Draft EN Tunnel Lighting

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Contents

Page

Foreword

This European Standard has been prepared by Technical Committee CEN/TC 169 “Light and Lighting”, the secretariat of which is held by DIN.

This European Standard shall be given the status of a national standard, either by publication of an identical text, at the latest by xxx yyyy, and conflicting national standards shall be withdrawn b at the latest by xxx zzzz.

Annexes A, B, E, F and G are informative.

This document includes a Bibliography.

According to the CEN/CENELEC…

1 Scope

This European standard gives requirements for the design of lighting for tunnels more than 500 m in length on roads forming part of the trans-European transport network, for motorized traffic only and for mixed traffic.

NOTE 1This standard may also be applied to the lighting of tunnels more than 500 m in length on roads not forming part of the trans-European transport network, and to tunnels of between 200 m and 500 m in length. In the latter case emergency lighting may not be required.

It includes requirements for normal traffic lighting, safety lighting to enable tunnel users to evacuate the tunnel in their vehicles in the event of a breakdown of the power supply, and evacuation lighting to guide tunnel users to evacuate the tunnel on foot in the event of an emergency. It supports the EC Tunnel Safety Directive 2004/54/EC.

It gives requirements for those aspects of normal lighting that are concerned with traffic safety, such as arrangements, levels and other parameters including daylight. It does not give recommendations for aspects of lighting that concern visual comfort.

It gives requirements for safety lighting and evacuation lighting.

It provides methods of calculation and measurement.

This standard does not include traffic or emergency signs in tunnels

NOTE 2 Signing should be in accordance with national requirements, and sign performance should be specified in accordance with EN 12899-1.

NOTE 3 This Standard is based on photometric considerations, and all values of luminance and illuminance are maintained values.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

EN 12665, *Light and lighting — Basic terms and criteria for specifying lighting requirements*.

EN 13201-2, *Road lighting — Part 2: Performance requirements*.

EN 13201-3, *Road lighting — Part 3: Calculation of performance*

prEN XXXX, *Luminance meters*

prEN YYYY, *Illuminance meters*

3 Terms, definitions and symbols

3.1 Terms and definitions

For the purposes of this Standard, the terms and definitions given in EN 12665, EN 13201-2, EN 13201-3 and the following apply.

access zone
part of the open road immediately outside (in front of) an entrance portal, covering the distance over which an approaching driver should be able to see into a tunnel

access zone length
distance between the stopping distance point ahead of an entrance portal, and the entrance portal itself

access zone luminance
average luminance contained in a conical field of view, subtending an angle of 20° with the apex at the position of the eye of an approaching driver and aimed at the centre of the entrance portal

NOTE Access zone luminance is assessed from a point at a distance equal to the stopping distance from the entrance portal at the middle of the relevant carriageway or traffic lane.

carriageway
part of a road normally used by vehicular traffic, normally subdivided into traffic lanes

contrast revealing coefficient
ratio between road surface luminance and illuminance on a vertical plane facing oncoming traffic and at a height of 0.2 m above the road surface, at a given point in a tunnel

counterbeam lighting
lighting comprising luminaires the luminous intensity distribution of which is asymmetrical in a plane parallel to the tunnel axis and the main beam of which is directed towards oncoming traffic in a tunnel

daylight screen
device that transmits (part of) the ambient daylight

NOTE Daylight screens may be applied for the lighting of the threshold zone of a tunnel.

design speed
speed adopted for a particular stated purpose in designing a road

emergency lane
lane parallel to the traffic lane(s), not destined for normal traffic, but for emergency (police) vehicles and/or for broken-down vehicles

NOTE An emergency lane is commonly referred to as a “hard shoulder”.

emergency exit
exit to allow tunnel users to leave the main tunnel on foot and reach a safe place via an escape route separate from the main tunnel in the event of an emergency

entrance portal
part of the tunnel construction that corresponds to the beginning of the covered part of a tunnel or, when open daylight screens are used, to the beginning of the daylight screens

entrance zone
combination of threshold zone and transition zone(s)

escape route
a route separate from the main tunnel leading from an emergency exit or shelter to a place of safety

exit portal
end of the covered part of a tunnel or, the end of the daylight screens if these are used at the exit

evacuation lighting
lighting system to guide tunnel users to evacuate the tunnel on foot in the event of an emergency.

evacuation route marker lights
visible marker lights to provide guidance along the main tunnel to an emergency exit

interior zone
part of a tunnel following directly after the transition zone

NOTE The interior zone stretches from the end of the transition zone to the exit portal, or to the start of the other transition zone if the tunnel is two way.

interior zone luminance
average road surface luminance of a transverse strip at a given location in the interior zone of a tunnel

lay-by
emergency area specifically designated for vehicles that have a legitimate cause to stop within the tunnel.

marker light
highly visible illuminated marker to clearly delineate the escape route or emergency exit in an emergency

mixed traffic
traffic that consists of motor vehicles, cyclists, pedestrians etc.

normal lighting
permanent lighting system provided so as to ensure appropriate visibility at all times for drivers for the entire tunnel under normal operating conditions.

overall uniformity
ratio of the lowest to the average road surface luminance

parting zone
first part of the open road directly after the exit portal of a tunnel

NOTE The parting zone is not a part of the tunnel, but it is closely related to the tunnel lighting. The parting zone begins at the exit portal.

safety lighting
lighting system to enable tunnel users to evacuate the tunnel in their vehicles in the event of a breakdown of the power supply

NOTE safety lighting normally forms part of the normal lighting system

speed limit
maximum legally allowed speed on any given road

standard object
flat quadratic object 0.2 m x 0.2 m used in the determination of contrast revealing coefficient

stopping distance
distance needed to bring a vehicle, driving at design speed, to a complete standstill

symmetrical lighting
lighting comprising luminaires the luminous intensity distribution of which is symmetrical in a plane parallel to the tunnel axis

threshold zone
first part of a tunnel, directly after the entrance portal or the beginning of the daylight screens

threshold zone lighting
lighting of the threshold zone of a tunnel, which allows drivers to see into the tunnel whilst in the access zone

threshold zone luminance
average road surface luminance of a transverse strip at a given location in the threshold zone of a tunnel

threshold zone luminance ratio
ratio between the threshold zone luminance and the access zone luminance at a given point in a tunnel

traffic flow
number of vehicles passing a specific point in a stated time in a stated direction

traffic lane
strip of carriageway intended to accommodate a single line of moving vehicles

transition zone
part a the tunnel following directly after the threshold zone

NOTE The transition zone stretches from the end of the threshold zone to the beginning of the interior zone. In the transition zone, the lighting level is decreased from the level at the end of the threshold zone to the level of the interior zone.

transition zone luminance
average road surface luminance of a transverse strip at a given location in the transition zone of a tunnel

vehicular cross-connection
vehicular carriageway connecting adjacent main tunnel tubes

visual guidance
optical and geometrical means of providing drivers with information on the course of the road in a tunnel

3.2 Symbols

For the purposes of this Standard, the following symbols apply.

A	area of a segment on a perspective view of a tunnel entrance
E	illuminance, in lux
E_w	maintained wall illuminance, in lux
f	focal length of camera lens, in millimetres (mm)
H	height of tunnel entrance portal, in metres (m)
H	height of printed film negative, in millimetres (mm)

H_L	mounting height of luminaire, in metres (m)
I	intensity, in candelas
I_w	intensity in direction of point on wall in candelas per kilolumen (cd/klm)
k	ratio of threshold zone luminance to access zone luminance
L	luminance, in candelas per square metre (cd/m^2)
L_{in}	interior zone luminance, in candelas per square metre (cd/m^2)
L_{th}	threshold zone luminance, in candelas per square metre (cd/m^2)
L_{tr}	transition zone luminance, in candelas per square metre (cd/m^2)
L_v	equivalent veiling luminance, in candelas per square metre (cd/m^2)
L_{20}	access zone luminance, in candelas per square metre (cd/m^2)
L_w	maintained wall luminance, in candelas per square metre (cd/m^2)
MF	maintenance factor
P	height of calculation point on wall above road surface, in metres (m)
q_c	contrast revealing coefficient
SD	stopping distance, in metres (m)
TI	threshold increment, as a percentage (%)
t	time, in seconds (s)
U_l	longitudinal uniformity
U_o	overall uniformity of road surface luminance
α	angle between vertical plane containing the incident light path and the vertical plane at right angles to the wall, in degrees (º)
α_I	visual angle for an apparent entrance portal in the vertical plane, in degrees (°)
α_u	visual angle for an apparent exit portal in the vertical plane, in degrees (°)
β_I	visual angle for an apparent entrance portal in the horizontal plane, in degrees (°)
β_u	visual angle for an apparent exit portal in the horizontal plane, in degrees (°)
ε	angle of incidence of light to the horizontal plane, in degrees (º)
ρ_{dif}	diffuse reflection factor of wall
θ_H	angle subtended by tunnel height, in degrees (°)
θ_P	angular height of print, in degrees (°)
Φ	initial luminous flux of the lamp or lamps in luminaire, in kilolumens (klm)

4 Tunnel conditions

4.1 Normal lighting

4.1.1 General

NOTE 1 Information on tunnel design, use and operational aspects that affect tunnel design is given in informative Annex A.

Road and traffic conditions in tunnels can differ considerably from those that prevail on the open road. The design of tunnel lighting installations should take these different conditions into account, particularly with regard to traffic safety.

The object of installing lighting in a road tunnel is to enable traffic to flow through it with the same speed, degree of safety and comfort as on the approach roads.

This aim can be achieved only when road users are sufficiently aware visually of the roadway ahead of them and, in particular, of the presence or absence of other vehicles and possible obstructions.

Driving comfort is an important aspect of the quality of the lighting installations of road traffic tunnels. As a result of feelings of anxiety, drivers are likely to slow down near a tunnel entrance. Sudden drops in speed reduce traffic capacity and might lead to traffic jams and possibly to accidents. A lighting system that helps to overcome any feeling of anxiety can improve traffic safety, increase road capacity and improve driving comfort.

The difficulty of the driving task when approaching and passing through a tunnel is influenced by the speed, the volume (flow) and the composition of the traffic and by the layout of the road and the tunnel and their immediate surroundings.

