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COMMISSION INTERNATIONALE DE L'ECLAIRAGE
INTERNATIONAL COMMISSION ON ILLUMINATION
INTERNATIONALE BELEUCHTUNGSKOMMISSION

TECHNICAL REPORT

ROAD SURFACE AND ROAD MARKING REFLECTION CHARACTERISTICS

CIE 144:2001

UDC: 535.312
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Descriptor: Regular reflection
Diffuse reflection. Scattered reflection
Street lighting
Lighting by motor vehicle lamps

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The International Commission on Illumination (CIE) is an organisation devoted to international co-operation and exchange of information among its member countries on all matters relating to the art and science of lighting. Its membership consists of the National Committees in 38 countries and one geographical area and of 8 associate members.

The objectives of the CIE are :

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2. To develop basic standards and procedures of metrology in the fields of light and lighting.
3. To provide guidance in the application of principles and procedures in the development of international and national standards in the fields of light and lighting.
4. To prepare and publish standards, reports and other publications concerned with all matters relating to the science, technology and art in the fields of light and lighting.
5. To maintain liaison and technical interaction with other international organisations concerned with matters related to the science, technology, standardisation and art in the fields of light and lighting.

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La Commission Internationale de l'Eclairage (CIE) est une organisation qui se donne pour but la coopération internationale et l'échange d'informations entre les Pays membres sur toutes les questions relatives à l'art et à la science de l'éclairage. Elle est composée de Comités Nationaux représentant 38 pays plus un territoire géographique, et de 8 membres associés.

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6. De constituer un centre d'étude international pour toute matière relevant de la science, de la technologie et de l'art de la lumière et de l'éclairage et pour l'échange entre pays d'informations dans ces domaines.
7. D'élaborer des normes et des méthodes de base pour la métrologie dans les domaines de la lumière et de l'éclairage.
8. De donner des directives pour l'application des principes et des méthodes d'élaboration de normes internationales et nationales dans les domaines de la lumière et de l'éclairage.
9. De préparer et publier des normes, rapports et autres textes, concernant toutes matières relatives à la science, la technologie et l'art dans les domaines de la lumière et de l'éclairage.
10. De maintenir une liaison et une collaboration technique avec les autres organisations internationales concernées par des sujets relatifs à la science, la technologie, la normalisation et l'art dans les domaines de la lumière et de l'éclairage.

Les travaux de la CIE sont effectués par 7 Divisions, ayant chacune environ 20 Comités Techniques. Les sujets d'études s'étendent des questions fondamentales, à tous les types d'applications de l'éclairage. Les normes et les rapports techniques élaborés par ces Divisions Internationales de la CIE sont reconnus dans le monde entier.

Tous les quatre ans, une Session plénière passe en revue le travail des Divisions et des Comités Techniques, en fait rapport et établit les projets de travaux pour l'avenir. La CIE est reconnue comme la plus haute autorité en ce qui concerne tous les aspects de la lumière et de l'éclairage. Elle occupe comme telle une position importante parmi les organisations internationales.

DIE INTERNATIONALE BELEUCHTUNGSKOMMISSION

Die Internationale Beleuchtungskommission (CIE) ist eine Organisation, die sich der internationalen Zusammenarbeit und dem Austausch von Informationen zwischen ihren Mitgliedsländern bezüglich der Kunst und Wissenschaft der Lichttechnik widmet. Die Mitgliedschaft besteht aus den Nationalen Komitees in 38 Ländern und einem geographischen Gebiet und aus 8 assoziierten Mitgliedern.

