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Code of practice for the design of road lighting —

Part 2: Lighting of tunnels

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Contents

Summary of pages

This document comprises a front cover, an inside front cover, pages i to iv, pages 1 to 36, an inside back cover and a back cover.

Foreword

Publishing information

This part of BS 5489 is published by BSI Standards Limited, under licence from The British Standards Institution, and came into effect on 30 April 2016. It was prepared by Subcommittee EL/1/3,*Tunnel lighting,* under the authority of Technical Committee EL/1, *Light and lighting*. A list of organizations represented on these committees can be obtained on request to their secretary.

Supersession

This part of BS 5489 supersedes BS 5489-2:2003+A1:2008, which is withdrawn.

Relationship with other publications

BS 5489 consists of two parts:

- Part 1: *Lighting of roads and public amenity areas*;
- Part 2: *Lighting of tunnels*.

Information about this document

This is a full revision of the standard to align the standard with current best practice.

The aim of this standard is to promote wider understanding of the lighting of tunnels for motorized and mixed traffic and to give guidance on the design decisions that need to be made. It contains recommendations that are essential to the design process and that will enable production of designs that are appropriate and justifiable.

Use of this document

As a code of practice, this part of BS 5489 takes the form of guidance and recommendations. It should not be quoted as if it were a specification and particular care should be taken to ensure that claims of compliance are not misleading.

Any user claiming compliance with this part of BS 5489 is expected to be able to justify any course of action that deviates from its recommendations.

It has been assumed in the preparation of this part of BS 5489 that the execution of its provisions will be entrusted to appropriately qualified and experienced people, for whose use it has been produced.

The design of lighting for tunnels is a complex process with many different aspects and therefore it is important that this standard is read thoroughly to ensure that all relevant issues are taken into account.

Presentational conventions

The provisions of this standard are presented in roman (i.e. upright) type. Its recommendations are expressed in sentences in which the principal auxiliary verb is “should”.

Commentary, explanation and general informative material is presented in smaller italic type, and does not constitute a normative element.

The word “should” is used to express recommendations of this standard. The word “may” is used in the text to express permissibility, e.g. as an alternative to the primary recommendation of the clause. The word “can” is used to express possibility, e.g. a consequence of an action or an event.

Notes and commentaries are provided throughout the text of this standard. Notes give references and additional information that are important but do not form part of the recommendations. Commentaries give background information.

Contractual and legal considerations

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

Compliance with a British Standard cannot confer immunity from legal obligations.

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1 Scope

This part of BS 5489 gives recommendations for the design of the lighting of tunnels for motorized and mixed traffic. It is applicable to all types of road, including motorways.

This standard is applicable to those aspects of lighting that are concerned with traffic safety, such as arrangements, levels and other parameters including daylight.

This standard is not applicable to aspects of lighting that concern aesthetics.

This part of BS 5489 is not applicable to the lighting of underpasses or subways reserved for pedestrians or cyclists, which is covered in BS 5489-1.

NOTE 1 This part of BS 5489 is based on photometric considerations, and all values of luminance and illuminance are maintained levels.

NOTE 2 In this standard "lamp" and "lamps" also include LED light sources.

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.

BS 667, *Illuminance meters – Requirements and test methods*

BS 7920, *Luminance meters – Requirements and test methods*

BS EN 12665, *Light and lighting – Basic terms and criteria for specifying lighting requirements*

BS EN 13201-2, *Road lighting – Part 2: Performance requirements*

BS EN 13201-3:2015, *Road lighting – Part 3: Calculation of performance*

BS EN 13201-4, *Road lighting – Part 4: Methods of measuring lighting performance*

3 Terms, definitions and symbols

3.1 Terms and definitions

For the purposes of this part of BS 5489, the terms and definitions given in BS EN 12665, BS EN 13201-2, BS EN 13201-3 and the following apply.

3.1.1 access zone

part of the open road immediately in front of an entrance portal, covering the distance over which an approaching driver can see into a tunnel

3.1.2 access zone length

distance between the stopping sight distance point ahead of an entrance portal and the entrance portal itself

3.1.3 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 sight distance from the entrance portal and 1.5 m above the middle of the relevant carriageway or traffic lane.

