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TECHNICAL REPORT

DESIGN METHODS FOR LIGHTING OF ROADS

CIE 132 - 1999

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CIE 132-1999

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DESIGN METHODS FOR LIGHTING OF ROADS

SUMMARY

Several recommendations and technical reports have been published over the past years by the CIE to provide calculation methods for designing road lighting installations, which satisfy certain quality criteria. These quality criteria are intended to ensure the safety, comfort and personal security of road users. These documents are often referred to in the national codes and recommendations of industrialised countries. The calculation methods necessitate the use of a computer.

Experience shows that the high degree of accuracy obtained with the recommended methods of calculation is not always necessary, at least during the first stage of design. In some countries simplified methods have been developed which show similarities. They do not require a computer for application by the user.

The aim of this report is to describe these and similar design methods for lighting installations for all categories of roads. The method to be used depends on the required accuracy and the type of data available to the designer.

METHODES POUR L'ETUDE D'ECLAIRAGE ROUTIER

RESUME

Au cours des dernières années la CIE a publié plusieurs recommandations et rapports techniques fournissant des méthodes de calcul pour l'étude d'installations d'éclairage routier qui remplissent certains critères de qualité. Ces critères de qualité sont destinés à assurer la sûreté, le confort et la sécurité des usagers de la route. Souvent les codes et recommandations nationaux dans les pays industrialisés se réfèrent à ces documents. Ces méthodes de calcul exigent l'usage d'un ordinateur.

L'expérience a montré que le haut degré de précision obtenu avec les méthodes recommandées n'est pas toujours nécessaire, du moins pendant la première phase de l'étude. Certains pays ont développé des méthodes simplifiées, mais similaires, qui ne nécessitent pas l'usage d'un ordinateur.

Le but de ce rapport est de décrire ces méthodes pour l'étude des installations d'éclairage pour toutes les catégories de routes. La méthode à utiliser dépend de la précision requise et du type des données disponibles.

PLANUNGSVERFAHREN FÜR DIE STRASSENBELEUCHTUNG

ZUSAMMENFASSUNG

In den vergangenen Jahren sind von der CIE mehrere Empfehlungen und Technische Berichte herausgegeben worden, in denen Berechnungsverfahren bereitgestellt werden zur Planung von Straßenbeleuchtungsanlagen, die bestimmte Gütemerkmale erfüllen. Diese Gütemerkmale dienen zur Erfüllung der Anforderungen der Straßennutzer nach Sicherheit, Beeinträchtigungsfreiheit und persönlichem Schutz.

Häufig wird in nationalen Normen und Empfehlungen industrialisierter Länder auf diese Veröffentlichungen Bezug genommen. Die Berechnungsverfahren erfordern den Einsatz von Computern.

Die Erfahrung zeigt allerdings, daß die mit den empfohlenen Berechnungsverfahren erreichbare hohe Genauigkeit nicht immer erforderlich ist, zumindest nicht in einer frühen Planungsphase. In einigen Ländern sind daher vereinfachte Verfahren entwickelt worden, die zum Teil große Ähnlichkeiten aufweisen. Die Anwendung dieser Verfahren erfordert keinen Einsatz von Computern durch den Nutzer. Ziel dieses Berichts ist es, diese und ähnliche Verfahren für die Beleuchtungsplanung von Straßen aller Art zu beschreiben. Welches dieser Verfahren jeweils Anwendung finden sollte, hängt von der erforderlichen Genauigkeit und von den dem Planer zur Verfügung stehenden Daten ab.

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SCOPE OF THIS REPORT

Several recommendations and technical reports have been published over the past years by the CIE to provide calculation methods for designing road lighting installations, which satisfy certain quality criteria. These quality criteria are intended to ensure the safety, comfort and personal security of road users. These documents are often referred to in the national codes and recommendations of industrialised countries. The calculation methods necessitate the use of a computer.

Experience shows that the high degree of accuracy obtained with the recommended methods of calculation is not always necessary, at least during the first stage of design. In some countries simplified methods have been developed which show similarities. They do not require a computer for application by the user.

The aim of this report is to describe these and similar design methods for lighting installations for all categories of roads. The method to be used depends on the required accuracy and the type of data available to the designer.

Most of the described methods only apply to straight sections of roads with continuous lighting. Some methods allow to investigate the effect of one luminaire only. Some methods allow for the design for curved road sections.