Die Ziele der CIE sind :

11. Ein internationaler Mittelpunkt für Diskussionen aller Fragen auf dem Gebiet der Wissenschaft, Technik und Kunst der Lichttechnik und für den Informationsaustausch auf diesen Gebieten zwischen den einzelnen Ländern zu sein.
12. Grundnormen und Verfahren der Meßtechnik auf dem Gebiet der Lichttechnik zu entwickeln.
13. Richtlinien für die Anwendung von Prinzipien und Vorgängen in der Entwicklung internationaler und nationaler Normen auf dem Gebiet der Lichttechnik zu erstellen.
14. Normen, Berichte und andere Publikationen zu erstellen und zu veröffentlichen, die alle Fragen auf dem Gebiet der Wissenschaft, Technik und Kunst der Lichttechnik betreffen.
15. Liaison und technische Zusammenarbeit mit anderen internationalen Organisationen zu unterhalten, die mit Fragen der Wissenschaft, Technik, Normung und Kunst auf dem Gebiet der Lichttechnik zu tun haben.

Die Arbeit der CIE wird in 7 Divisionen, jede mit etwa 20 Technischen Komitees, geleistet. Diese Arbeit betrifft Gebiete mit grundlegendem Inhalt bis zu allen Arten der Lichtanwendung. Die Normen und Technischen Berichte, die von diesen international zusammengesetzten Divisionen ausgearbeitet werden, sind von der ganzen Welt anerkannt.

Tagungen werden alle vier Jahre abgehalten, in der die Arbeiten der Divisionen überprüft und berichtet und neue Pläne für die Zukunft ausgearbeitet werden. Die CIE wird als höchste Autorität für alle Aspekte des Lichtes und der Beleuchtung angesehen. Auf diese Weise unterhält sie eine bedeutende Stellung unter den internationalen Organisationen.

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This Technical Report has been prepared by CIE Technical Committee 4-25 of Division 4 "Lighting and Signalling for Transport" and has been approved by the Board of Administration of the Commission Internationale de l'Eclairage for study and application. The document reports on current knowledge and experience within the specific field of light and lighting described, and is intended to be used by the CIE membership and other interested parties. It should be noted, however, that the status of this document is advisory and not mandatory. The latest CIE proceedings or CIE NEWS should be consulted regarding possible subsequent amendments.

Ce rapport technique a été préparé par le Comité Technique CIE 4-25 de la Division 4 "Eclairage et signalisation pour les transports" et a été approuvé par le Bureau d'Administration de la Commission Internationale de l'Eclairage, pour étude et application. Le document traite des connaissances courantes et de l'expérience dans le domaine spécifique indiqué de la lumière et de l'éclairage, et il est établi pour l'usage des membres de la CIE et autres groupements intéressés. Il faut cependant noter que ce document est indicatif et non obligatoire. Pour connaître d'éventuels amendements, consulter les plus récents comptes rendus de la CIE ou le CIE NEWS.

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ROAD SURFACE AND ROAD MARKING REFLECTION CHARACTERISTICS

SUMMARY

The purpose of this technical report is to provide the technical basis for the application of reflection characteristics of road surfaces and road markings in road lighting, daylight and vehicle headlamp illumination.

The technical report describes relevant conventions and the influence of measurement angles. For road lighting and daylight the technical report further details reflection tables, a description system, and the classification and luminance of road surfaces and road markings.

Recommendations are given for in situ measurement of characteristics relating to the lightness and the retroreflection of surfaces, some thoughts are provided for characteristics relating to the specularity of road surfaces and road markings.

PROPRIETES DE REFLEXION DES SURFACES DE CHAUSSEE ET DES MARQUES ROUTIERES

RESUME

Ce rapport technique a pour objectif de fournir les bases techniques pour l'évaluation des propriétés de réflexion des surfaces de chaussée et des marques routières sous éclairage public, sous la lumière du jour et sous l'éclairage des projecteurs de véhicules.

Ce rapport précise les conventions et l'influence des angles de mesure. En éclairage public et sous la lumière du jour, il présente les tableaux de réflexion, la méthode de description simplifiée, la classification des surfaces et le calcul de la luminance des surfaces de chaussée et des marques routières.

Des recommandations sont données pour la mesure in-situ de la clarté et de la rétro réflexion des surfaces, ainsi que quelques conseils pour la mesure de la spécularité des surfaces de chaussée et de marques routières.