The tunnel lighting class and lighting levels are affected by the traffic flow, and the type and mix of traffic, and should be determined in accordance with Clause 5.

NOTE 2 Information on different lighting systems is given in informative Annex B.

4.1.2 Daytime conditions

The major difference between tunnel lighting and conventional road lighting is in the need for lighting by day. A driver needs to be able to see a certain distance ahead such that if an unexpected hazard appears, the driver can react and stop within that distance. When this distance extends into a tunnel there should be a sufficiently high lighting level inside to maintain visibility. If the lighting level is not high enough, the driver will be unable to see into the tunnel, the so-called "black hole effect".

During approach and entry to a tunnel, drivers' eyes become adapted to the darker surroundings. This adaptation is a continuous process with the result that further into the tunnel, providing it is of sufficient length, the lighting level may be steadily reduced until it reaches the constant level in the tunnel interior zone. On emerging from a tunnel into daylight the eye adapts far more quickly to the higher luminance level.

The lighting of a tunnel shall be sufficient to:

- avoid the "black hole effect" when a driver is unable to see into the tunnel;
- reduce the likelihood of a collision with another vehicle (or bicycle or pedestrian);
- enable a driver to react and stop within the stopping distance *SD* (see 5.1) if an unexpected hazard appears;
- provide visual guidance.

4.1.3 Night-time conditions

During night-time the "black hole effect" does not exist, as the external luminance values are low. Lower lighting levels are needed in the tunnel than during daytime, with all zones treated in the same manner. (See 5.8.)

4.2 Emergency lighting

4.2.1 Safety lighting

In the event of a failure of the power source that supplies the normal lighting system, a safety lighting system shall be provided that that enables drivers to see adequately to complete their journey through the tunnel, although possibly at reduced speeds. (See 6.2)

NOTE Drivers are normally prevented from entering the tunnel once a power failure has occurred.

4.2.2 Evacuation lighting

In emergency circumstances such as a serious vehicle accident or fire the primary purpose of the emergency lighting is to provide guidance and visibility for pedestrians abandoning their vehicles, to facilitate their safe evacuation of the tunnel through the tunnel to an emergency exit or the tunnel portal. As visual conditions may be impaired by smoke evacuation cannot rely on the normal tunnel lighting, even if it remains in operation, and additional visual guidance shall be provided. (See 6.3)

5 Normal tunnel lighting design

5.1 Determination of stopping distance

The stopping distance *SD* should be taken from Table 1, relative to the design speed of the tunnel.

Table 1 — Stopping distances for various design speeds

Design speed[a] km/h	Stopping distance (*SD*) m
120	215
100	160
85	120
70	90
60	70
50	50
NOTE These values are extracted from Volume 6, Section 1, Part 1 of the Highways Agency publication DMRB TD9/93 [1].	
[a] The design speed is that which is applicable to normal usage of the tunnel. In abnormal usage, such as contraflow operation, a lower design speed will normally apply with implications for the lighting design at all portals.	

5.2 Tunnel lighting classification

The tunnel lighting classification should be based on the characteristics of the tunnel's known usage (for existing tunnels) or projected usage (for new tunnels). The main influencing factors are:

— traffic flow;

— traffic type and mix;

Traffic flow should be classified as high, medium or low using Table 2.

Table 2 — Traffic flow

Traffic flow category	Volume/rate of flow[a]	
	One-way traffic	Two-way traffic
High	>1 500	>400
Medium	500 to 1 500	100 to 400
Low	<500	<100
NOTE If the actual value is not known, peak hour traffic can be derived as follows. Average daily traffic (ADT, vehicle s per day) is the most used concept in traffic planning and it is always known. Peak hour traffic (vehicles per hour) is in rural areas 10 % and in urban areas 12 % of ADT. On undivided roads, the number of vehicles per hour per lane can be calculated by dividing peak hour value by the total number of lanes. If the actual directional distribution is not known on dual carriageway roads, it can be assumed that the worst case direction carries two thirds of the traffic flow. The higher flow is then divided by the number of lanes of this carriageway.		
[a] Vehicles per hour per lane during peak hour.		

The appropriate class of tunnel lighting should be determined from Figure 1, which takes into account the traffic flow category and whether traffic is mixed or motorized only.

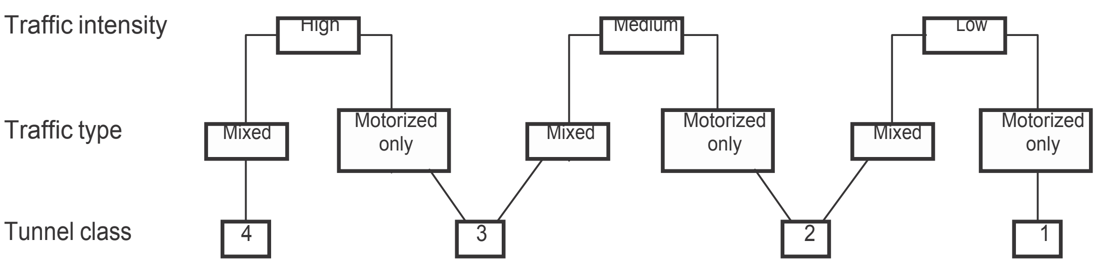


Figure 1 — Tunnel lighting class selection

5.3 Determination of access zone luminance

In order to determine the necessary daytime lighting levels within a tunnel, the access zone luminance shall first be determined. This enables the threshold zone luminance and the luminance in the other zones to be determined.

There are two methods of determining access zone luminance L_{20}. Whenever possible direct measurement at the site shall be used, as described in Annex C.

Where direct measurement is not possible, the grid method shall be used, as described in Annex D.

A method of estimating L_{20} may be used to provide an interim value for provisional design purposes, but shall not be used for the final design.

NOTE A method of estimating L_{20} is given in informative Annex E.

5.4 Determination of tunnel zone daytime lighting levels

5.4.1 Threshold zone

The road surface luminance of the threshold zone shall be derived from the luminance of the access zone during daytime. The length of the threshold zone is equal to the stopping distance *SD*.

The threshold zone luminance L_{th} shall be provided during daytime from the beginning of the threshold zone for a length of 0.5*SD* (see Figure 2). The appropriate value of *k* shall be selected from Table 3, and the threshold zone luminance L_{th} calculated using equation (4).

$$L_{th} = k \times L_{20} \quad (4)$$

NOTE As the relative size of the entrance portal in the field of view is dependent on the access zone length, which in turn is dependent on the design speed, the value of *k* is dependent on the design speed. Furthermore, in order to reflect different tunnel traffic conditions, *k* is also dependent on traffic flow and type, which affect the tunnel lighting class, as shown in 5.2.

Table 3 — Values of *k* for different speed limits and tunnel lighting classes

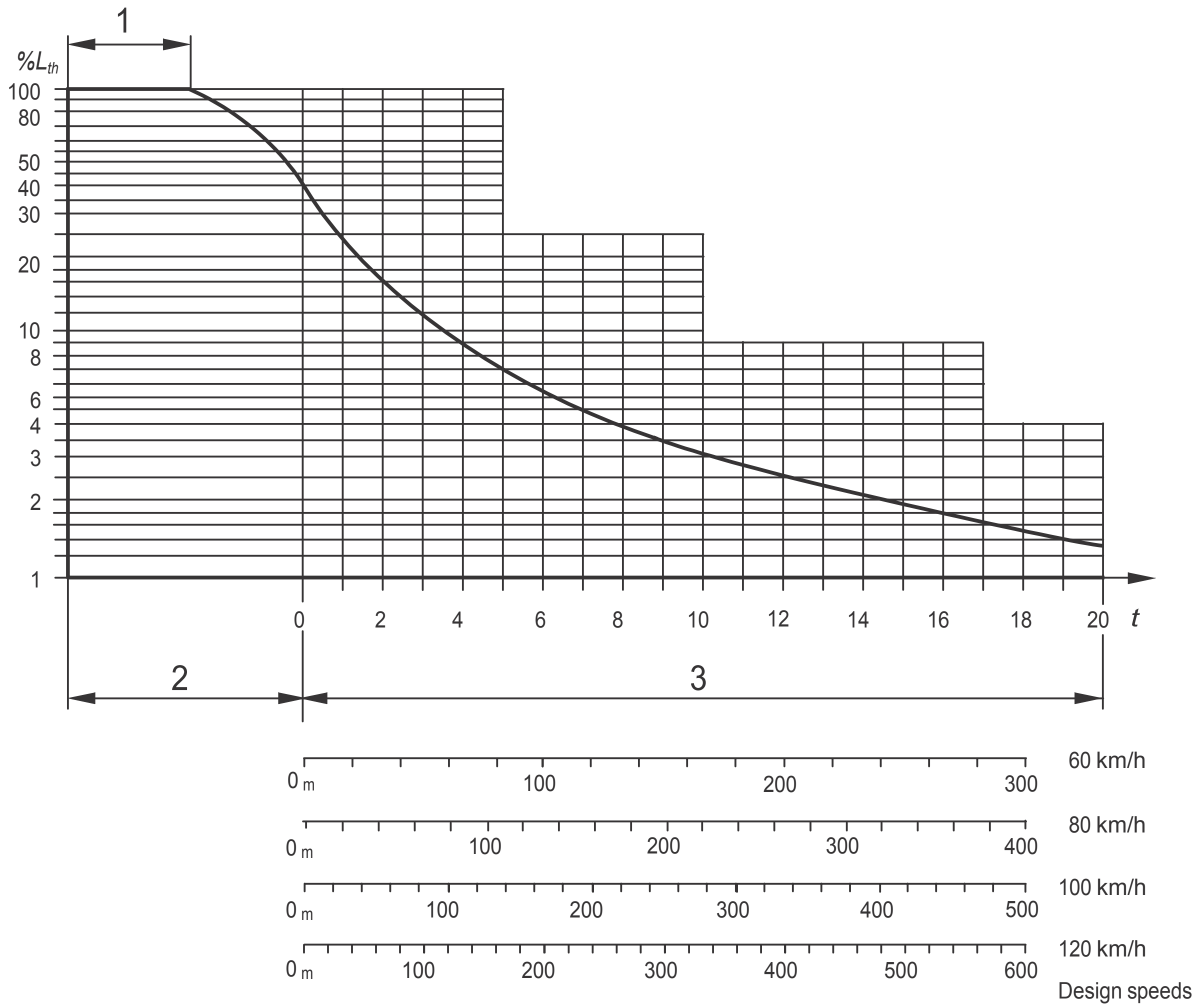
Tunnel lighting class	***k* value**		
	Speed limit50 km/h to 70 km/h	**Speed limit 80 km/h to 100 km/h**	**Speed limit 110 km/h to 120 km/h**
4	0.05	0.06	0.10
3	0.04	0.05	0.07
2	0.03	0.04	0.05
1	—	—	—

From half the stopping distance *SD* onwards, the lighting level shall gradually and linearly decrease to a value, at the end of the threshold zone, equal to $0.4L_{th}$. The gradual reduction over the last half of the threshold zone may also be in steps. However, the luminance level shall not fall below the values corresponding to a gradual linear decrease.

