mounting height, H, as follows:

- From -4H to +12H longitudinally, and
- From zero to +3H laterally (one side only).

Note that this is one-half the space angle by which the value Q0 has been defined (2,4-6).

In particular, Figures 11a to 11d represent the matrices of the standard R tables (1). Figures 11e and 11f are typical matrices measured on the Highway 401 test sections. Their shape is comparable to one of the standard R shapes shown to the left or to a shape between them. This means that there is sufficient similarity between measured and standardized matrices for the traditional method of classification.

However, special attention must be given to the shape of the surface shown in Figure 11g, which represents an HL-3 pavement type containing limestone coarse aggregate from the Highway 7/Lindsay test section No. 15. The aggregate was observed to be highly polished. Although this test section has been nominally classified as R3 or N3, the measurements on this surface fall out of the traditional CIE classification system because there is no provision to take into account the second hump along the longitudinal axis. Such an odd case has never been reported. If this discovery turns out to be of some importance, it should probably be named the Ontario Hump; however, the particular pavement does not belong to the preferred standard designs and should be avoided in any case because of low skid resistance. The parameters listed for this pavement have been calculated in the usual manner, but probably result in underestimating its specularity. A more suitable class would probably be R4 or N4.

In order to estimate the magnitude of change in luminance design calculations when a shift in specularity class occurs (Q0 being constant), the data in Table 6 are presented. The data indicate the percent differences in maximum, minimum, and average luminance values for each Class R1, R2, R3, compared to those using the standard R4 as input. The values given in Table 6 are based on a typical example and do not represent maximum possible differences.

TABLE 6 Percent Luminance Change

Specularity Class	R4	R3	R4	R1
Average	0	+3.3	+4.6	+7.5
Maximum	0	+1.1	+13.9	+16.8
Minimum	0	+0.7	+6.5	+7.8

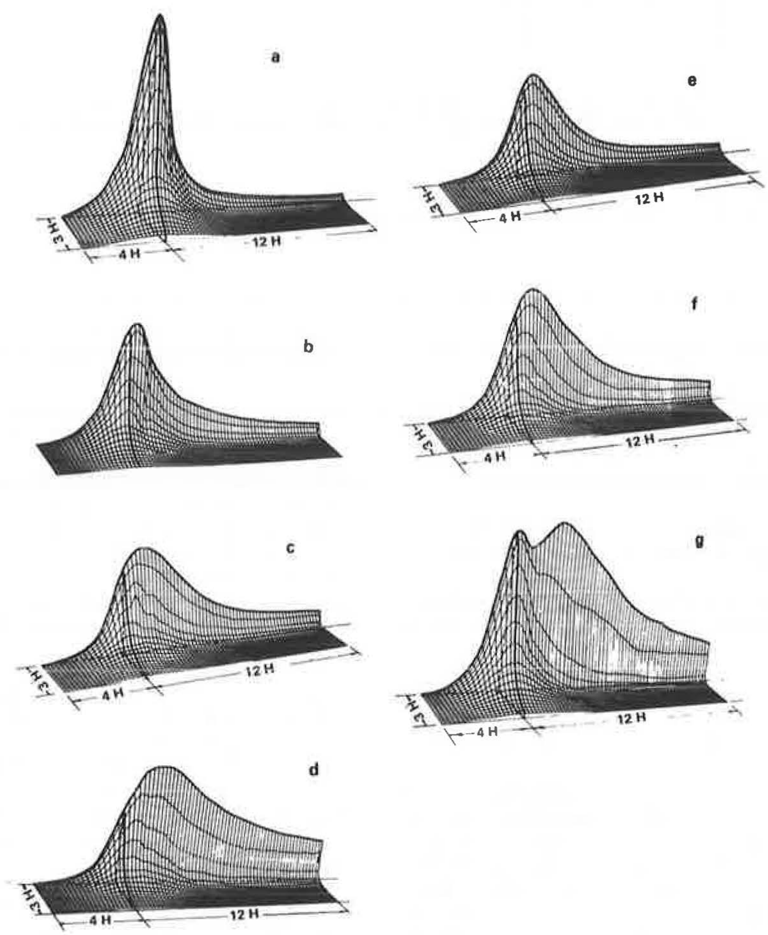

FIGURE 11 Visual representations of reflectance matrices.

INVESTIGATION OF CHANGES IN VIEWING ANGLE

All measurements and classification work on reflectance matrices to date were based on a viewing angle of 1 degree (α = 1 degree). This angle, as a rounded value, is related to (what was believed to be) the prevailing or most critical viewing distance of an automobile driver, namely 80 to 100 m ahead of his current position, so that he could see a critical size object (a 20 cm cube) in time to take evasive action. Drivers of trucks, buses, and vans, however, view objects from a more elevated eye level and their viewing angle for the same distance ahead is larger than 1 degree. On the other hand, drivers of sports cars may view the road surface from an angle much smaller than 1 degree. Further, it would simplify field measurements of luminance on road surfaces if the viewing angle could be set to a larger angle of, for example, 1.5 or 2 degrees without substantial error or difference in the results. For all these reasons, it is important to study the influence of the viewing angle α.