REFLEXIONSEIGENSCHAFTEN VON STRASSEN OBERFLÄCHEN UND STRASSEN MARKIERUNGEN

ZUSAMMENFASSUNG

Ziel dieses technischen Berichtes ist es, die technische Grundlage für die Anwendung der Reflexionseigenschaften von Straßenoberflächen und Straßenmarkierungen bei der Straßenbeleuchtung, bei Tageslicht und bei der Beleuchtung durch Fahrzeugscheinwerfer zu liefern.

Der technische Bericht beschreibt die maßgebenden Vereinbarungen und den Einfluß der Meßwinkel. Für die Straßenbeleuchtung und für Tageslicht enthält der technische Bericht daneben Reflexionstabellen, ein Beschreibungssystem sowie die Klassifizierung und die Leuchtdichte von Straßenoberflächen und Straßenmarkierungen.

Empfehlungen für die Vor-Ort-Messung der Helligkeit und der Retroreflexionseigenschaften von Oberflächen werden gegeben und einige Überlegungen werden der Charakterisierung der Spiegelungseigenschaften von Straßenoberflächen und Straßenmarkierungen gewidmet.

1. INTRODUCTION

The reflection characteristics of road surfaces relate to the lightness (degree of whiteness or blackness) and the specularity (shininess) of the surface. The reflection characteristics are equally relevant for roadway markings and for daylight illumination. Current usage of the reflection characteristics of road surfaces is based primarily on laboratory measurements carried out during the 60's and 70's on samples of road paving.

Although the reflection characteristics are simple to define, they are difficult to measure in situ. Neither portable nor vehicle mounted equipment has been developed for widespread use. One of the tasks of CIE TC 4-25 has been to reconsider the conventions with respect to reflection characteristics and to consider modifying them so as to make in situ measurement more practical.

The lightness of the road surface has so far been represented by the average luminance coefficient Q_0 which, however, has turned out to be difficult to measure as well in laboratory as in situ conditions. Therefore, this report introduces the luminance coefficient in diffuse illumination Q_d , which is easier to measure, as an alternative to Q_0 . The report accounts for the relationship between the two parameters. Q_d was developed for road markings, but is equally relevant for road surfaces in general. For in situ measurements recommendations have been developed which include a standard measurement geometry. These recommendations agree with some of the standards which are being applied and equipment for such in situ measurement is available.

The specularity of the roadway surface is represented by the specular factor S_1 , which has turned out to be difficult to measure, at least for in situ conditions. No substitute or alternative has been found, however, for S_1 . That is an unfortunate result as specularity influences the uniformities of the road surface luminance in roadway lighting, as well as the contrast and visibility of road markings in some conditions and the road surface luminance in tunnel lighting if the counter beam technique is used.

It has been recognized by TC 4-25 that further knowledge of reflection properties is needed over a larger range of geometrical situations for purposes such as visualization of roadway scenes and the calculation of reflected illumination. This has been an additional task of CIE TC 4-25. A mathematical approach based on the facet model of reflection had seemed promising but measurement data are not available for the completion and testing of the model. The facet model is not included here or described.

The final task of CIE TC 4-25 has been to describe the reflection characteristics of road surfaces and road markings in vehicle headlamp illumination. The reflection characteristic is the coefficient of retroreflected headlamp illumination. For the driver's own headlamps the variation with the measurement angles is relatively simple to describe. For the opposing headlamps the variation with the measurement angles is complex and is not described except in general terms. Some indications are given as to in situ measurements.

An important issue is that the standard measurement geometries for Q_d and R_L include an observation angle of $2,29^\circ$ which disagrees with the value of 1° for traditional use in laboratory measurements for road lighting. It is recommended that both values be used for the time being and that the value of $2,29^\circ$ be adopted in the future.

Suitable methods for in situ measurements are described in Annex A.