The use of computers has a drawback; the designer may lose contact with the basics of the profession. This report can therefore also be used for educational purposes and as a reminder.

This report consists of 7 sections:

- 1 - A short introduction to the quality criteria for public lighting.
- 2 - The calculation principles for the quality criteria.
- 3 - A survey of the necessary photometric data and recommendations for their format.
- 4 - Design methods based on photometric data.
- 5 - Simple but accurate design methods.
- 6 - Approximate design methods.
- 7 - Maintenance and design.

This report provides tools for determining a number of technically possible solutions, which then can be analysed regarding the economic consequences.

Remark 1

In some countries the design criteria also include the wet condition of the road surface. These conditions are not considered in this report. For wet conditions see [0.1].

Remark 2

Some of the values of the standard r -tables C1 and C2, as published in this report, differ from earlier publications (see for instance [3.2]). These differences are partly due to obvious typing errors in earlier publications and partly to misinterpretation of the basic data. The corrections are made based on the tables published in [0.2]

1. INTRODUCTION

1.1 Quality criteria for road lighting

Road lighting must provide safety, comfort and personal security to any road user. In particular the road user must be able to see the lay-out of the road, locate and recognize any special signs and obstacles with certainty and in time.

The aims of road lighting, the principles of night vision, the requirements of night driving etc. are dealt with in CIE 115 - 1995 [1.1]. This gives the fundamental quality criteria for good road lighting practice.

For the lighting of roads for motor traffic, these are:

- average luminance;
- luminance uniformity;
- limitation of glare;

- lighting of the surrounds (surround ratio);
- optical guidance.

For typical pedestrian areas these are:

- average illuminance;
- minimum illuminance.

The methods considered in this document give various solutions for the determination of illuminance values, luminance values and glare limitation.

1.2 Recommendations for lighting of roads for motor traffic

For complete information refer to [1.1]. This section will only summarize the recommendations. The recommended lighting classes are selected according to the status of the road as is shown in table 1.1. The photometric requirements for the recommended lighting classes are summarized in table 1.2.

1.2.1 Average luminance

The luminance level, described by the average luminance of the road surface and its immediate surrounds determine to a great extent the state of adaptation of the road users eye. Therefore the average luminance is of utmost importance for the ability to see and thus it is in the first place related to traffic safety. It is also related to the comfort of the road user.

1.2.2 Luminance uniformity

The second quality criterion is that of luminance uniformity. This criterion is both related to traffic safety and to comfort:

- Too dark areas on the road surface may conceal possible obstacles.
- A repetition of darker and brighter areas causes continuous changes in adaptation level, which causes fatigue and is uncomfortable.

To describe the uniformity of the luminance pattern, two ratios, are used:

- the overall uniformity $U_0 = L_{\min}/L_{\text{av}}$
in which $L_{\min}$ and L_{av} represent the lowest and the average value of the luminance of the considered road section, respectively;
- the longitudinal uniformity $U_1 = (L_{\min}/L_{\max})_{\text{long}}$
where $L_{\min}$ and $L_{\max}$ are the lowest and the highest value of the luminance on the centre line of a driving lane, respectively.

1.2.3 Glare

Glare is caused by the presence of bright sources (luminaires) in the field of view of the observer. Glare is experienced in the form of:

- Discomfort, referred to as discomfort glare.
The unpleasant sensation of the presence of bright spots in the field of view, not necessarily impairing vision.
Discomfort glare is a subjective criterion.
In [1.1] discomfort glare is not considered as a quality criterion for the lighting of roads. For this reason discomfort glare will not be considered in this report.
- Reduced visibility, referred to as disability glare.
It is the effect of impaired vision due to the presence of light sources in the field of view. These sources cause stray light in the eye, which is superimposed to the image on the retina. The result is a reduction in contrast of the image so that the ability to see low contrasts and/or small objects is reduced. Therefore disability glare is directly related to road safety.
Disability glare is an objective measurable quantity.
The measure of disability glare is TI (Threshold increment).

1.2.4 The surround ratio

The surround ratio is defined as the ratio of the average illuminance on strips, 5 m wide (or less if space does not permit) adjacent to the edges of the carriageway to the average illuminance

on the strips, 5 m wide (or half the width of the carriageway, whichever is the smaller) in the carriageway. For dual carriageways, both carriageways together are treated as a single carriageway unless they are separated by more than 10 m.