5.4.2 Transition zone

In the transition zone, the average road surface luminance shall be gradually reduced from the threshold zone towards the interior zone. At any position in the transition zone, the transition zone luminance L_{tr} shall not be less than the luminance derived from Figure 2.

NOTE The transition zone starts at the end of the threshold zone (t = 0).



Key

1 Length of threshold zone where L_{th} is 100 % = 0.5*SD*

2 Threshold zone stopping distance (*SD*)

3 Transition zones

The curve may be replaced by a stepped curve with levels that do not fall below the continuous curve. In this case, within the transition zone, the maximum ratio on passing from one level to another should not be greater than 3:1.

Figure 2 — Luminance reduction curve

5.4.3 Interior zone

The average value of interior zone road surface luminance L_{in} shall be not less than the value shown in Table 4 for the appropriate tunnel lighting class.

Table 4 — Road surface luminance of the interior zone

Values in candelas per square metre (cd/m^2)

Tunnel lighting class	Average luminance		
	Speed limit 50 km/h to 70 km/h	Speed limit 80 km/h to 100 km/h	Speed limit 110 km/h to 120 km/h
4	3	6	10
3	2	4	6

2	1.5	2	4
1	—	0.5	1.5
NOTE The luminance values in Table 4 are maintained values.			

5.5 Luminance and uniformity values

For all zones, the average road surface luminance values specified in 5.4.1, 5.4.2, and 5.4.3 shall be provided for the total carriageway width of the tunnel, together with emergency lanes where they are provided.

NOTE 1 The luminance values given are maintained values.

During daytime, road surface luminance uniformity shall be not less than the values given in Table 5 for the appropriate tunnel lighting class. Overall uniformity shall be calculated for the full road width, i.e. for the carriageway driving lane(s) and for the emergency lanes if they are provided in the tunnel. Longitudinal uniformity shall be calculated for each lane separately, including emergency lanes where they are provided.

Table 5 — Uniformity of the road surface luminance

Tunnel lighting class	Overall uniformity, U_o	Longitudinal uniformity, U_l
4	≥0.4	≥0.7
3	≥0.4	≥0.6
2	≥0.4	≥0.6
1	-	-

NOTE 2 It can be appropriate to measure tunnel lighting installations after completion to ensure that the design recommendations have been met. Requirements for measurement are given in Clause 9.

5.6 Counterbeam lighting systems

The requirements of 5.5 and 5.6 shall apply to the design of counterbeam lighting systems. In addition the average value and minimum value of contrast revealing coefficient q_c on the carriageway, including emergency lanes where they are provided, shall not be les than [?] and [0.6] respectively in any part of any zone at all times.

5.7 Tunnel walls

For class 4 tunnels, the average luminance of that part of the tunnel walls up to a height of 2 m shall be not less than the average road surface luminance at the corresponding location.

For class 3 and 2 tunnels, the average luminance of that part of the tunnel walls up to a height of 2 m shall be not less than 60 % of the average road surface luminance at the corresponding location.

For class 1 tunnels, no luminance requirements are given for the walls. However, for such tunnels the average vertical illuminance of that part of the tunnel walls up to a height of 2 m shall be not less than 25 % of the average illuminance of the road surface.

5.8 Lay-bys and vehicular cross connections

5.8.1 Lay-bys

At all times, the average maintained horizontal illuminance level in lay-bys shall not be less than three times the level which is achieved on the adjacent carriageway when using the same light sources, or two times the level if the light source is different.

The overall uniformity of illuminance shall not be less than that on the adjacent carriageway at any time.

Light sources used for the lighting of lay-bys shall have a colour rendering index
Ra ≥ 60.

5.8.2 Vehicular cross connections

At all times, the average maintained horizontal illuminance level and uniformity in vehicular cross-connections shall be at least equal to the level in the interior zone.

5.9 Determination of night-time lighting levels

If the tunnel is on a section of illuminated road, the night-time luminance inside the tunnel shall be at least equal to the access road luminance, but not more than three times this value.

If the tunnel is on a section of unlit road it shall be lit at night to a luminance level of not less than 1.0 cd/m^2.

Where night-time lighting is provided to a tunnel on an otherwise unlit length of road, the decision to provide lighting on a short section of the access zone and parting zone is a matter for the tunnel administrative authority.

NOTE 1 Where such lighting is provided, the length of this section should normally be not less than the stopping distance *SD* related to the tunnel design speed in Table 1, unless there are particular reasons such as environmental reasons for a reduced length.

NOTE 2 Requirements and recommendations for night-time lighting of roads are given in EN 13201.

The luminance uniformity of night-time lighting of a tunnel on an otherwise unlit road shall be not less than the value given in Table 5 for the appropriate tunnel lighting class.

5.10 Flicker

The sensation of flicker can cause visual discomfort to drivers and in some cases can induce epileptic seizures. It is induced by periodic changes in luminance within the field of vision. Driving under incorrectly spaced luminaires within the tunnel or through an entrance zone with daylight louvres can give rise to this effect.

The degree of discomfort is dependent on:

a) total duration of the flicker experience;

b) contrast between the flicker source luminance and its background;

c) flicker frequency;

d) rate of change of luminance.

Where the duration of the flicker experience (i.e. the time taken to pass through the zone(s)) is no greater than 20 s, flicker can be ignored. Where the duration is greater than 20 s, the effect of flicker shall be minimized by ensuring that:

1) unlit length between adjacent flashed areas in a luminaire row is less than the flashed length of a luminaire; and/or

2) flicker frequency falls outside the band 2.5 Hz to 15 Hz.

NOTE Flicker frequency can be calculated by dividing the speed, in metres per second (m/s) by the luminaire spacing [centre-to-centre, in metres (m)]. For example: for a vehicle speed of 60 km/h (= 16.6 m/s) and luminaire spacing of 4 m, the flicker frequency is 16.6/4 = 4.2 Hz.

When considering flicker the effect of luminaires in lay-bys shall be taken into account.

The effect of flicker from the evacuation route marker lights described in 7.1, if permanently illuminated, shall also be taken into account.

5.11 Glare

Disability glare reduces visibility, and shall be minimized. If disability glare is controlled under tunnel lighting conditions then discomfort glare will also be controlled. Disability glare effects shall be quantified by means of threshold increment (*TI*), which shall be calculated in accordance with 8.2.

To minimize the likelihood of disability glare, the threshold increment *TI* shall be:

a) less than 15 % for the threshold zone and the interior zone of the tunnel during the day;

NOTE There are no recommendations for *TI* values for the exit zone during daytime.

b) less than 15 % for all tunnel zones during the night.

For shorter threshold and transition zones, this method for calculation of threshold increment is not strictly relevant as the observer might be sitting in one zone while viewing another zone (60 m ahead). It is sufficient for calculations of *TI* to be made in the threshold zone (if it is of sufficient length). If this meets the recommendations for *TI* values then it may be assumed that all other zones will meet the recommendations providing the same type of luminaire/optical system is used for all zones.

For the purpose of the calculation of *TI*, it shall be assumed that the tunnel zones are of infinite length.

When considering glare and calculating TI the effect of luminaires in lay-bys shall be taken into account.

When considering glare and calculating TI, the luminaires used to illuminate the emergency exits as described in 6.3.2 shall be taken into account.

5.12 Lighting controls

The access zone luminance varies with changes in daylight conditions. During the day, the luminance levels in the threshold and transition zones shall be controlled automatically according to the luminance level in the access zone.

NOTE 1 Two systems are possible: switching groups of lamps, or dimming them. The first is the most commonly applied, particularly at high luminance levels.

NOTE 2 For automatic control, the most practicable solution is to place a luminance meter with a measuring field of 20°, centred on the tunnel portal and positioned at the stopping distance (*SD*) in front of the tunnel portal. For practical reasons, the luminance meter usually has to be mounted at a greater height than the driver's eye position. The instrument therefore has to be calibrated for use in that specific location in order to give the correct L_{20} reading.

The switching or dimming control shall have a time delay of several minutes to avoid unnecessary switching owing to transient variation in the local lighting level caused by passing clouds.

If the control system utilizes steps in luminance levels, the steps should be arranged to give the optimum arrangement so that electricity consumption is minimized and control system costs are not excessive. The ratio between successive steps in luminance levels shall not exceed 3:1.

NOTE 3 More steps give reduced electricity consumption.

NOTE 4 Consideration should be given to the provision of emergency overrides to the tunnel lighting control system.

6 Emergency lighting

6.1 Power supplies

Safety lighting and evacuation lighting shall be supplied from an uninterruptible power supply.

Under power failure conditions, the response time to bring this power supply into operation shall not be greater than 0.25 s and the duration of operation of this supply providing the full rated lumen output of the connected luminaires shall not be less than 30 minutes.

Guidance on the periodic inspection of the system is given in Annex F.

6.2 Safety lighting

In the event of a failure in the power source that supplies the lighting system, an emergency uninterruptible power supply shall be available to energize sufficient system luminaires to allow users to exit the tunnel in safety in their vehicles, although possibly at reduced speeds.

NOTE It is recommended that speed restriction signs are automatically brought into operation when a power failure occurs

A proportion of the luminaires responsible for night-time lighting shall be automatically energized from the uninterruptible power supply. The average maintained horizontal illuminance on the carriageway surface provided by these luminaires shall be not less than 10 lx, and the illuminance level at any point on the carriageway shall be not less than 2 lx.