2. ROAD LIGHTING AND DAYLIGHT

2.1 Conventions

The luminance coefficient q of a surface element on a roadway surface is the quotient of the luminance L of the field in the given direction by the illuminance E on the field. The unit is $\text{cd}\cdot\text{m}^{-2}\cdot\text{lx}^{-1}$.

The luminance coefficient, when measured for a single light source, depends on the surface and the geometry of illumination and observation as described by the three angles shown in Fig. 2.1.

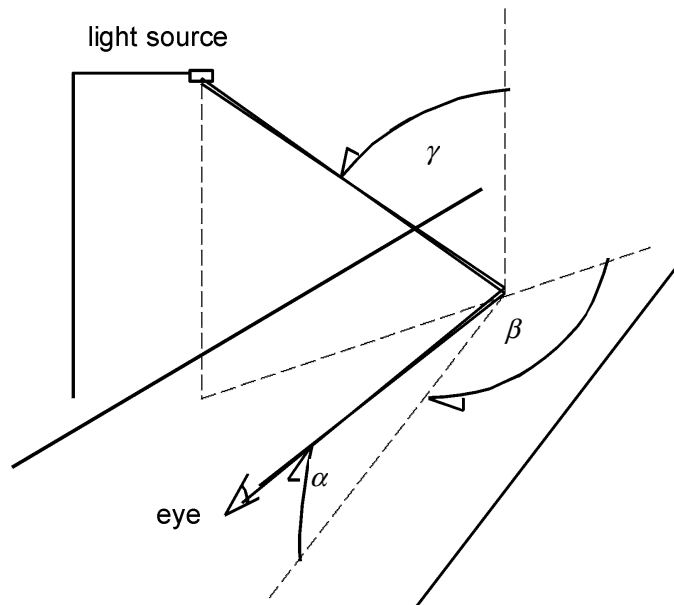


Fig. 2.1 Angles used to describe the geometry of illumination and observation in road lighting and daylight:

α : angle of observation measured between the direction of observation and the horizontal plane;

β : azimuth angle measured between the two vertical planes containing the directions of illumination and observation;

γ : angle of incidence measured from the vertical to the direction of illumination.

Note: A full description of the geometry requires an additional, fourth angle δ , measured as a rotation of the direction of observation around the vertical, bringing this direction away from the direction of the road. This angle, however, is considered as not influencing the value of the luminance coefficient and is normally set to 0° during measurement.

2.2 Influence of measurement angles

The angle γ varies in the range from 0° up close to 90° , while β is relevant from -180° to 180° . Generally q is considered to be independent of the sign of β , its interesting range therefore is from 0° to 180° .

All surfaces show a feature called specular reflection, which is caused by mirror reflection in the glossy surfaces of facets in the texture. This type of reflection provides large q values in a small angular range. It is indicated by a strong increase in the value of q , when γ increases and β is close to 0° . Some explanation is given in Fig. 2.2.

In the remaining part of the angular range, a diffuse type of reflection from the texture dominates, leading to roughly constant q values. However, there is a gradual increase in q , when γ increases and β is about 180° . The reason is simply that the illumination direction gets closer to the observation direction, so that those facets in the texture that are unobstructed for the observer are simultaneously unobstructed for illumination.