The principal aim of lighting the direct surrounds of the road is to make tall objects visible against the surrounds.

1.2.5 Optical guidance

Optical guidance is an important quality criterion for traffic safety. Good optical guidance is achieved when the row of luminaires give a clear and non-misleading indication of the course of the road. No rules based on light-technical quantities can be given for the design of a road lighting installation that will provide good optical guidance. One or more perspective drawing(s), accurate to scale, can reveal possible problems. For complicated situations (junctions), model studies are necessary. Poor optical guidance is a potential danger!

1.3 Recommendations for lighting for pedestrian traffic

In areas where pedestrians, cyclists and other slow moving traffic prevail, the lighting requirements differ from those for fast motorized traffic.

The road users here must see small obstacles and be able to orient themselves. Even more important is their personal security. The surround mostly forms a complex visual scene and the road users have no fixed viewing direction. This makes it impossible to make valuable predictions of the luminances of the scene. For this reason only recommendations for illuminance values can be given.

Also here lighting classes based on the different road types in pedestrian areas are used. See table 1.3 and 1.4 for the lighting classes and relevant lighting requirements.

Table 1.1 Lighting classes for different road types.

DESCRIPTION OF ROAD	LIGHTING CLASS
High speed roads with separate carriageways, free of crossings at grade and with complete access control: motorways, express roads. Traffic density and complexity of road layout (<i>Note 1</i>): High Medium Low	M1 M2 M3
High speed roads, dual carriageway roads. Traffic control (<i>Note 2</i>) and separation (<i>Note 3</i>) of different types of road user (<i>Note 4</i>): Poor Good	M1 M2
Important urban traffic routes, radial roads, district distributor roads. Traffic control and separation of different types of road user: Poor Good	M2 M3
Connecting less important roads, local distributor roads, residential major access roads. Roads providing direct access to property and lead to connecting roads. Traffic control and separation of different types of road user: Poor Good	M4 M5

Note 1 Complexity of road layout refers to infrastructure, traffic movements and visual surrounds.

Factors, which should be considered, are:

- number of lanes, inclines;
- signs and signals.

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Entrance and exit ramps, merging traffic, gores etc, the presence of which should also be considered, are dealt with in chapter 8 of CIE 115 - 1995, The lighting of conflict areas.

Note 2 *Traffic control* refers to the presence of signals and signs, and the existence of regulations.

Methods of control are:

traffic lights, priority rules, priority regulations and signs, traffic signs, directional signs and road markings.

Where these are absent or sparse the traffic control is regarded as poor and vice versa.

Note 3 *Separation* may be by means of dedicated lanes or by the restriction of use to one or more of the traffic types. The lower grade of lighting can be considered as appropriate when this separation exists.

Note 4 *Different types of road user* are, for example, motor cars, trucks, slow vehicles, buses, pedal cyclists and pedestrians.

Table 1.2 Lighting requirements for motorized traffic.

LIGHTING CLASS	EXTENT OF APPLICATION				
	All roads	All roads	All roads	Roads with few or no intersections	Roads with footways not lit to classes P1 to P4 (see table 1.4)
	L_{av} (cd/m ²) Minimum Maintained	U_0 Minimum	TI (%) Maximum Initial	U_1 Minimum	SR Minimum
M1	2,0	0,4	10	0,7	0,5
M2	1,5	0,4	10	0,7	0,5
M3	1,0	0,4	10	0,5	0,5
M4	0,75	0,4	15	NR	NR
M5	0,5	0,4	15	NR	NR

Note: See the definition of TI in Section 2.2.1.

Table 1.3 Lighting Classes for different road types in pedestrian areas.

DESCRIPTION OF ROAD	LIGHTING CLASS
High prestige roads	P1
Heavy night-time use by pedestrians or pedal cyclists	P2
Moderate night-time use by pedal cyclists or pedestrians	P3
Minor night-time use by pedal cyclists or pedestrians solely associated with adjacent properties	P4
Minor night-time use by pedal cyclists or pedestrians solely associated with adjacent properties Important to preserve village or architectural character of environment	P5
Very minor night-time use by pedal cyclists or pedestrians solely associated with adjacent properties Important to preserve village or architectural character of environment	P6
Roads where only visual guidance provided by the direct light from the luminaires is required	P7

Note: Classes P5, P6 and P7 should be used only where the crime risk is negligible.

Table 1.4 Lighting requirements for pedestrian traffic.