The photometer shown in Figure 6 was modified to allow an adjustment of the angle of view from α = 0.75 degrees to α = 3 degrees. Reduced reflectance coefficients were measured on three core samples, each from three different sections of Highway 401 (Sections 2, 11, and 14). Figures 12-14 show the averages from three samples of the parameters Q0, S1, and S2 plotted versus the angle α. The following observations can be made:

- In Figure 12, there is little difference in Q0 for α = 0.75 degrees and α = 1 degree, but there is a sharp drop in Q0 from α = 1 to 1.5 degrees and some further decrease toward α = 2 degrees. The total drop in Q0 is about 12 to 15 percent.
- In Figures 13 and 14 there is also a downward trend of the specularity parameter with increasing viewing angle α up to 10 percent at α = 2 degrees. All these drops in parameters appear to level off between α = 2 to 3 degrees.

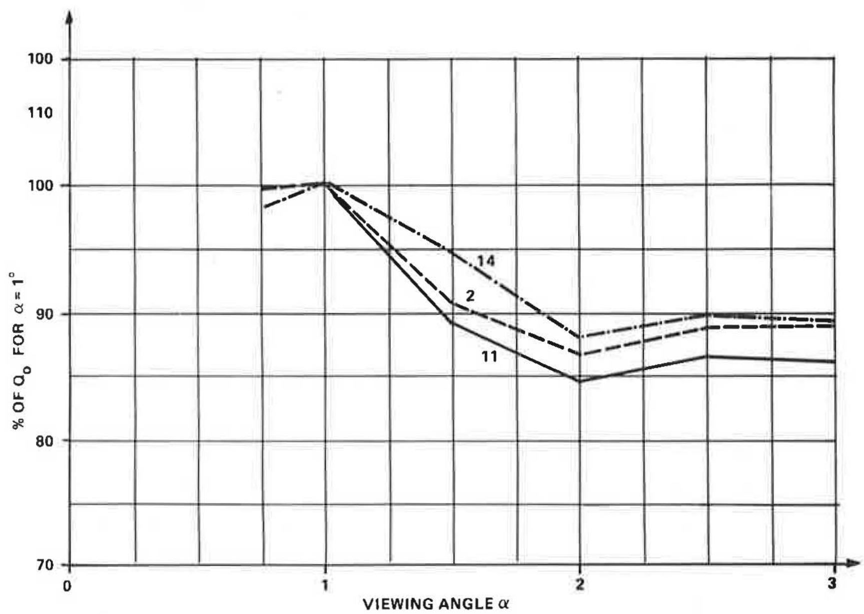

FIGURE 12 Brightness parameters Q0 versus viewing angle α.

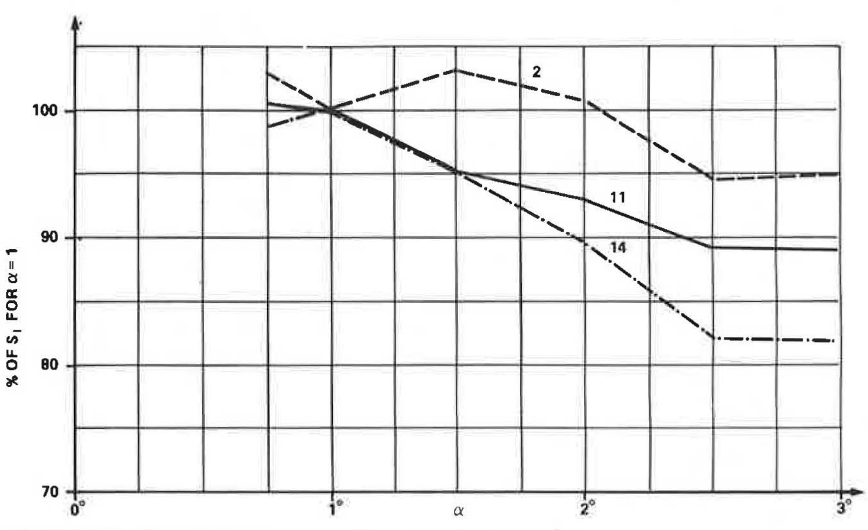

FIGURE 13 Specularity parameter S1 versus viewing angle α.

- Generally speaking, viewing angles of 2 or 3 degrees result in less specularity and less overall brightness compared with the standard 1-degree angle.

CONCLUSIONS AND RECOMMENDATIONS

It is possible to measure pavement reflectance matrices using the photometer equipment built at the University of Toronto, based on averages of three core samples of 150 mm (6 in.) diameter, and to classify most pavement types within the CIE system.

The more than 400 samples measured in Ontario represent about 100 pavement types including differences of wear under traffic, that is, counting the driving, center, and passing lanes of the same section as different types.