3.1.4 carriageway
part of a road normally used by vehicular traffic

3.1.5 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

3.1.6 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

3.1.7 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.

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

3.1.9 emergency lane
lane parallel to the traffic lane(s), not intended 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".

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

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

3.1.12 exit portal
end of the covered part of a tunnel or, when daylight screens are used, end of the daylight screens

3.1.13 exit zone
part of a tunnel where, during daytime, the vision of a driver approaching the exit is influenced predominantly by the brightness outside the tunnel

NOTE The exit zone stretches from the end of the interior zone to the exit portal of the tunnel.

3.1.14 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 beginning of the exit zone.

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

3.1.16 look-through percentage
area of the apparent exit portal of a tunnel, as a percentage of the area of the apparent entrance portal, when viewed in perspective from the stopping sight distance

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

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

3.1.19 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.

3.1.20 speed limit
maximum legally allowed speed on any given road

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

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

3.1.23 threshold zone
first part of a tunnel, directly after the entrance portal

NOTE The threshold zone begins at the entrance portal.

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

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

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

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

3.1.28 transition zone
part of a 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.

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

3.1.30 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 part of BS 5489, the following symbols apply.

A area of a segment on a perspective view of a tunnel entrance

E_w maintained wall illuminance, in lux (lx)

f	focal length of camera lens, in millimetres (mm)
H	height of tunnel entrance portal, in metres (m)
H_L	mounting height of luminaire, in metres (m)
h	height of printed film negative, in millimetres (mm)
I_w	luminous 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_w	maintained wall luminance, in candelas per square metre (cd/m^2)
L_{20}	access zone luminance, in candelas per square metre (cd/m^2)
LTP	look-through percentage
MF	maintenance factor
P	height of calculation point on wall above road surface, in metres (m)
q_c	contrast revealing coefficient
SSD	stopping sight 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 (°)
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 (°)
θ_H	angle subtended by tunnel height, in degrees (°)
θ_P	angular height of print, in degrees (°)
ρ_{dif}	diffuse reflection factor of wall
Φ	initial luminous flux of the lamp(s) in luminaire, in kilolumens (klm)

4 Tunnel conditions

4.1 General

*COMMENTARY ON **4.1***

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. Lighting can prevent any feeling of anxiety and 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 external lighting conditions, the speed, volume (traffic flow) and composition of the traffic, the layout of the approach road and the tunnel, and the immediate surroundings.

Tunnels should be classified according to the traffic flow, and the type and mix of traffic, in accordance with **5.2**.

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

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

4.2 Daytime conditions

*COMMENTARY ON **4.2***

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 needs to be a sufficiently high lighting level to maintain visibility. If the lighting level is not high enough, the driver might be unable to see into the tunnel, the so-called "black hole effect".

During approach and entry to a tunnel, drivers' eyes adapt 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 should be sufficient to:

a) avoid the "black hole effect" when a driver is unable to see into the tunnel;

b) reduce the likelihood of a collision with another vehicle (or cyclist or pedestrian);

c) enable a driver to react and stop within the stopping sight distance, *SSD* (see **5.1**), if an unexpected hazard appears;

d) provide visual guidance.

For tunnels longer than 200 m, the lighting design should be designed in accordance with Clause **5**. For shorter tunnels, the recommendations in **4.4** should be followed.

A linear lighting system or illuminated road studs can reinforce visual guidance. However, lighting levels should not be reduced.

4.3 Night-time conditions

During night-time the "black hole effect" does not exist, as the external luminance values are low. Lower lighting levels than during daytime should be used in the tunnel, with all zones treated in the same manner (see **5.7**).

4.4 Daytime lighting of short tunnels

*COMMENTARY ON **4.4***

Lighting design for short tunnels differs according to the degree to which an approaching driver can see through the tunnel to the exit portal, from a point at a distance equal to the stopping sight distance in front of the entrance portal.

The ability of a driver to see through a tunnel depends primarily on the length of the tunnel, although other design parameters also have an effect (width, height, horizontal and/or vertical curvatures, etc.).