6.3 Evacuation lighting

6.3.1 Evacuation route

In the event of an emergency, the main tunnel carriageway becomes a footway for pedestrians who have abandoned their vehicles and must make their way via the evacuation route to the emergency exits or tunnel portals. The normal lighting is adequate for this purpose in conditions of good visibility, but such visual conditions cannot be assumed to exist during an emergency.

NOTE The evacuation route can be the carriageway, emergency lane or a separate walkway, depending on the tunnel design.

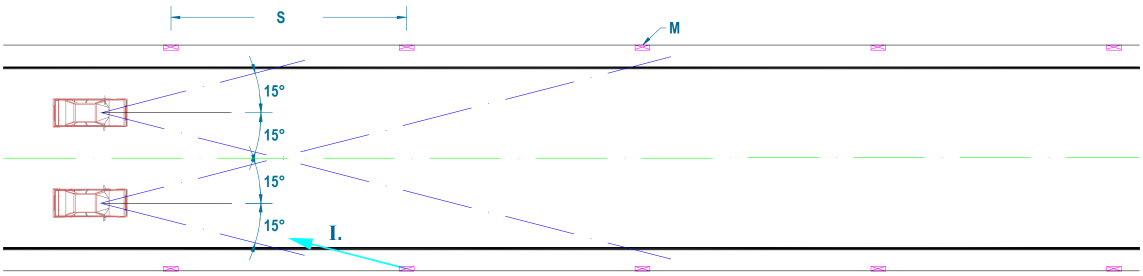
Therefore, for use in an emergency, as a complement to the normal lighting, evacuation route marker lights shall be provided to give visual guidance to pedestrians to facilitate their evacuation of the tunnel on foot towards the emergency exits or tunnel portals.

The evacuation route shall be clearly and unambiguously marked with evacuation route marker lights at a spacing not exceeding 10 m and not higher than 1m above the carriageway level on both sides of the tunnel.

At all times evacuation route marker lights along the evacuation route shall be operational, either in standby mode to be illuminated in an emergency, or permanently illuminated.

Where the marker lights are permanently illuminated, in order to limit disability glare to drivers, the intensity in the critical directions shall be limited so as not to exceed 40 cd in a cone of 2 x 15° with the axis formed by the driver's observation direction, as shown in Figure 3.

To ensure adequate visibility of the marker lights in smoke, the minimum maintained intensity, in all directions from each luminaire shall be 1 cd.



KEY
M = Marker light
S = Marker light spacing ≤ 10 m
I = Direction of maximum intensity ≤ 40 cd

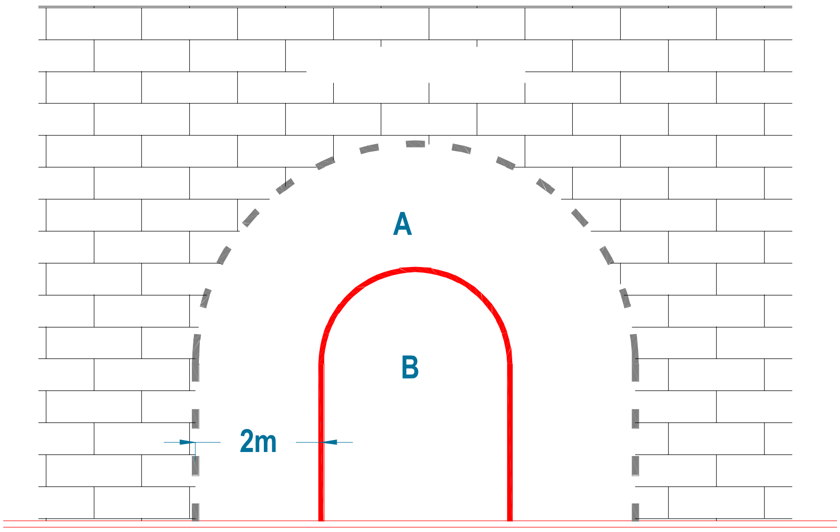
Figure 3: Limitation of intensities emitted towards driver (TOP view with the cone and the markers)

6.3.2 Emergency exits

Exits clearly identified by dedicated emergency exit lighting helps to encourage vehicle occupants to leave their vehicles when necessary. Different systems of lighting shall be provided to a) illuminate and to b) mark the emergency exit.

a) In normal conditions in order to make the emergency exit adequately visible and to familiarize all tunnel users with their positions and geometry, the emergency exit including the door and an area of tunnel wall extending to 2 m beyond the door frame as shown in Figure 4 shall be illuminated at all times. The maintained average vertical illuminance at all times on the defined area of wall and the door shall be within a range of 3 to 5 times the average illuminance level on that section of the walls up to 2 m height in the interior zone in daytime. The overall uniformity of illuminance on the area of door and surround shall not be less than 0.6.

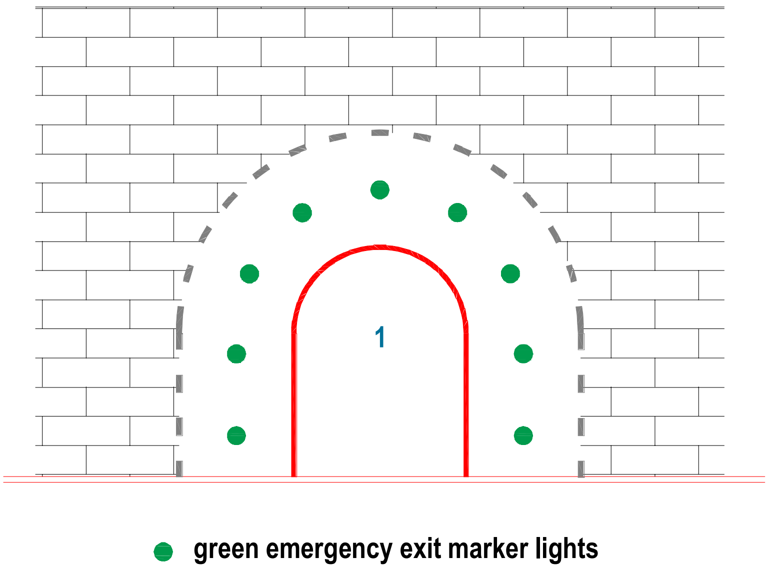
Light sources used to illuminate the emergency exits shall have a colour rendering index Ra ≥60.



Key
A = illuminated area of wall
B = emergency exit door

Figure 4: Illumination of emergency exit

b) For operation only during an emergency, green emergency exit marker lights shall be provided generally as shown in Figure 5. In order to attract the attention of evacuating pedestrians the emergency exit marker lights shall flash with a frequency within a range of 1 to 2 Hz and shall have an intensity, in all directions, not lower than 150 cd.



Key
1 = emergency exit door

Figure 5: Location of marker lights at emergency exits

6.3.3 Escape routes

In an emergency when pedestrians may be present, escape route lighting shall provide an average maintained horizontal illuminance level of not less than the tunnel interior zone daytime level, with an overall uniformity of not less than 0.2. Light sources shall have a colour rendering index Ra ≥40.

6.3.4 Shelters

In an emergency when pedestrians may be present, the lighting of shelters leading to an escape route shall provide an average maintained horizontal illuminance level not less than 100 lx with an overall uniformity of not less than 0.2. Light sources shall have a colour rendering index Ra ≥40.

7. Traffic signals

When sodium vapour lamps (both high and low pressure) which have an orange hue are used for tunnel lighting, and there are traffic signals in the tunnel, there can be visual confusion for drivers between such lamps and an amber signal head. In order to avoid such confusion, the location of luminaires containing such lamps, and traffic signal heads, shall be carefully selected to take into account the way in which their relative positions will be viewed by approaching drivers.

8 Calculation

8.1 Luminance and illuminance

When designing tunnel lighting, luminance values and uniformity ratios shall be calculated for each luminance step at which the lighting is designed to operate. Luminance shall be calculated in accordance with EN 13201-3, 7.1, 8.3 and 8.4 and illuminance in accordance EN 13201-3, 7.2, except that grid spacing shall not be less than 1.0 m. Uniformity in the second half of the threshold zone and in the transition zone shall be calculated using the assumption that the luminaire type and array at the point of calculation is continued for an infinite distance

Although the performance is generally specified in terms of luminance, illuminance values shall also be calculated using the same calculation grid for the selected compliant design, as calculated illuminance values have the advantage of direct comparison with measured illuminance values.

Luminance levels and uniformity ratios and illuminance levels shall be calculated for each luminance step at which the lighting is designed to operate (see 5.12). In addition, a grid shall be added on the walls of the tunnel with calculation points at heights of 0.5 m and 1.5 m, in line with the transverse rows of calculation points on the carriageway, to calculate luminance on the walls. Wall luminance shall be calculated from calculated illuminance values and the reflectivity of the walls, using the formulae:

Wall illuminance $$E_{\mathrm{w}} = \frac{I_{\mathrm{w}} \times \cos^2 \varepsilon \times \sin \varepsilon \times \cos \alpha \times \Phi \times MF}{(H_{\mathrm{L}} - P)^2} \qquad (5)$$

Wall luminance $$L_{\mathrm{w}} = \frac{\rho_{\mathrm{dif}} \times E_{\mathrm{w}}}{\pi} \qquad (6)$$

where

E_{w} is the maintained vertical illuminance at the calculation point, in lux;

I_{w} is the luminous intensity in the direction of the calculation point, in candelas per kilolumen;

ε is the angle of incidence of the light to the horizontal plane, at the calculation point, in degrees;

α is the angle between the vertical plane containing the incident light path and the vertical plane at right angles to the wall at the calculation point, in degrees;

Φ is the initial luminous flux of the lamp or lamps in the luminaire, in kilolumens;

MF is the maintenance factor;

H_{L} is the mounting height of the luminaire, in metres;

P is the height of the calculation point above the road surface, in metres;

L_{w} is the maintained wall luminance, in candelas per square metre; and

ρ_{dif} is the diffuse reflection factor of the wall.

NOTE 1. This calculation takes the wall to be vertical at the calculation point, as errors due to wall curvature are considered to be insignificant.