Reflectance parameters Q0, S1, and S2 were established for each type from matrix tables of reduced reflectance coefficients measured on at least three samples from each type. All pavement types were then classified in accordance with the CIE or IES classes R1, R2, R3, and R4; in accordance with the IES classes N1, N2, N3, and N4; and in accordance with the 240 standard surfaces in the Erbay Atlas.

Some pavement types were subjected to more measurements and to a subsequent statistical analysis in order to obtain an estimate of standard deviations for various levels of such experimental measurements. It was found that measurement procedure

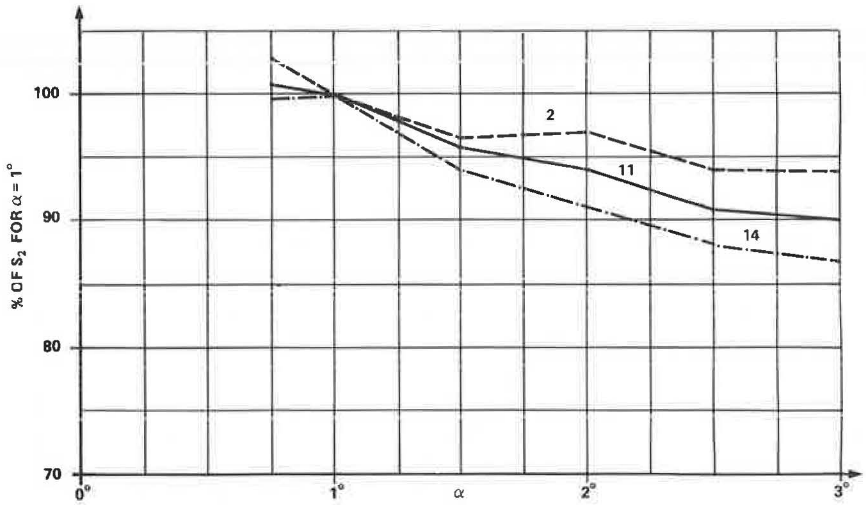

FIGURE 14 Specularity parameter S2 versus viewing angle α.

TABLE 7 Recommended Design Values for Southern Ontario

COMPOSITION	R or N CLASS	BRIGHTNESS
steel slag, open grade	R2, N3, R3	Q0 = 0.06
traprock, open grade	R3, R4	Q0 = 0.07
blend of igneous & lime, open grade	N3	Q0 = 0.09
limestone, open grade	N3	Q0 = 0.10
steel slag, dense friction course	R4 or N4	Q0 = 0.075
blast furnace slag, dense friction course	R2 or N2	Q0 = 0.075
traprock, dense friction course	R2, N3, R3	Q0 = 0.065
blend of igneous & lime, dense f.c.	R3 or N3	Q0 = 0.085
limestone, dense friction course	R2, N2, R3, N3	Q0 = 0.10
concrete limestone plain	R3 or N3 old: R4	Q0 = 0.12
concrete limestone lateral grooves	R3 or N3 old: R4	Q0 = 0.095

NOTE: The higher specularity class is valid for older pavements.

or small sample size were not critical for any kind of classification, but that variations in the surface texture of a lane or section sometimes exceed specified classification boundaries. Sometimes outside and inside wheelpath textures fall in two different classes but these were nevertheless recorded as an average in this paper.

The aforementioned classification was carried out with regard to specularity only, and the four classes, either R or N, can be regarded as sufficiently accurate for design purposes. However, the parameter Q0 should be estimated more accurately by considering the surface course composition and aggregate.

Asphalt pavements exposed to traffic become gradually brighter and more specular, which is reflected in increases of Q0 and S1 (and S2), respectively. The physical reasons are that aggregates become more exposed or cleansed of asphalt and more polished or flattened.

More specifically, with regard to the luminance method of design, the data in Table 7 are presented and can be used for the necessary input of reflectance parameters.

Some measurements were carried out with varying viewing angle α. It was found that brightness (Q0) and specularity (S1/S2) decrease somewhat with increasing α toward 1 or 2 degrees.

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Influence of Leading Vehicle Turn Signal Use on Following Vehicle Lane Choice at Signalized Intersections

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ABSTRACT

The findings of a phenomenological study of a rarely addressed subject are discussed: the degree to which turn signals are properly used at signalized intersections and the effect that nonuse has on the lane-choice behavior of subsequent through vehicles. The situation studied involved a lane drop at the far side of the intersection. Three experiments were conducted at two locations to observe the lane preferences of isolated subject vehicles and three cases of car-following. The study revealed that a considerable proportion of left turners failed to properly indicate their movement intentions and this had a significant effect on following through vehicles. Lane choice was also found to be affected by the distance to the lane drop and by the traffic signal display. On the basis of these findings additional study of this subject is recommended.

The driving task involves the response of a driver to numerous stimuli generated by the environment, the traffic control system, and other vehicles on the roadway. Cues from other vehicles are given by their location, their status, and their actions, current or impending. Because of their critical nature in terms of traffic safety, certain leading vehicle actions are accompanied by reinforcing warnings to following drivers. A prime example of this situation is the universal use of brake lights. Concerning these, Rockwell and Treiteter (1) conducted