LIGHTING CLASS	HORIZONTAL ILLUMINANCE (lx) on whole of used surface Maintained	
	AVERAGE	MINIMUM
P1	20	7,5
P2	10	3
P3	7,5	1,5
P4	5	1
P5	3	0,6
P6	1,5	0,2
P7	Not applicable	Not applicable

2. CALCULATION PRINCIPLES

2.1 Calculation of illuminance and luminance

In fig. 2.1, the geometry of a luminaire A that is illuminating the point P at the road surface is given. This point is observed by the observer O.

If the luminous intensity of the luminaire in the direction of P is given by $I(C, \gamma)$, then the horizontal illuminance at P follows from:

$$E_{\text{hor},P} = \frac{I(C, \gamma) \cdot (\cos \gamma)^3}{h^2} \quad (2.1)$$

and the luminance at P is proportional to $E_{\text{hor},P}$:

$$L_P = q(\beta, \gamma) \cdot E_{\text{hor},P} \quad (2.2)$$

or:

$$L_P = \frac{q(\beta, \gamma) \cdot (\cos \gamma)^3 \cdot I(C, \gamma)}{h^2} \quad (2.3)$$

with:

- β, C and γ the angles defined according to fig. 2.1;
- h the mounting height in m;
- $q(\beta, \gamma)$ the luminance coefficient defined as the ratio $L_P/E_{\text{hor},P}$ for the direction (β, γ)

These formulae form the basis of all illuminance and luminance calculations. They require the knowledge of the luminous intensity distribution of the luminaire, the values of the luminance coefficient of the actual road surface for all relevant directions and the geometry of the installation.

The total illuminance or luminance at P is found by adding the contributions of all relevant luminaires.

The distribution of the illuminance or luminance is found by carrying out these calculations for a number of points.

These calculations, though simple in principle, are very time consuming and therefore computer programs have been published by the CIE [2.1].

2.2 Calculation of glare

Many investigations have been performed to relate the effect of glare to the photometric and geometric characteristics of the lighting installation. The method applicable for road lighting, as adopted by the CIE will be summarized in the next section.

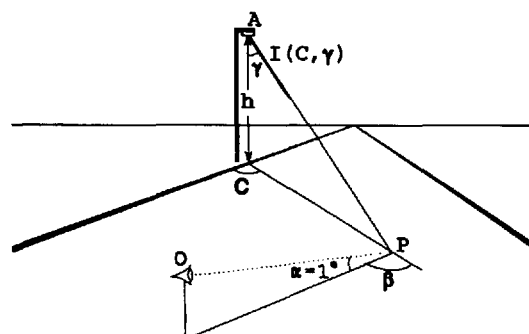


Fig. 2.1 Lighting geometry.

2.2.1 Calculation of disability glare

Disability glare is evaluated in two steps.

The first step is to calculate the stray light in the eye that reduces the contrast in the images on the retina. This stray light is described by an equivalent uniform luminance, L_v on the retina.

The second step is to calculate the necessary increase of the contrast to restore vision under threshold conditions (these are the conditions on the borderline between seeing and not seeing). This increase is called the threshold increment TI .

Step 1: Calculation of L_v

According to Holladay [2.2] and others, L_v can be expressed by:

$$L_v = \frac{K \cdot E_{gl}}{\theta^2} \quad (2.4)$$

with:

- L_v the equivalent veiling luminance in cd/m^2 ;
- K a constant;
For practical purposes $K = 10$ when θ is expressed in degree or equal to 0.003 when θ is expressed in radian. K is amongst others dependent on the age of the observer.
- E_{gl} the illuminance in lux on the observer's eye in the plane perpendicular to the line of sight, produced by the glare source;
- θ the angle (in degree or radian) between the line through the eye and the centre of the glare source and the line of sight. See fig. 2.2.
The exponent of θ is valid from about $1,5^\circ$ to 60° (or 0,025 to 1,00 radian). To ensure that this angle never falls shorter than the lower limit, the viewing direction of the observer should be chosen in a plane parallel to the road axis and directed 1° downward from the horizontal. This coincides with the standardized observation geometry for average luminance measurements. For smaller angles the exponent of θ differs considerably.

For a complete lighting installation, the individual equivalent veiling luminance L_{vi} have to be added as follows:

$$L_{v,\text{total}} = \sum L_{vi} \quad (2.5)$$

for all the relevant luminaires.