NOTE 2. The type of road surface and diffuse reflection factor of the walls are usually obtained from the tunnel designer or operator.

All calculations shall include contributions from all luminaires within a distance of 12 x H_L in all directions from the calculation point.

Lamp output used in calculations shall be initial values related to 100 h use.

When calculating luminance and illuminance values a maintenance factor (*MF*) of 0.7 shall be used, unless a detailed knowledge of lamp and luminaire depreciation factors in relation to planned maintenance procedures is available and a more accurate maintenance factor can be calculated.

NOTE The calculation methods in EN 13201-3 incorporate a maintenance factor (*MF*), which is product of the lamp maintenance factor and the luminaire maintenance factor. See also Annex A.

8.2 Threshold increment

Threshold increment (*TI*) shall be calculated in accordance with EN 13201-3:2003, 8.5, except that, where the initial average road surface luminance is ≥5 cd/m^2, in equation 42 of that standard the value of the constant should be changed from 65 to 95 and the power to which the value of road surface luminance is raised should be increased from 0.85 to 1.05. The calculation shall use a moving observer.

In the threshold zone and in the transition zone, for the purposes of calculating TI, the calculation shall assume that the luminaire type and array at the point of calculation is continued for an infinite distance

8.3 Contrast revealing coefficient

In the case of counterbeam lighting systems only, the contrast revealing coefficient q_c shall be calculated for each luminance calculation grid position, using the formula:

$$q_c = L/E_v \quad (7)$$

Where

L is the road surface luminance at the calculation position

E_v is the vertical illuminance at the centre of a notional standard object on the road surface at the calculation position with its normal vector parallel to the tunnel axis and oriented against the driving direction

9 Measurement

9.1 General

There are many practical difficulties and uncertainties in accurately carrying out tunnel lighting measurements. Luminance values are dependant on the reflectance *R* of the road surface and tunnel walls. The designer usually selects an *R*-table, which is assumed to be approximate to the characteristics of the road surface, but as the performance of road surfaces can vary dependant on the specific materials and over time there is often a significant difference between the selected *R*-table and actual performance. Similarly, wall reflectivity is usually an estimated value.

For this reason, when measurements are taken for the purpose of checking that the lighting installed complies with the design requirements (see clause 5), both luminance and illuminance values shall be measured. The luminance values give a general guide to the performance as seen by the driver, but the measured illuminance values shall be checked against the calculated illuminance values to verify the lighting design.

NOTE 1 Calculated results are maintained values allowing for luminaire maintenance factor and lamp lumen maintenance factor. To compare calculated and measured values, all calculated and measured values are converted to equivalent initial values, using the factors from the design calculations with the design values, and the appropriate maintenance factors related to the period in operation of the lamps and current condition of the luminaires.

There can be significant uncertainties in the measurement of illuminance, resulting in potential inaccuracy. The uncertainty shall be quantified in order to compare the calculated and measured values.

NOTE 2 Guidance on quantifying uncertainty in the measurement of illuminance values is given in informative Annex G

Luminance meters and illuminance meters shall comply with prEN XXXX and prEN YYYY respectively, and in each case shall be Type F.

When measuring luminance the meter shall have a measuring field of 6′ of arc.

Measurements shall be taken when the lighting is fully commissioned and declared operational, and this shall include visual checks to ensure that the lighting pattern, and types, position and orientation of luminaires are all in accordance with the design. Walls, luminaires and road surface shall be dry, clean and in good condition. The tunnels shall be free from traffic and any other activity.

All measurements shall be made during dark hours to avoid the influence of daylight penetration.

In addition to the lighting measurements the following data shall be recorded:

- Average supply voltage during measurement period
- Lowest supply voltage during measurement period
- Ambient temperature
- Condition of the road surface and tunnel walls
- Age of lamps in terms of hours of operation

NOTE 3 Measurements of voltage and ambient temperature should be made as close as possible to the relevant luminaires

9.2 Threshold and transition zones

A single transverse row of measurement points shall be established across each zone, at a position approximately 1/3 of the zone length from the start of the zone, co-incident with a row of points in the calculation grid. The observer position(s) shall be in accordance with EN 13201-3, but 60 m in advance of this row.

The row of measurement points shall consist of the outer two calculation points in each traffic lane and in any emergency lane, together with points on each wall at heights of 0.5 and 1.5 m.

Measurements of the luminance and illuminance levels shall be taken at each luminance step at which the lighting is designed to operate.

NOTE 1 It is not normally necessary to determine uniformity by measurement in the threshold and transition zones, as due to the close spacing of luminaires necessary to achieve the high luminance values, uniformity is generally very high.

NOTE 2 The procedure recommended above is appropriate for lighting systems with set luminance steps which are achieved by switching off selected luminaires or lamps. Some lighting systems instead keep all the luminaires and lamps in operation, and use dimming systems to provide continuous modulation of the lamp output to achieve the necessary variation in luminance levels. In such cases the measurements should be taken with the system controls set a) to provide 100% and b) at the first operational level of L_{20}.

9.3 Interior zone

A measurement grid shall be established, commencing at a position approximately 1/3 of the zone length from the start of the zone, co-incident with the calculation grid between two luminaire positions (or two pairs of luminaire positions for a twin luminaire off-centre or cornice mounted installation).

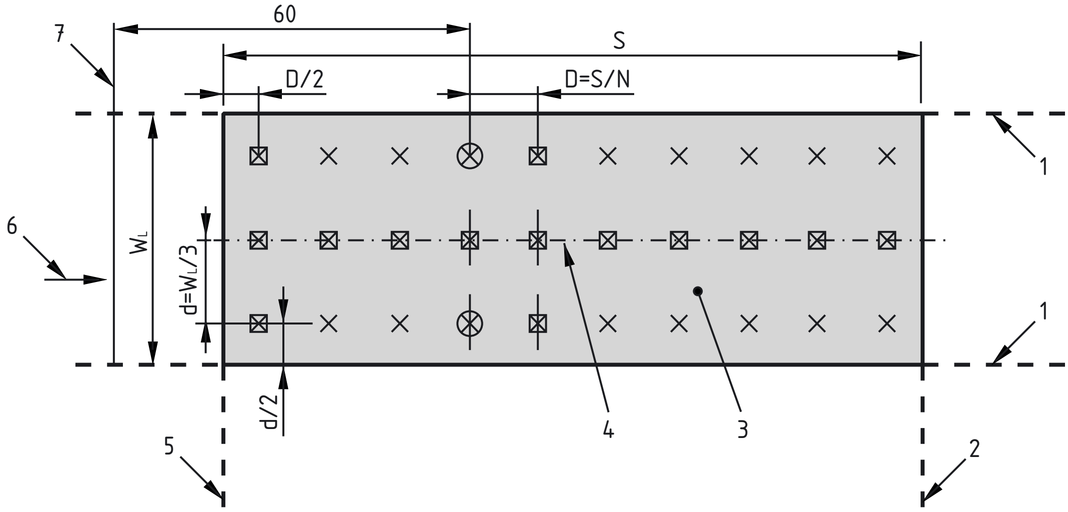
Measurements of luminance and illuminance for each lane and any emergency lane shall be taken at the points indicated in Fig 6.

In addition, luminance and illuminance measurements shall be taken on the walls in line with rows 1 and 5 at heights of 0.5 m and 1.5 m.

The observer position(s) shall be in accordance with EN 13201-3, but with the longitudinal position as shown in Figure 6.

Measurements of the luminance and illuminance levels should be taken at the night-time and daytime stage levels at which the lighting is designed to operate.

NOTE: If the type and array of luminaires and lamps used for night-time lighting in the threshold and transition zones are the same as in the interior zone, the measured values in the interior zone are valid for all zones. If the type and array of luminaires and lamps are different in any way in those zones, measurements will be necessary in those zones with the night-time level in operation.



Key
1 Edge of lane
2 Centre line of last luminaire in calculation field
3 Field of calculation
4 Centre-line of lane
5 Centre line of first luminaire in calculation field
6 Observer direction
7 Observer’s longitudinal position
X Denotes calculation points
O Denotes illuminance measurement points
 Denotes luminance measurement points

Figure 6 Interior zone measurement positions

9.4 Counterbeam lighting systems

In the case of counterbeam lighting systems only, in addition to the requirements of 9.1, 9.2 and 9.3, the vertical illuminance shall be measured at every measurement point at the centre of a standard object placed at the measurement point with its normal vector parallel to the tunnel axis and oriented against the driving direction

Annex A (informative)
Tunnel design, use and operational aspects that affect tunnel lighting design

A.1 Driver comfort

In a tunnel, driving is very different to driving on the open road, as spatial perception is confined and cut off from any familiar reference marks. The walls can generate a "wall shyness effect" which tends to make drivers keep further away. Drivers' visual performance in a tunnel can be considerably lower than on an open road, especially regarding visual acuity, the perception of contrast and distances, peripheral vision and the discrimination of colours. Time perception can change: the perceived duration seems to be about twice as long as the actual time span. Some drivers can be affected by sensations such as claustrophobia.

Thus in addition to providing the appropriate luminance levels to facilitate visual adaptation and the perception of objects on the carriageway, an appropriate lighting design can help to overcome these effects of the tunnel environment on the driver.

A.2 Tunnel design

There are aspects of tunnel design that materially affect the lighting design and thus the complexity, maintenance requirements and energy consumption of the lighting system, particularly those that affect the luminance of the visible surfaces in the access zone. The driver's adaptation level can be reduced by taking practical measures to reduce the luminance of visible surfaces in this zone. Consultation between the tunnel designer and lighting designer can help to provide the optimum solution. Particular aspects to be considered include the following.

a) Approaching the tunnel:

— portals and external road surfaces constructed with dark materials reduce the access zone luminance, and thus reduce lighting levels in the access and transition zones. A dark tunnel façade and dark walls with a rough surface for the cutting, with surfaces with a reflectance less than 0.2, can be beneficial.