The critical factor is whether approaching drivers can see vehicles, other road users or obstacles when their distance from the entrance portal is less than or equal to the stopping sight distance. When the exit portal is a large part of the scene visible through the entrance, other road users and objects can easily be seen silhouetted against the lighter scene behind the exit portal. On the other hand, when the exit portal is in a relatively large dark frame, other road users and objects can be hidden. This can happen when a tunnel is relatively long in relation to width, or when a tunnel is curved in such a way that only a part of the exit can be seen or the exit cannot be seen at all.

Tunnels shorter than 25 m do not normally need daytime lighting. For tunnels of length between 25 m and 200 m, the method described in Annex C should be used to determine what daytime lighting is needed, if any. If full daytime lighting is needed, it should be in accordance with Clause **5**.

NOTE A tunnel of length 200 m or less is a short tunnel.

5 Tunnel lighting design

5.1 Determination of stopping sight distance

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

Table 1 **Stopping sight distances for various design speeds**

Design speed A) km/h	**Stopping sight distance (*SSD*)** m
120	215
100	160
85	120
70	90
60	70
50	50

A) The design speed is that which is applicable to normal usage of the tunnel. In abnormal usage, such as contraflow operation, the design speed does not apply.

NOTE 1 These values are extracted from Volume 6, Section 1, Part 1 of the Highways Agency publication DMRB TD9/93 [1]. At the time of publication of this standard, TD9/93 is undergoing revision.

NOTE 2 Where a speed limit of 20 mph applies, SSD can be taken as 35 m.

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 design should take account of the following influencing factors:

a) traffic flow;

b) traffic type and mix;

c) visual guidance.

Traffic flow should be classified as high, medium or low in accordance with the values in Table 2.

Table 2 **Traffic flow**

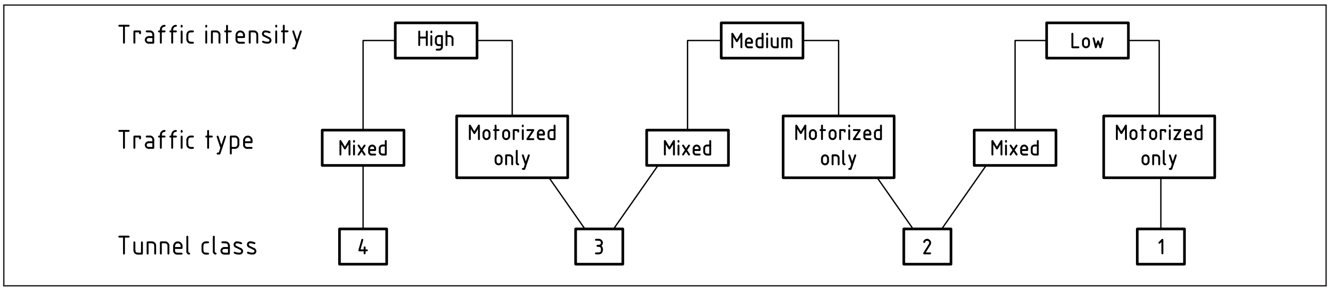
Traffic flow category	Volume/rate of flow[A)]	
	One-way traffic	Two-way traffic
High	>1 500	>400
Medium	500 to 1 500	100 to 400
Low	<500	<100

[A)] Vehicles per hour per traffic lane during peak hour.

NOTE If the actual value is not known, peak hour traffic can be derived as follows. Average daily traffic (ADT, vehicles 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 traffic lane can be calculated by dividing peak hour value by the total number of traffic 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 traffic lanes of this carriageway.

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 ascertain the necessary daytime lighting levels within a tunnel, the access zone luminance should first be determined. The threshold zone luminance and the luminance in the other zones is governed by the access zone luminance.

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

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

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

NOTE 1 The method given in Annex F is preferable, particularly when the orientation of the tunnel is likely to produce different results for each approach.

NOTE 2 A method of estimating L_{20} is given in Annex G.

5.4 Determination of tunnel zone daytime lighting levels

5.4.1 Threshold zone

The road surface luminance of the threshold zone should be derived from the luminance of the access zone during daytime. The length of the threshold zone is equal to the stopping sight distance, *SSD*.