All glare calculations are performed with the observation point placed at one quarter of the road width from the right (left in case of left hand traffic) side of the road.

It is assumed that the screening angle of a car roof is 20° with the line of sight (or 19° with the horizontal). This means that luminaires placed above the inclined plane in fig. 2.2 are not included in the glare calculations.

It is necessary to calculate the value of L_v for a number of observer positions relative to the first luminaire in the field of view. The maximum value of L_v thus found has to be used in the calculation of TI .

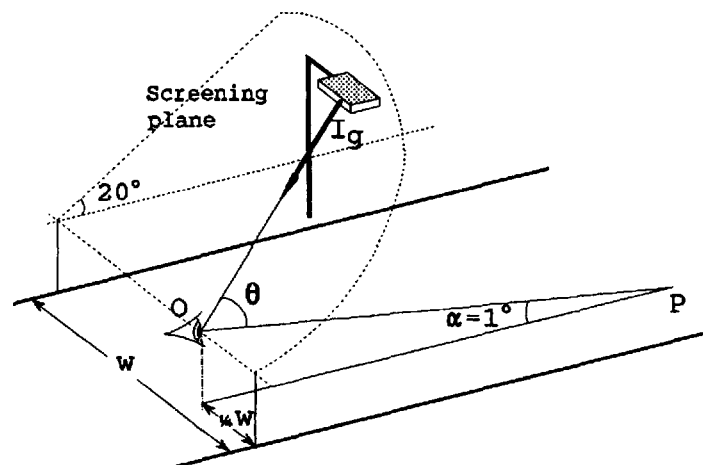


Fig. 2.2 Symbols used for disability glare calculation.

Step 2: Calculation of Tl

The threshold increment Tl is not only dependent on the veiling luminance, it also depends on the adaptation condition of the eye and thus on the value of the average road surface luminance.

Tl can be calculated in good approximation by the formula:

$$Tl = 65 \cdot \frac{L_{v,\text{total}}}{L_{\text{av}}^{0,8}} \quad (2.6)$$

with:

Tl the threshold increment in %;
 $L_{v,\text{total}}$ the veiling luminance in cd/m^2 ;
 L_{av} the average road surface luminance in cd/m^2 .

The calculation is to be made for a clean luminaire with a lamp emitting the initial luminous flux (Initial values).

This formula is valid for an object subtending $8'$ of arc (equivalent with a disk of 23 cm diameter seen at a distance of 100m) within the range $0,05 \leq L_{\text{av}} \leq 5 \text{ cd/m}^2$. Values of Tl less than 2% can be neglected.

3. PHOTOMETRIC DATA**3.1 I -tables**

As shown in section 2.1, the luminous intensity distribution of the luminaire is part of the basic data needed for installation performance calculations. These data should be given in the format of table 3.1 so as to be compatible with the computer programs published in [2.1]. The symbols used in table 3.1 are explained in fig. 3.1.

Table 3.1 I -table for road lighting luminaire.

$\gamma =$	$C =$															
	270°	285°	300°	310°	←(5° steps)→	50°	60°	75°	90°	105°	120°	130°	←5° (steps)→	230°	240°	255°
0°	x	x	x	x		x	x	x	x	x	x	x		x	x	x
↑																
10° steps																
↓																
30°	x	x	x	x		x	x	x	x	x	x	x		x	x	x
↑																
5° steps																
↓																
45°	x	x	x	x		x	x	x	x	x	x	x		x	x	x
↑																
2.5° steps																
↓																
105°	x	x	x	x		x	x	x	x	x	x	x		x	x	x
↑																
15° steps																
↓																
180°	x	x	x	x		x	x	x	x	x	x	x		x	x	x

3.2 *r*-tables

In section 2.1 it is shown that the luminance at the point P, as perceived by the observer O (fig. 2.1) is proportional to the horizontal illuminance at P:

$$L_P = q(\beta, \gamma) \cdot E_{\text{hor}, P} \quad (3.1)$$

where

$q(\beta, \gamma)$ is the luminance coefficient in $\text{cd}/(\text{m}^2 \cdot \text{lux})$.

q is to a large extent dependent upon the angle of light incidence (γ) and the angle between the vertical planes containing the directions of incident light and observation

(β), respectively. As the influence of the angle of observation (α) is relatively small, q can be considered as a function of β and γ only. This function however differs from road surface to road surface and must in principle be determined for every individual road surface!