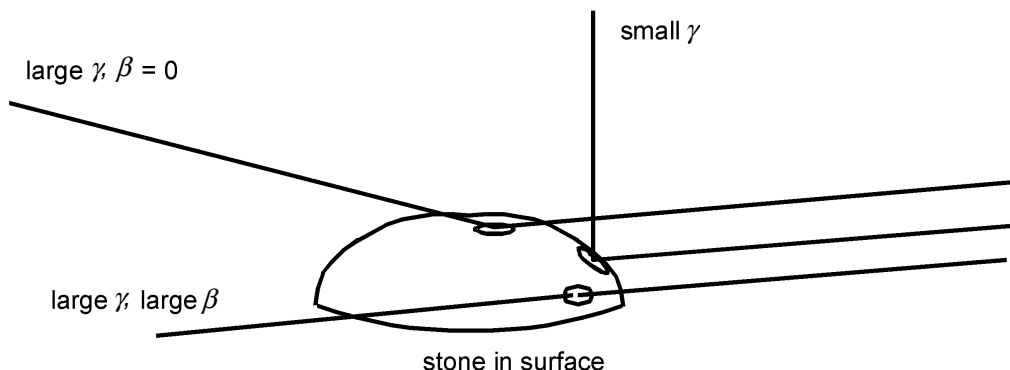


Fig. 2.2 Specular reflection is strong when the angle of incidence γ is large and the azimuth angle β is about 0° because:

- 1) reflection occurs through a small angle, where the reflectance of glossy surfaces is large;
- 2) reflection occurs on the top of stones, where a relatively large area is available.

This is related to retroreflection and is not as strong as specular reflection in the geometrical conditions of interest in road lighting or daylight. For headlamp illumination it is a significant feature. See section 3.2.

For car driving the observation angle α in the range from $0,5^\circ$ to 2° is of interest. In this range, the value of q does not change significantly with α according to de Boer, Onate and Oostrijk (1952). Measurements have traditionally been done at $\alpha = 1^\circ$.

It is necessary to consider the q values in an extended range of α to allow the calculation of road surface luminance at larger α values for various purposes, such as the visualization of road scenes. Extension to the full range from 0° to 90° would allow calculation of reflected illumination of for instance objects in tunnel lighting.

2.3 Reflection tables

Reflection tables provide q values for certain angle ranges.

Usually, the observation angle α is fixed at 1° so that the tabulation is for ranges of the angles β and γ . Table 2.1 shows the standard format, which is adopted by most computer programs for the design of road lighting installations.

The standard format contains values of the reduced luminance coefficient r defined as $q \cdot \cos^3 \gamma$. For convenience, values in the table have been multiplied by 10 000. Steps are arranged according to $\tan \gamma$ instead of γ directly.

Tables in the standard format providing r values are often called r -tables. For storing in files and transfer electronically, the standard file format shown in Table 2.2 is used.

Table 2.1 Standard format for r -tables. Values are $r = q \cdot \cos^3 \gamma$ multiplied by 10 000.

	$\beta(^{\circ})$																				
tg γ	0	2	5	10	15	20	25	30	35	40	45	60	75	90	105	120	135	150	165	180	
0	474	474	474	474	474	474	474	474	474	474	474	474	474	474	474	474	474	474	474	474	
0.25	472	471	471	470	470	468	466	464	463	459	456	450	443	439	435	434	434	435	436	436	
0.5	427	426	426	423	418	413	408	399	390	382	375	359	347	343	341	344	348	352	353	356	
0.75	374	372	370	361	349	336	322	309	297	285	275	255	245	244	245	253	256	262	265	268	
1	326	323	319	303	284	263	243	227	213	202	193	177	170	170	174	180	186	192	196	199	
1.25	284	281	275	251	224	198	176	161	149	139	132	121	117	119	123	129	135	141	145	147	
1.5	249	246	235	203	172	146	127	113	104	97	92	84	83	85	89	94	99	105	108	110	
1.75	219	216	201	162	129	106	91	81	73	68	64	60	59	62	65	70	74	79	82	84	
2	194	190	171	129	97	78	65	57	53	49	46	44	44	46	49	53	57	61	64	65	
2.5	157	150	124	82	57	44	37	32	30	28	27	26	26	28	30	33	37	40	42	43	
3	130	120	90	52	35	26	22	19	18	17	17	16	17	18	20	22	24	27	28	29	
3.5	110	98	65	34	22	16	14	13	12	11	11	11	11	12	14	16	18	19	21	21	
4	94	80	48	23	15	11	9	9	8	8	8	8	8	9	10	12	13	15	16	16	
4.5	80	65	36	17	10	8	7	6	6	6	6	6	6	7	8	9	10	11	12	13	
5	70	55	28	12	8	6	5	5	4	4	4	4	5	5	6	7	8	9	10	10	
5.5	61	46	22	9	6	4	4	4	3	3											
6	54	39	18	7	5	4	3	3	3	3											
6.5	48	34	14	6	4	3	2	2													
7	43	30	12	5	3	2	2	2													
7.5	39	27	10	4	2	2	2														
8	36	23	9	3	2	2	1														
8.5	33	21	7	3	2	1	1	1													
9	30	18	6	2	1	1	1														
9.5	28	17	5	2	1	1	1														
10	26	16	5	2	1	1	1														
10.5	25	14	4	1	1	0															
11	23	13	4	1	1	0															
11.5	22	12	3	1	1																
12	21	12	3	1	1																