The threshold zone luminance L_{th} should be provided during daytime from the beginning of the threshold zone for a length of 0.5 *SSD* (see Figure 2). The appropriate value of *k* should be selected from Table 3, and the threshold zone luminance L_{th} should be calculated using equation (1).

$$L_{th} = k \times L_{20} \tag{1}$$

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 limit up to 40 mph	**Speed limit 50 mph to 60 mph**	**Speed limit 70 mph**
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 sight distance, *SSD*, onwards, the lighting level should 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 should 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 should be gradually reduced from the threshold zone towards the interior zone. At any position in the transition zone, the transition zone luminance L_{tr} should be not less than the luminance derived from Figure 2.

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

5.4.3 Interior zone

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

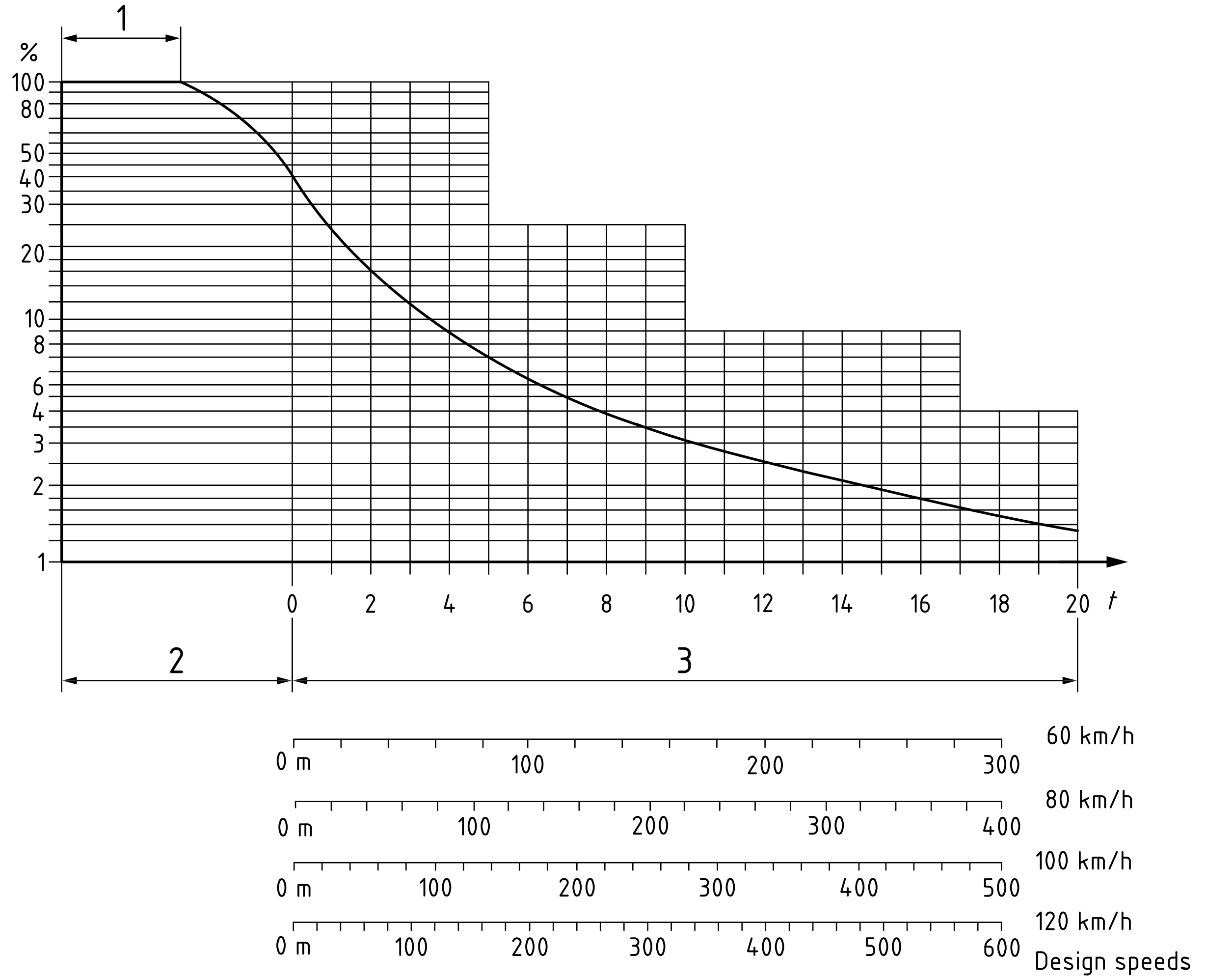
Table 4 **Road surface luminance of the interior zone**