In the formula 2.3 the product $q(\beta, \gamma) \cdot (\cos \gamma)^3$ appears. This product, "the reduced luminance coefficient", $r(\beta, \gamma)$ is the established quantity in which the road surface reflection properties are expressed.

For use with the computer programs listed in [2.1] the reduced luminance coefficient must be given in the format of table 3.2.

Table 3.2 Table of reduced luminance coefficients (*r*-table). The table contains values of $r \cdot 10^4$.

β : $\text{tg} \gamma$	0	2	5	10	15	20	25	30	35	40	45	60	75	90	105	120	135	150	165	180
0	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
0,25	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
0,5	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
0,75	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
1	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
1,25	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
1,5	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
1,75	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
2	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
2,5	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
3	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
3,5	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
4	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
4,5	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
5	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
5,5	x	x	x	x	x	x	x	x	x	x										
6	x	x	x	x	x	x	x	x	x											
6,5	x	x	x	x	x	x	x	x												
7	x	x	x	x	x	x	x													
7,5	x	x	x	x	x	x														
8	x	x	x	x	x															
8,5	x	x	x	x																
9	x	x	x																	
9,5	x	x																		
10	x																			
10,5	x																			
11	x																			
11,5	x																			
12	x																			

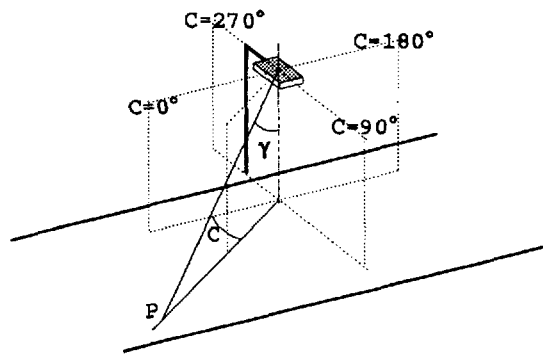


Fig. 3.1 Definition of the angles C and γ

3.3 Derived photometric data

A number of diagrams and tables can be derived from the photometric data for the luminaire and the road surface. They enable different simplified design methods. These diagrams and tables can be calculated by the user himself, provided that the luminaire manufacturer provides the luminaire photometric data in accordance with [2.1] and the user has both a computer and a specific computer program available. In many cases however, the luminaire manufacturer provides these diagram and tables not as standard documentation with their luminaires.

Some of these diagrams or tables are:

- isocandela diagrams;
- isolux diagrams;
- utilization factor curves;
- iso- r diagrams;
- isoluminance diagrams;
- luminance yield factor diagrams;
- luminaire performance tables.

The last four types of data require the knowledge of road surface reflection data. Therefore a last but very important means to simplify road lighting design is the:

Road surface classification.

The following sections will discuss the derived photometric data mentioned here and their application will be shown in chapter 4.

3.3.1 Polar diagram

Usually the luminous intensity distributions of luminaires are presented in the form of polar diagrams. In these diagrams, the luminous intensity distribution is given in a number of C -planes. Most commonly used are the planes:

- (▲) $C_{0^\circ-180^\circ}$
- (●) $C_{90^\circ-270^\circ}$
- (■) The C -plane which contains the maximum luminous intensity.

The diagrams are generally normalized for a luminous flux of the lamp(s) of 1000 lm. An example is given in fig. 3.2.

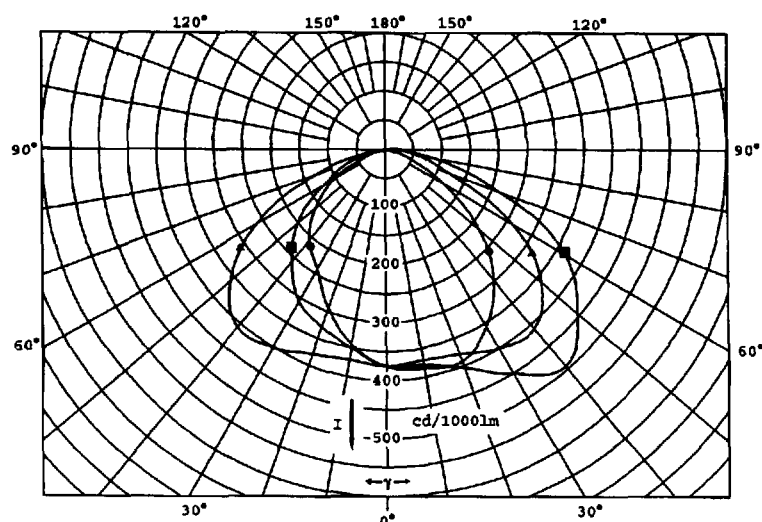


Fig. 3.2 Polar diagram.