— the design of the tunnel façade and treatment of its immediate surrounds can limit the effect of low-angle sun, which can be a particular problem with tunnels having an East–West orientation, and reduce the amount of sky in the visual field as far as possible. For example, trees or other screens above the entrance portal can reduce direct glare from the sun.

b) Inside the tunnel:

— any features such as junctions and slip roads, need particular consideration within the overall tunnel lighting scheme;

— a light coloured road surface and light coloured walls will increase the overall efficiency of the lighting solution;

— visual guidance is provided by lighting in combination with road markings and signage.

c) At the exit:

— any junctions and/or slip roads immediately at or outside the exit portal of the tunnel need particular consideration within the tunnel lighting scheme, as does the ability of a driver exiting the tunnel to see in the rear view mirror images of vehicles still within the tunnel.

A.3 Tunnel maintenance

The maintenance factor (*MF*) used in the design calculations in Clause 8 refers to the depreciation in the photometric performance of a luminaire and lamp from its state when new to its worst acceptable state in service. It is a multiple of the lamp and luminaire maintenance factors.

A value of 0.7 is recommended for maintenance factor in Clause 8. This can be varied and related to the specific performance of the lamps and luminaires if a more accurate maintenance factor can be calculated based in the actual performance of lamps and luminaires in relation to known arrangements for lamp changing and luminaire cleaning.

The finish of the walls plays a significant part in the effectiveness of the lighting, and in order to maintain the designed performance, cleaning is particularly important, including frequent washing of walls and luminaires, with the actual cleaning cycle related to the luminaire and lamp maintenance factors used in the calculation of the lighting levels.

Monitoring of the re-lamping and cleaning regime can be used to ensure that the maintenance factor does not fall below that used in the design calculations, or that failed lamps do not give rise to an unacceptable degree of uniformity.

Annex B (informative)
Lighting systems

B.1 General

There are two artificial lighting systems in common use; symmetrical, which provides a mixture of negative and positive contrast, and counterbeam, which provides negative contrast.

NOTE 1 A third system, pro-beam lighting, is seldom used and is not described in this annex.

The terms “symmetrical” and “counterbeam” refer to the luminous intensity distribution of the luminaires that are used for the two systems.

B.2 Symmetrical lighting systems

The symmetrical lighting system uses luminaires the luminous intensity distribution of which has a vertical plane of symmetry normal to the tunnel axis (see Figure B.1).

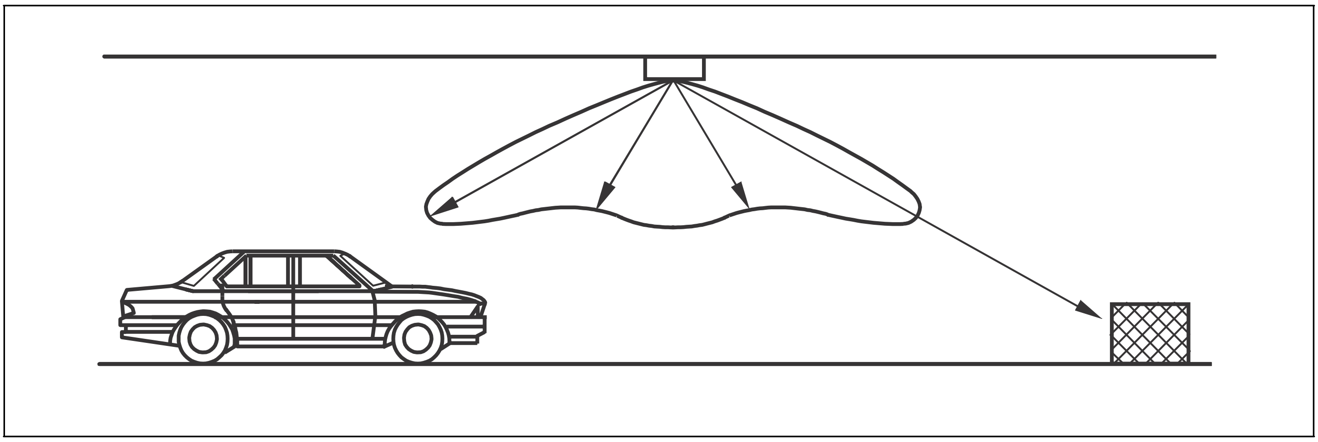


Figure B.1 — Symmetrical lighting system

Symmetrical lighting systems can provide good contrast between objects on the road and the background road surface, and assist the visibility of other vehicles moving in the same direction. It is beneficial when tunnels are bi-directional, either in normal use or during maintenance operations.

NOTE It is not necessary to take into account the contrast revealing coefficient q_c for symmetrical lighting systems.

B.3 Counterbeam lighting systems

The counterbeam lighting system uses luminaires the luminous intensity distribution of which is mainly directed towards oncoming traffic and which is consequently strongly asymmetric (see Figure B.2).

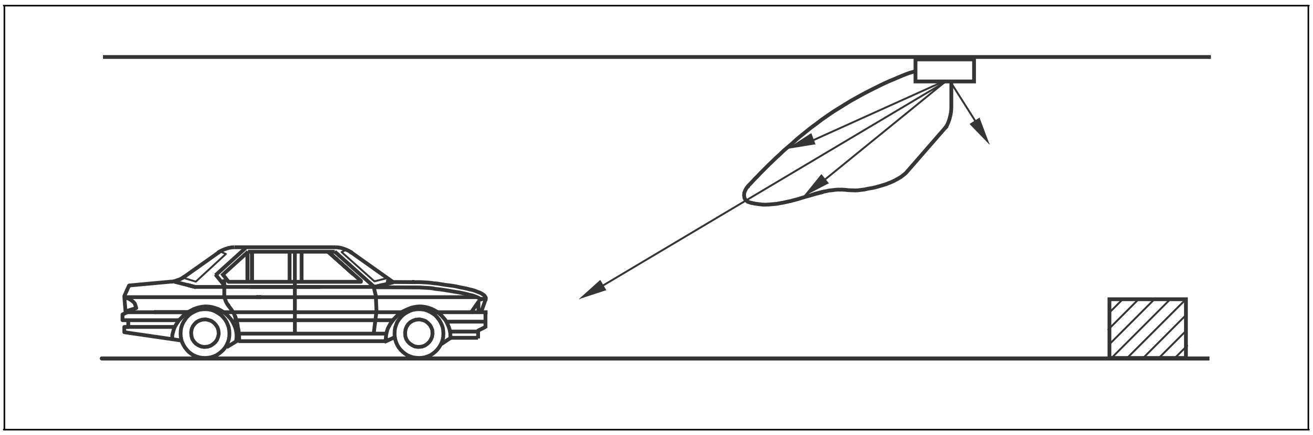


Figure B.2 — Counterbeam lighting system

Counterbeam lighting systems normally create greater contrast between objects on the road and the background road surface brightness. When specular road surfaces are used (R3, R4, C2, see the joint

CIE/PIARC publication *Road surfaces and lighting* [2]), the luminance yield usually is significantly higher than with symmetrical lighting.

NOTE For counterbeam lighting systems a minimum value of 0.6 is normally used for contrast revealing coefficient q_c.

The counterbeam system can have the following disadvantages:

— it might not be appropriate for a tunnel entrance with high daylight penetration;

— it can be less effective for tunnels with very high traffic flows or for tunnels with a high percentage of heavy goods vehicles;

— it might not be appropriate for bi-directional tunnels;

— it can be difficult to achieve the necessary luminance on the tunnel walls;

— it can reduce drivers' rearward visual performance when looking in driving mirrors.

Annex C (normative)

Determination of access zone luminance by direct measurement

NOTE The most precise determination of access zone luminance L_{20} is by direct measurement at the time of the year when its value is at a maximum. This time is most likely to be around midsummer in June, but it is possible for a tunnel in winter covered in snow to reach a higher L_{20} value.

C.1 Apparatus

C.1.1 Luminance meter, preferably accepting a 20º circular field of view (see Note), mounted on a tripod.

NOTE If a luminance meter accepting a 20º field of view is not available, then a meter with a smaller field (e.g. 3º or 1º) may be used, provided that several spot measurements of luminance are made over the 20º field and averaged to give L_{20} in the manner described in Annex D.

C.2 Procedure for existing tunnels

C.2.1 The luminance meter and tripod (C.1.1) shall be placed in the centre of the carriageway approaching the tunnel at a height of 1.5 m above the road surface and aimed with the 20º field centred on the tunnel entrance. The meter and tripod shall be positioned at a distance from the portal equal to the stopping distance.

C.2.2 Measurements shall be taken on several days when the sun is shining. Conditions with white clouds in the sky, particularly in the field of measurement, shall be included as they can produce a higher value of L_{20}. Any situation where the sun enters the 20º field of view shall be excluded from measurement because these situations result in extremely high luminance readings.

NOTE In practice drivers cope with this situation by lowering their visors.

C.2.3 A series of measurements shall be taken at both ends of the tunnel around the times when the maximum L_{20} values are reached, and shall be plotted against time.

NOTE In east–west tunnels it is probable that the maximum value at the east portal will occur in the morning and that at the west portal in the afternoon. It is not always obvious, though, when these maxima occur, and care should be taken to check whether, for example, scattered light from haze on a shaded hillside is producing a significantly high L_{20} value at a different time of day.

C.3 Procedure for planned tunnels

C.3.1 Where a tunnel is yet to be constructed, L_{20} measurements shall be made from positions corresponding to where the new road will be. The luminance meter shall be aimed at the point to be occupied by the tunnel entrance.

NOTE It might not be possible to position the meter precisely because of the terrain and/or trees, etc., but a reasonably close alternative may be used. If even this is difficult, then it is better not to attempt to make direct measurements of L_{20}, but to use the method described in Annex D.

C.3.2 Measurements shall be taken as detailed in C.2.2.

NOTE Measurements made on the site of a proposed tunnel might need to be adjusted for the eventual presence of the road surface in place of the existing terrain. This can be done by measuring the average luminance of the area to be occupied by the road and comparing it with the luminance of a similarly orientated road in the vicinity, or with an appropriate luminance from the list in Table E.1 (see Annex E). If there is an appreciable difference, then a correction can be made by substituting the road luminance in a new average, weighted according to the area it occupies in the 20º field of view.