Values in candelas per square metre (cd/m²)

Tunnel lighting class	Average luminance		
	Speed limit up to 40 mph	Speed limit 50 mph to 60 mph	Speed limit 70 mph
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 levels.

Figure 2 **Luminance reduction curve**



Key

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

2 Threshold zone stopping sight distance (*SSD*)

3 Transition zones [A)]

A) The curve can 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.

5.4.4 Exit zone

Where traffic is likely to be weaving in the exit or parting zones or there is a junction shortly after the exit portal, additional lighting should be provided in the exit zone to:

a) give direct illumination of smaller vehicles which can otherwise be inconspicuous behind larger vehicles because of the glare effect of the exit;

b) enable drivers who are leaving the tunnel to have sufficient rear vision via their mirrors.

If additional lighting is provided in the exit zone, a road surface luminance value of about 5 × L_{in} should be provided in this zone, and the length of the zone in metres (m) should be numerically equal to the design speed in kilometres per hour (km/h).

NOTE 1 In a two-way tunnel, the threshold zone lighting for the opposing traffic provides the recommended luminance.

NOTE 2 When a one-way tunnel is likely to be used in two directions (e.g. during maintenance) exit zone lighting, if provided, can be sufficient to function as threshold zone lighting for the other direction as this is usually related to traffic travelling at reduced speed through a traffic management area.

If additional lighting is not provided at the exit zone, the road surface luminance should remain at L_{in}.

5.5 Luminance and uniformity values

For all zones, the average road surface luminance values recommended in **5.4.1**, **5.4.2**, **5.4.3** and **5.4.4** should be provided for the total carriageway width of the tunnel, including emergency lanes where present.

NOTE 1 The luminance values given are maintained levels.

During daytime, road surface luminance uniformity in the first half of the threshold zone, the whole of the interior zone and the exit zone should be not less than the values given in Table 5 for the appropriate tunnel lighting class. Overall uniformity should be calculated for the full road width, i.e. for the traffic lane(s) and for the emergency lanes if they are provided in the tunnel. Longitudinal uniformity should be calculated for each lane separately, including emergency lanes where they are provided.

*NOTE 2 It might be appropriate to measure tunnel lighting installations after completion to ensure that the design recommendations have been met. Recommendations for measurement are given in Clause **6**.*

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	—	—

5.6 Tunnel walls

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

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

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

5.7 Determination of night-time lighting levels

If the tunnel is on a section of illuminated road, the night-time luminance and uniformity inside the tunnel should be not less than the access road luminance and uniformity. If the road lighting is dimmed at certain times the tunnel lighting should follow the same regime. If the road lighting operates part-night only, the tunnel lighting should remain in operation throughout the night.

If a tunnel on a section of unlit road and is between 25 m and 200 m in length, the highway authority should be consulted regarding provision of night-time lighting, taking account of matters including tunnel lighting class, type of usage at night and environmental considerations.

NOTE 1 If a tunnel is shorter than 25 m it does not normally need to be lit;

*NOTE 2 For tunnels between 25 m and 200 m in length, if daytime lighting is provided (see **4.4** and Annex C), night-time lighting is normally also required.*

Tunnels longer than 200 m should be lit at night to a luminance level of not less than 1.0 cd/m^2.

Where night-time lighting is provided in a tunnel on an otherwise unlit length of road, lighting on a short section of the access zone and parting zone can assist the driver's visual adaptation on entering and leaving the tunnel. The decision to provide such lighting is a matter for the highway authority. Where such lighting is provided, the length of this section should be not less than the stopping sight distance, *SSD*, related to the tunnel design speed in Table 1, unless there are particular reasons (e.g. environmental) for a reduced length.