3.3.2 Relative isocandela diagram in azimuthal projection

A possible way of plotting a luminous intensity distribution is by drawing lines of equal luminous intensity on the surface of a sphere with the luminaire in its centre. Each point on this sphere corresponds to one combination of C and γ . In such a point the luminous intensity can be indicated. The lines that connect the points with equal luminous intensity are isocandela lines.

The disadvantage of such a representation is the fact that it is three-dimensional. It is however possible to transform the spherical surface with the isocandela lines onto a flat surface. This is done in such a way that:

- Equal areas in the diagram represent equal solid angles.
- Straight lines parallel to the road axis are in the diagram represented by straight lines through its centre.

Generally, the values of the luminous intensity are expressed as a percentage of the maximum intensity. An example is given in fig.3.3.

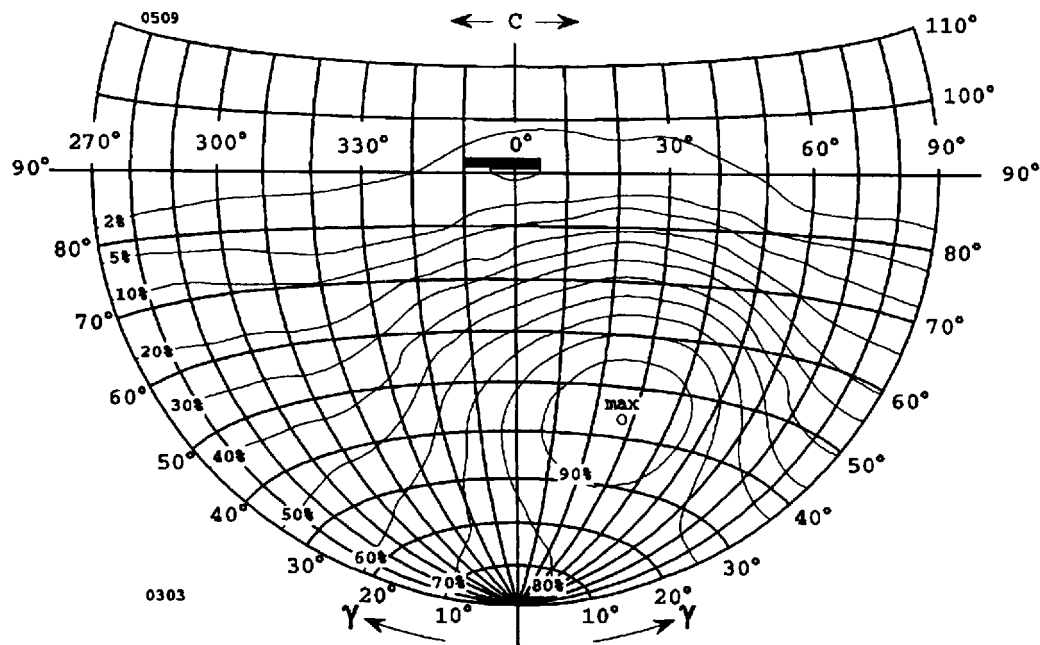


Fig. 3.3 Relative isocandela-diagram in azimuth projection.

3.3.3 Relative isolux diagram

This diagram shows contours of equal illuminance on a plan of the road for a specific luminaire. The values are calculated by means of formula (2.1). To make these diagrams universally applicable, the mounting height h is chosen to be of unit length and the values of the illuminance are given as a percentage of the maximum illuminance. It is recommended that the contours are shown for 90; 80; 70; 60; 50; 40; 30; 25; 20; 15; 12,5; 10; 5; 2; and 1% of the maximum illuminance. The location of the maximum illuminance is to be indicated. An example is given in fig.3.4.

The absolute value of the maximum illuminance can be calculated as:

$$E_{\max} = K_1 \cdot \frac{\Phi}{h^2} \quad (3.2)$$

with:

- $E_{\max}$ the maximum illuminance in lux;
- K_1 the constant, typical for the luminaire under consideration. The value of K_1 has to be given with the relative isolux diagram.
- Φ the luminous flux of the lamp(s) in the luminaire in lm.