Annex D (normative)

Determination of access zone luminance by the grid method

NOTE 1 The access zone luminance L_{20} can be calculated by the grid method, which can be used either during initial design or when determining the maximum luminance for an existing tunnel. The method breaks up the field of view into small areas so that individual luminance values can be applied to each area and then an average luminance level is calculated for the whole area. This method is an approximation and its accuracy is dependent on the particular luminances used in the calculation.

The view of the tunnel as seen at the stopping distance *SD* before the entrance portal shall be constructed in perspective using drawings, or a computer model, or obtained directly with a photograph. Whichever method is used the observation point shall be 1.5 m above the road surface at the centre of the carriageway, at a distance from the portal equal to the stopping distance *SD*.

It is necessary to know the angular extent of the view so that a circle subtending 20º at the observer's eye can be superimposed. If a photograph is used, there shall be a reference object such as a surveyor's pole in the field of view at a known distance to establish the angular scale. For an existing tunnel portal, its height *H* provides a suitable reference and then, together with the distance at which the picture was taken *SD*, an angular calibration of the photograph shall be determined using equation (D.1).

$$\theta_H = \tan^{-1} \frac{H}{SD} \qquad \text{(D.1)}$$

NOTE 2 This equation gives an approximate value.

Where the tunnel has not been constructed, and there is no reference object of known length included in the photograph, the angular height of the print shall be calculated using equation (D.2).

$$\theta_P = 2\tan^{-1} \frac{h}{2f} \qquad \text{(D.2)}$$

With the use of an overlay, the tunnel portal shall be drawn onto the photograph of the tunnel site using the appropriate scale. Similarly, the road verge, retaining walls, gantries and other objects forming part of the final field of view shall be added. Care should be taken to allow for any change in road level in the reconstruction.

NOTE 3 The overall accuracy of the drawing is not critical, provided that the main features are present to an approximate scale.

The calculation of L_{20} from the photograph, drawing or computer model shall be carried out as follows.

a) The limit of the field of view shall be added by superimposing a circle of 20º subtense centred on the tunnel portal from a viewing point height of 1.5 m from the road surface as shown in Figure D.1.

b) The 20º field of view shall be divided into segments (see Figure D.2) and each segment identified with a reference number or letter. A luminance value *L* shall be assigned to each segment using a measured value taken at the site or a typical value from Table D.1.

c) A schedule of the segments shall be made up (an example is shown in Table D.2) showing the area *A* of each segment, its assigned luminance *L* and the product of the two, $A \times L$. The average luminance L_{20} shall then be calculated using equation (D.3).

$$L_{20} = \frac{AL}{A} \qquad \text{(D.3)}$$

NOTE 4 The finish of the portal and retaining walls can have a significant effect on the value of access zone luminance, and thus on the recommended level of threshold zone lighting. It can be beneficial to consider the effect of different finishes, so that appropriate advice can be given to the tunnel designer.

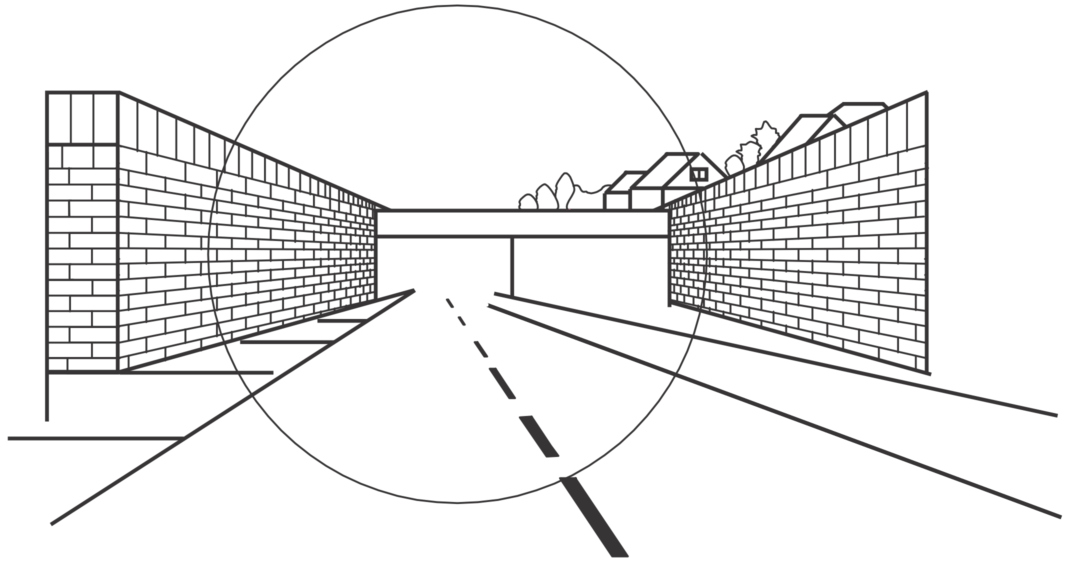
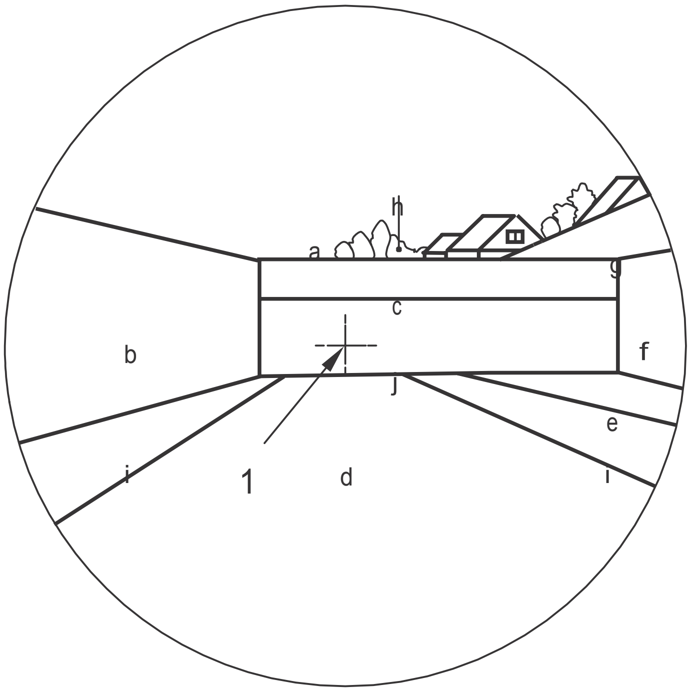


Figure D1 – perspective view of a tunnel entrance with superimposed 20° subtense circle



Key
1 Centre of entrance portal

Figure D.2 — 20º field of view divided into assessment areas

Table D1 — Typical luminance values

Background	**Luminance, *L*** cd/m^2
Earth/sand	3 500
Grass	2 000
Hill (rock, scree)	3 500
House (brick)	3 500
Portal (dark)	1 000
Road (asphalt)	4 000
Road (asphalt) in sun when facing in southerly direction	6 000
Road (concrete)	8 000
Sky (clear)	8 000
Sky (hazy, bright) occurs when facing in southerly direction	20 000
Tree	1 000
Wall (dark)	1 000
Wall (light)	6 000

NOTE These values are for midsummer in full sun with horizontal illuminance approximately 100 000 lx. Where a surface is in shadow at the time that the value of L_{20} is at a maximum, then the value of L given for that surface should be multiplied by 0.25.

Table D2 — Example of determination of access zone luminance, L_{20}

Segment [a]	**Background**	**Area, *A***[b]	**Luminance, *L*** cd/m^2	**Product of** $A \times L$
a	Sky (clear)	2 600	8 000	20 800 000
b	Dark wall	1 150	1 000	1 150 000
c	Dark wall over portal	300	1 000	300 000
d	Road (asphalt) in sun	3 300	4 000	13 200 000
e	Road in shadow	80	1 000	80 000
f	Dark wall in shadow	128	250	32 000
g	House (brick) in shadow	130	875	114 000
h	Trees	90	1 000	90 000
i	Sandy medians	800	3 500	2 800 000
j[c]	Tunnel interior	922	—	—
Total	—	9 500	—	38 566 000

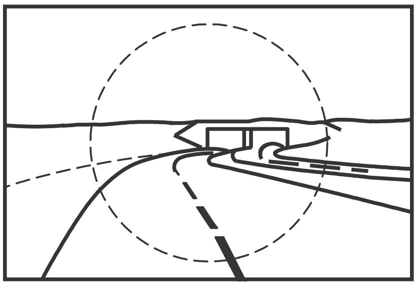
Average luminance $L_{20} = AL/A = 4\ 060$ cd/m^2

[a] As shown in Figure E.2.
[b] The units of area for *A* are relative, with all areas in a given exercise using the same units, and may be whatever is convenient to the size of the drawing or photograph in use.
[c] Where daytime lighting is to be provided to short tunnels where the exit portal is visible at the stopping distance *SD* before the entrance portal (see Annex C), due to light penetration the tunnel interior “j” will have a luminance value. This luminance value should be entered as a negative value in Table E.2, and will give a slight reduction in the value of L_{20}.

Annex C (informative)
Estimation of the access zone luminance

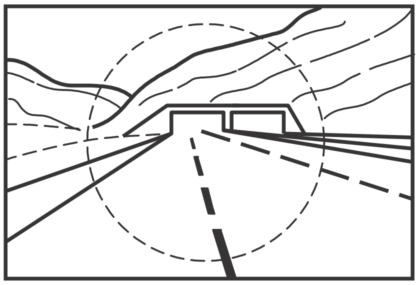
An initial estimate, for provisional design purposes only, of access zone luminance L_{20} may be obtained using Figure E.1. This gives examples of perspective views for different types of tunnel entrance. In each case an estimation of the likely access zone luminance L_{20} is shown. The view most similar in terms of topography and stopping distance should be selected and, taking into account the orientation of the tunnel entrance, the approximate value for L_{20} noted.

NOTE The methods to be used in the final design are described in Annex C and Annex D.