NOTE 3 Recommendations for night-time lighting of roads are given in BS 5489-1.

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

5.8 Flicker

*COMMENTARY ON **5.8***

The sensation of flicker can cause visual discomfort to drivers and in some cases can induce epileptic seizures. It arises from 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.

NOTE 1 Where the duration of the flicker experience [i.e. the time taken to pass through the zone(s)] is not greater than 20 s, the flicker effect may be ignored.

NOTE 2 Luminaires comprising a linear arrangement of evenly spaced LEDs may be treated as linear luminaires.

NOTE 3 Where linear luminaires are used and the unlit length between adjacent flashed areas in a luminaire row is less than half the flashed length of a luminaire, the flicker effect is low and can be ignored.

In all other situations, the effect of flicker should be minimized by ensuring that the flicker frequency falls outside the band 2.5 Hz to 15 Hz.

NOTE 4 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.

5.9 Glare

Disability glare reduces visibility, and should be minimized. If disability glare is minimized under tunnel lighting conditions then discomfort glare is also minimized. Disability glare effects can be quantified by means of threshold increment, *TI*, which should be calculated in accordance with **6.1**.

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

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

NOTE 1 There are no recommendations for TI values for the exit zone during daytime.

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

NOTE 2 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 meet the recommendations given in this standard, provided the same type of luminaire/optical system is used for all zones.

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

5.10 Lighting controls

The access zone luminance varies with changes in daylight conditions. During the day, the luminance levels in the threshold and transition zones should 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. Dimming systems are usually more energy efficient.

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 sight distance, SSD, 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.

NOTE 3 Where real-time data on traffic speed and/or traffic flow are available this may also be used to control the tunnel lighting levels. However, it is impractical to dynamically adjust SSD, which remains fixed.

The switching or dimming control should be damped to prevent transient variations in the tunnel lighting shorter than a few seconds. Damping should be increased to several minutes where switching of discharge lamps is involved.

If the control system utilizes switched 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.

NOTE 4 More switched steps give reduced electricity consumption.

The ratio between successive steps in luminance levels should not exceed 3:1.

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

5.11 Mains failure lighting

In the event of a failure in the normal power source that supplies the lighting system, an emergency uninterruptible power supply should be available to energize sufficient system luminaires to allow users to exit the tunnel in safety in their vehicles. Conventionally, a proportion of the luminaires responsible for night-time lighting is energized from the uninterruptible power supply. The average illuminance level of the mains failure lighting should be not less than 10 lx, and the level at any location within the tunnel should be not less than 2 lx.

NOTE 1 Requirements for evacuation lighting are specified in BS EN 16276.

NOTE 2 Mains failure lighting is sometimes referred to as "standby lighting".

6 Calculation and measurement

6.1 Calculation

When designing tunnel lighting, luminance values and uniformity ratios should be calculated for each luminance step at which the lighting is designed to operate. Luminance should be calculated in accordance with BS EN 13201-3:2015, **7.1**, **8.2**, **8.3** and **8.4**, except that grid spacing should be not less than 1.0 m.

Although performance is specified in terms of luminance, illuminance values should also be calculated using the same calculation grid for the selected design, as calculated illuminance values have the advantage of direct comparison with measured illuminance values. Illuminance should be calculated for each luminance step at which the lighting is designed to operate (see **5.10**). Illuminance should be calculated in accordance with BS EN 13201-3, **7.2**, except that grid spacing should be not less than 1.0 m.

In addition, a grid should 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 should be calculated from calculated wall illuminance values and the reflectivity of the walls, using the formulae:

Wall illuminance

$$E_\mathrm{w} = \frac{I_\mathrm{w} \times \cos^2\varepsilon \times \sin\varepsilon \times \cos\alpha \times \varphi \times MF}{\left(H_\mathrm{L} - P\right)^2} \qquad (2)$$

Wall luminance

$$L_\mathrm{w} = \frac{\rho_\mathrm{dif} \times E_\mathrm{w}}{\pi} \qquad (3)$$

where

E_w is the maintained vertical illuminance at the calculation point, in lux (lx);

I_w is the luminous intensity in the direction of the calculation point, in candelas per kilolumen (cd/klm);

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(s), in kilolumens (klm);

MF is the maintenance factor;

H_L is the mounting height of the luminaire, in metres (m);

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

L_w is the maintained wall luminance, in candelas per square metre (cd/m²); 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 negligible.