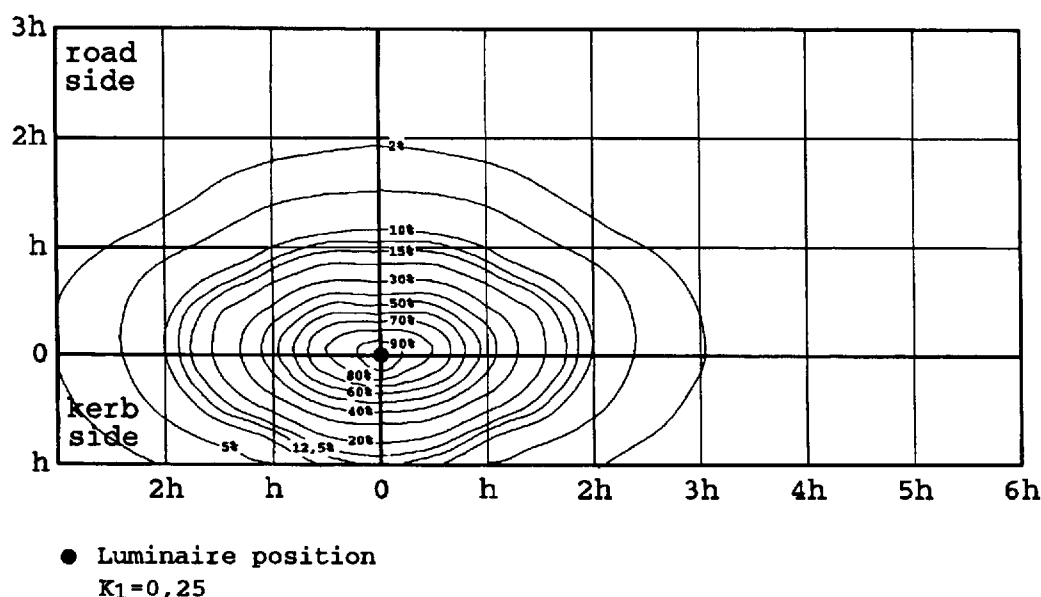


Fig. 3.4 Relative isolux diagram.

3.3.4 Utilization factor diagram

In fig.3.5 a luminaire is shown in its relation to the kerbs of the road to be lighted. With the luminaire as origin and the surface area of the road between two lines parallel to its axis (which extends in principle from $-\infty$ to $+\infty$) a solid angle is defined. The position of the two circumscribing lines is given by their transverse angle or transverse distance as shown in fig. 3.5.

It is common practice to choose one of these circumscriptions at a transverse distance equal to zero.

The utilization factor is defined by the ratio of the luminous flux emitted by the luminaire within this solid angle to the total luminous flux of the lamp(s) in the luminaire. The value of the utilization factor can be calculated from the I -table.

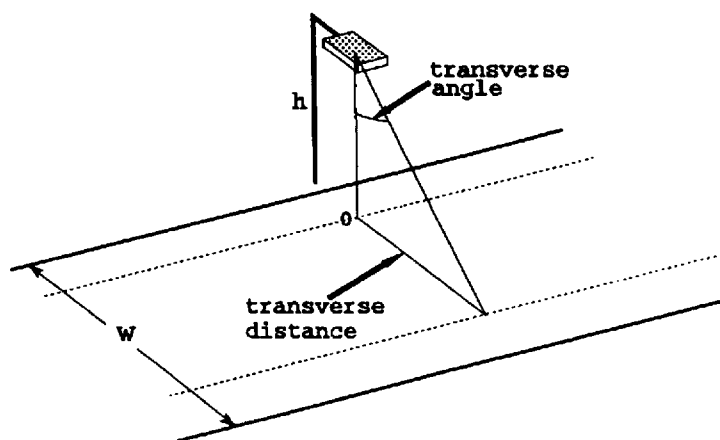


Fig. 3.5 Definition of transverse angle and transverse distance.

It is recommended that the utilization factor is plotted both as a function of the transverse angle and of the transverse distance. In the latter case the mounting height is chosen as of unit length.

Examples of utilization factor diagrams are given in fig. 3.6.

The average illuminance can be calculated as:

$$E_{av} = \eta_E \cdot \frac{\Phi}{(w \cdot s)} \quad (3.3)$$