Table 2.2 Standard file format of *r*-tables.

999,562 N2 (DRY), Q0(DRY)= 0,07, (FILE=N2C30)																
29																
474	472	427	374	326	284	249	219	194	157	130	110	94	80	70	61	54
48	43	39	36	33	30	28	26	25	23	22	21					
29																
474	471	426	372	323	281	246	216	190	150	120	98	80	65	55	46	39
34	30	27	23	21	18	17	16	14	13	12	12					
.																
.																
.																
.																
15																
474	435	352	262	192	141	105	79	61	40	27	19	15	11	9		
15																
474	436	353	265	196	145	108	82	64	42	28	21	16	12	10		
15																
474	436	356	268	199	147	110	84	65	43	29	21	16	13	10		

Note: The file is a text file with:

- an initial line containing a reference identification number for the table and perhaps additional description of the table;
- maximum three lines for each column of the standard *r*-table format, where the first line contains the number of values in the column, the second line contains the first 17 values of the column and the third line contains the last 12 values of the column;
- values are integers using four characters per value.

The standard format of the *r*-table covers a certain field of the surface below a single light source, see Fig. 2.3. This field may be considered to extend a distance of $4 \cdot h$ from the light source onwards in the direction of travel (away from the observer), a distance of $12 \cdot h$ from the light source in the opposite direction (towards the observer) and $\pm 3 \cdot h$ in the transverse direction, where h is the mounting height of the light source above the surface. The tables are intended primarily for design calculations of road lighting installations.

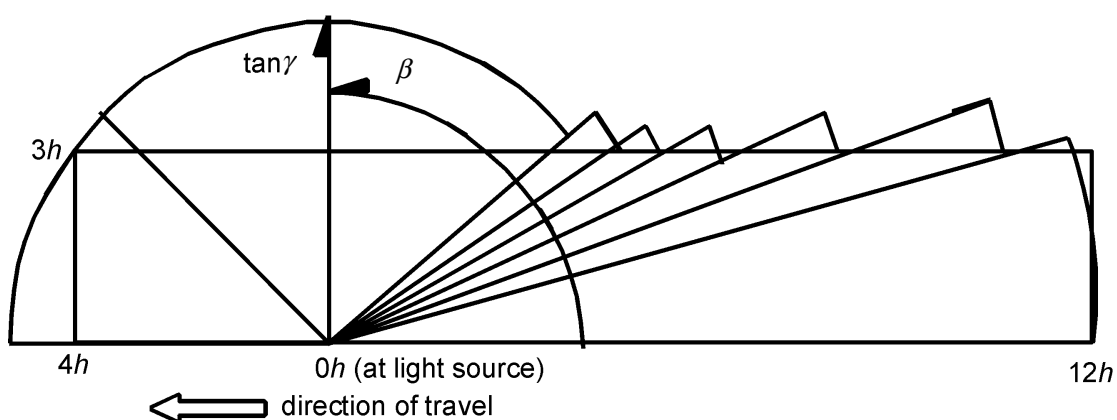


Fig. 2.3 A: Coverage of the *r*-table seen from above. The format of the *r*-table defines a field confined by sections of circles, but for road lighting purposes the coverage is defined as a rectangular field which, except at a few corners, is enclosed within the above-mentioned field (see text).