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 should include contributions from all luminaires within a distance of 12 × H_L in all directions from the calculation point.

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

When calculating luminance and illuminance values a maintenance factor, *MF*, of 0.7 should 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.

Threshold increment, *TI*, should be calculated in accordance with BS EN 13201-3:2015, **8.5**, except that, where the initial average road surface luminance is >5 cd/m², in equation 42 of that standard 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 0.8 to 1.05. The calculation should use a moving observer.

6.2 Measurement

6.2.1 General

*COMMENTARY ON **6.2.1***

There are many practical difficulties and uncertainties in accurately carrying out tunnel lighting measurements. Luminance values are dependent 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 depending 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.

When measurements are taken for the purpose of checking that the lighting installed conforms to Clause **5**, both luminance and illuminance values should be measured. The luminance values give a general guide to the performance as seen by the driver, but the measured illuminance values should be checked against the calculated illuminance values to verify the lighting performance.

NOTE 1 Calculated results are maintained levels allowing for luminaire maintenance factor and lamp lumen depreciation 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 depreciation factors related to the period in operation of the lamps and current condition of the luminaires.*

There can be major uncertainties in the measurement of illuminance, resulting in inaccuracy. Guidance on quantifying uncertainty in the measurement of illuminance values is given in Annex H. This Annex is derived from the relevant chapter in ILE Technical Report TR28 [2].

Measurement equipment should be as recommended in BS EN 13201-4. Luminance meters and illuminance meters should conform to BS 7920 and BS 667 respectively, and in each case should be Type F.

NOTE 2 An imaging luminance measurement device can be used instead of a luminance meter.

When using a luminance meter it should have a measuring field of 6′ of arc.

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

NOTE 3 Measurements are only valid if taken when walls, luminaires and the road surface are dry, clean and in good condition.

All measurements should be taken during dark hours to avoid the influence of daylight penetration. In addition to the lighting measurements the following data should be recorded:

a) average supply voltage during measurement period;

b) lowest supply voltage during measurement period;

c) ambient temperature;

d) condition of the road surface and tunnel walls;

e) age of lamps, in terms of hours of operation.

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

6.2.2 Threshold and transition zones

A single transverse row of measurement points should be established across each zone, at a position approximately one third of the zone length from the start of the zone, coincident with a row of points in the calculation grid. The observer position(s) should be in accordance with BS EN 13201-3, but 60 m in advance of the row of measurement points.

The row of measurement points should 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 m and 1.5 m.

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

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

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

6.2.3 Interior zone

A measurement grid should be established, commencing at a position approximately one third of the zone length from the start of the zone, coincident 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 traffic lane and any emergency lane should be taken at the points indicated in Figure 3.

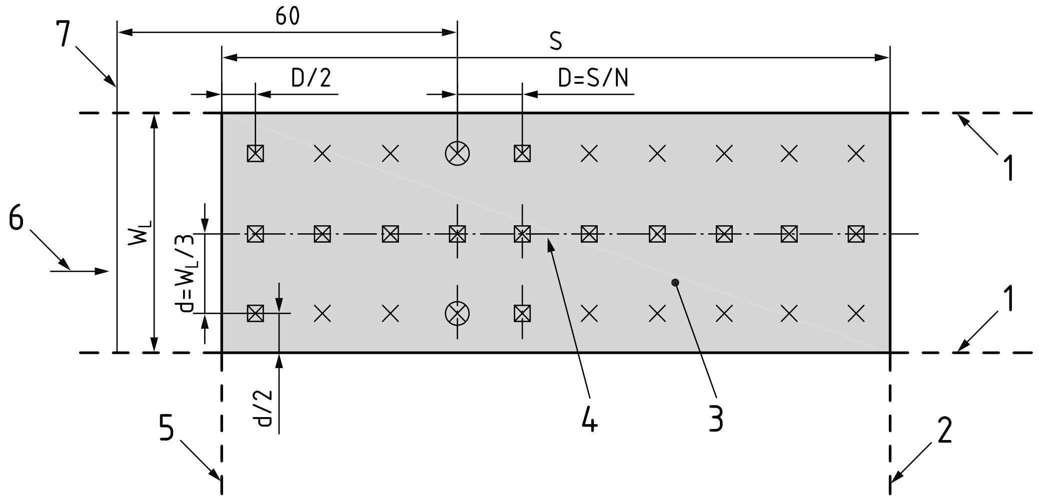
In addition, luminance and illuminance measurements should be taken on the walls in line with rows 1 and 5 at heights of 0.5 m and 1.5 m.