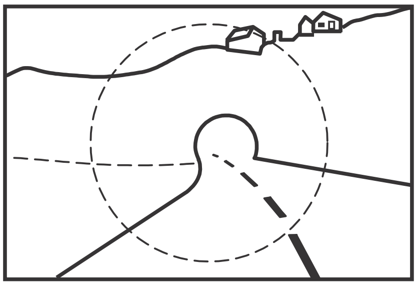
160 m distance
L_{20} driving north 5 000 cd/m^2
L_{20} driving south 7 500 cd/m^2

a) High speed rural road, low horizon



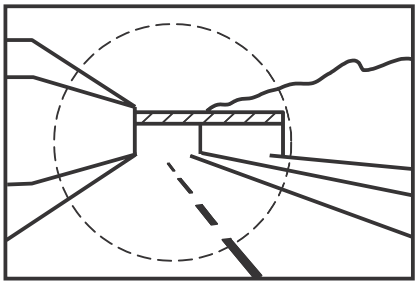
90 m distance
L_{20} driving north 4 000 cd/m^2
L_{20} driving south 5 500 cd/m^2

b) Medium speed rural road, hilly background



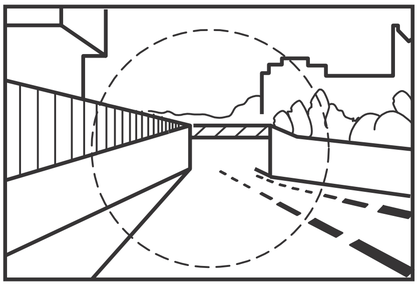
90 m distance
L_{20} driving north 3 000 cd/m^2
L_{20} driving south 3 000 cd/m^2

c) Medium speed rural road, tunnel bored in hillside



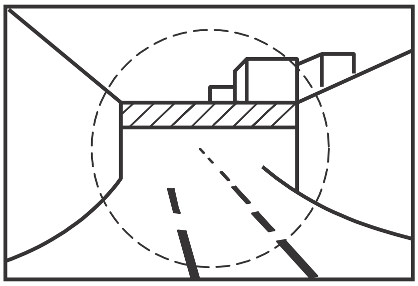
90 m distance
L_{20} driving north 4 500 cd/m^2
L_{20} driving south 7 000 cd/m^2

d) Medium speed urban road, low rise buildings



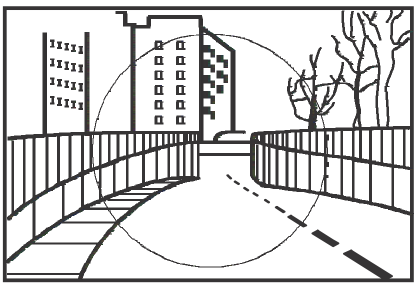
90 m distance
L_{20} driving north 3 500 cd/m^2
L_{20} driving south 5 500 cd/m^2

e) Medium speed urban road, high-rise buildings with landscaping



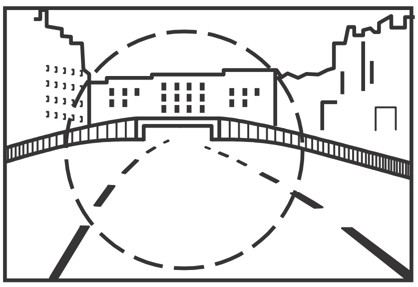
50 m distance
L_{20} driving north 3 000 cd/m^2
L_{20} driving south 4 000 cd/m^2

f) Low speed urban underpass



90 m distance
L_{20} driving north 3 000 cd/m^2
L_{20} driving south 4 000 cd/m^2

g) Medium speed urban road, high-rise buildings in close proximity



160 m distance
L_{20} driving north 4 500 cd/m^2
L_{20} driving south 6 500 cd/m^2

h) High speed urban road, high-rise buildings

Figure E.1 — Examples of tunnel approaches giving access zone luminances to be used

Annex F (Informative)

Periodic inspection of emergency lighting systems

Safety and evacuation lighting systems should be periodically inspected in accordance with Table F1

Table F1 Emergency lighting inspection

Monthly	• Visually check that all lamps are operating and that all system healthy indicators on Central Power Supply Systems (Central Battery Systems) are illuminated. • Check that any system fault recorded is given urgent attention and record all corrective actions in the log book provided. • Check all luminaires and other emergency lighting equipment are in a good condition, and that all lamps and light controllers are clean, undamaged and not blackened. • Briefly test all emergency lighting equipment by simulating a failure of the normal lighting supply. The test should not exceed a quarter of the equipment rated duration. Check that all equipment functions correctly. • Check that, upon restoring the mains supply, all supply healthy indicators are again illuminated.
Annually	• A full system test should be conducted by a competent service engineer. • Compliance of the installation and system with local requirements should be considered and documented.

The results of all testing and any necessary corrective action should be recorded in a log record held on site, to be available if required for inspection by any authorised person.

Annex G (Informative)
Uncertainty in measurement of illuminance

There are many factors that introduce uncertainties (inaccuracies) into the measurement of illuminance in an installation. Generally point values (values at individual calculation grid points) are more uncertain and in some cases substantially more uncertain than the overall average. This is particularly true for the key point value of E_{min}, which often depends upon intensity in directions where the luminaire light distribution might be changing quite rapidly, and small changes in luminaire position or angle can have much greater effects on the intensity at the point of interest.

It is important to recognize the likely effect of these uncertainties when making measurements, and when subsequently comparing the measured values with those calculated. There is such a variety of installation geometries and light distributions that it is impossible to give blanket values to the uncertainty that ought to be applied to illuminance measurements. Table G.1 gives examples of the magnitude of the uncertainties for a number of factors. However, values differ for different luminaires (sensitivity of light distribution to lamp position, for example), for different lamp types (large lamps such as fluorescent lamps are less sensitive, but are usually sensitive to ambient temperature), and for different installation geometries.

Therefore, uncertainties ought to be assessed, where possible, for the specific installation to be measured, by calculating the sensitivity of the installation to various factors. The installation design is calculated with the nominal values of the parameters, and the effect of variations in these parameters on the designed performance needs to be checked. It is often useful to see what effect each variation has on the average and minimum illuminance value. Where possible, it is advisable to use values quoted by the manufacturer for lamp light output tolerance, when operated on the particular control gear being used, and tolerance in luminaire performance (total light output and variation in intensities). Any lamp sensitivity to temperature also needs to be taken into account.

To ensure the best measurement accuracy, it is important to control those factors that can be controlled and to eliminate as many uncertainties as possible by, for example:

- making sure the exact geometry of the installation (luminaire spacing and layout) is known, to allow comparison of the calculated and measured values on a like-for-like basis;
- measuring voltage and applying any correction factors;
- only using a meter that conforms to prEN YYYY with up-to-date calibration and correcting for ambient temperature etc.;
- using the correct measuring technique; and
- if the installation is not new, considering the effect of dirt on the luminaire glazing.

Many factors are under the control of the supplier or installer; for example, ensuring that the luminaire is installed level and correctly positioned and spaced, and that the luminaire height above carriageway is as designed.

If factors such as these are properly controlled, the uncertainty associated with them can be reduced or eliminated. The accuracy required ought to be specified as part of the installation design.

Uncertainties are not all incremental in their effect. They do not all occur at their maximum, nor all in the same direction. One way to combine them to give an indication of the overall uncertainty value is to use the root of the sum of the squares value. This involves summing the squares of the percentage uncertainties of each of the contributing factors, and taking the square root. For example, taking just three factors from Table G.1:

- if the variation in lamp output is ±5%, and
- the variation in meter reading is ±6%, and
- the variation in supply voltage measurement is ±1% (equal to ±2.5% in light output),

then the overall uncertainty in illuminance could be:

$$\sqrt{5^2 + 6^2 + 2.5^2} = \pm 8\% \qquad \text{(G1)}$$

Table G1 - Typical uncertainties in parameters and examples of their effect on illuminance values

Factor	Uncertainty	Suggested value	Example of effect on	
			E_{av} %	E_{min} %
Lamp output	Variation in light output of production lamps from published value used in calculations. These are typical values. Values for the particular lamp/manufacturer being used ought to be obtained.	SOX ±6% SON ±4% CMH ±2% CFL ±5%	±6 ±4 ±2 ±5	±6 ±4 ±2 ±5
Luminaire output	Variation in light distribution and output due to manufacturing tolerances on luminaire Variation in intensities (HID reflector optic) Variation in light output due to variation in HID arc tube position within optic	±10% ±2% light output	±2	±10 up to ±30
Mounting height	Variation in luminaire mounting height above carriageway due to tolerances in carriageway surface and luminaire mounting.	± 150 mm	up to ±3	up to ±2
Spacing	Variation in luminaire positioning (E_{av} is inversely proportional to change in spacing).	± 150 mm	up to ±3	up to ±5
Tilt	Variation in luminaire level transverse to the carriageway due to tolerances in carriageway surface and luminaire mounting.	3°	±1	±8
Supply voltage	Variation in voltage of ±6%, typically giving up to ±15% change in discharge lamp output on magnetic ballast (there ought to be no change on electronic ballast). The voltage close to the luminaire is measured, and the lamp output corrected using manufacturer's data. The tolerance then is only related to tolerance in voltage measurement.	±1% voltage	±2.5	±2.5

Maintenance (dirt)	Variation in luminaire output due to dirt on luminaire exterior. Measurements indicate that even on “clean” glazing the luminaire output may be 3% lower than with a new unused bowl.	−3%	−3	−3
Light meter	Where applicable, use of a field illuminance meter conforming to prEN YYYY.	±6% reading	±6	±6
Measuring technique	Use of different measuring techniques, e.g. positioning and levelling the meter cell accurately.	±5%	±1	±5
Design software	Variation in calculated values from different lighting design programs.	±5%	±5	±5

Bibliography

Standards publications

CR 14380:2003, *Lighting applications — Tunnel lighting*.

Other publications

[1] HIGHWAYS AGENCY. *Design manual for roads and bridges — Volume 6: Road geometry — Section 1: Links — Part 1: Highway link design*. DMRB TD9/93. London: The Stationery Office, 1993.

[2] COMMISSION INTERNATIONALE DE L'ÉCLAIRAGE. *Road surfaces and lighting*. CIE 66-1984. Paris: Commission Internationale de l'Éclairage/PIARC (World Road Association), 1984.1)

[3] INSTITUTION OF LIGHTING ENGINEERS (UK). *TR 28 – Measurement of road lighting performance on site*

1) Obtainable in the UK from CIE-UK, Delta House, 22 Balham High Road, London, SW12 9BS.