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

Measurements of the luminance and illuminance levels should be taken at the night-time and daytime 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.

Figure 3 **Interior zone measurement positions**



Key

1	Edge of lane	6	Observer direction
2	Centre line of last luminaire in calculation field	7	Observer's longitudinal position
3	Field of calculation	×	Denotes calculation grid points
4	Centre line of lane	○	Denotes luminance measurement points
5	Centre line of first luminaire in calculation field	□	Denotes illuminance measurement points

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 from 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.

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:
   1) portals and external road surfaces constructed with dark materials can reduce the access zone luminance, and thus reduce lighting levels in the access and transition zones. A dark tunnel facade and dark walls with a rough surface for the cutting, with surfaces with a reflectance less than 0.2, can be beneficial;
   2) the design of the tunnel facade 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, thus reducing the access zone luminance. This can be achieved with trees or other screens above the entrance portal;
   3) provision of daylight screens as part of the threshold zone can reduce the amount of artificial lighting needed. Such screens would normally be of the sun-tight type.

b) Inside the tunnel:
   1) any features such as junctions and slip roads, need particular consideration within the overall tunnel lighting scheme;
   2) a light coloured road surface and light coloured walls can increase the overall efficiency of the lighting solution;
   3) visual guidance can be enhanced by road markings and signage.

c) At the exit:

1) 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 **6** 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 **6**. 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 on the actual performance of lamps and luminaires in relation to known arrangements for lamp replacement 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 unacceptably poor 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.

NOTE 2 Cornice lighting is sometimes referred to as "asymmetrical" but the lighting system is nevertheless symmetrical.

B.2 Symmetrical lighting systems

A 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).

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).

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 CIE 144 [3]), 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:

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

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

c) it is not appropriate for bi-directional tunnels;

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

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

Figure B.1 **Symmetrical lighting system**

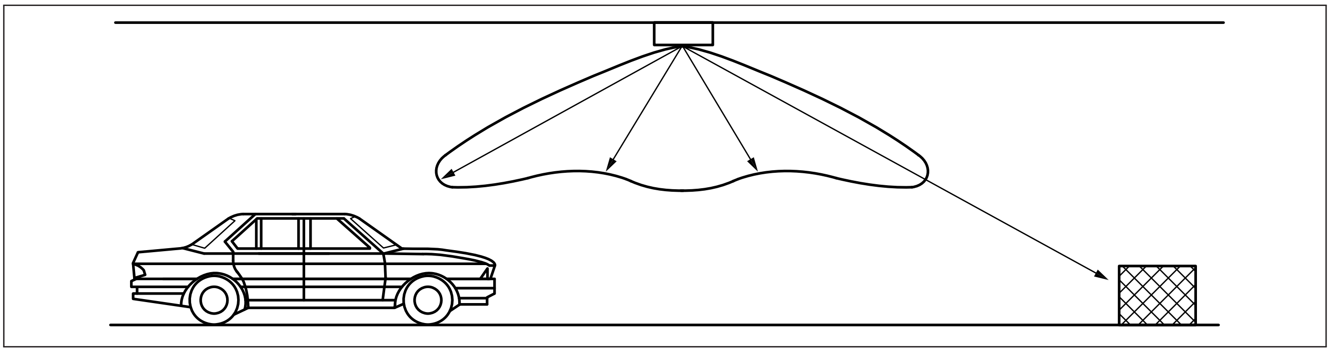
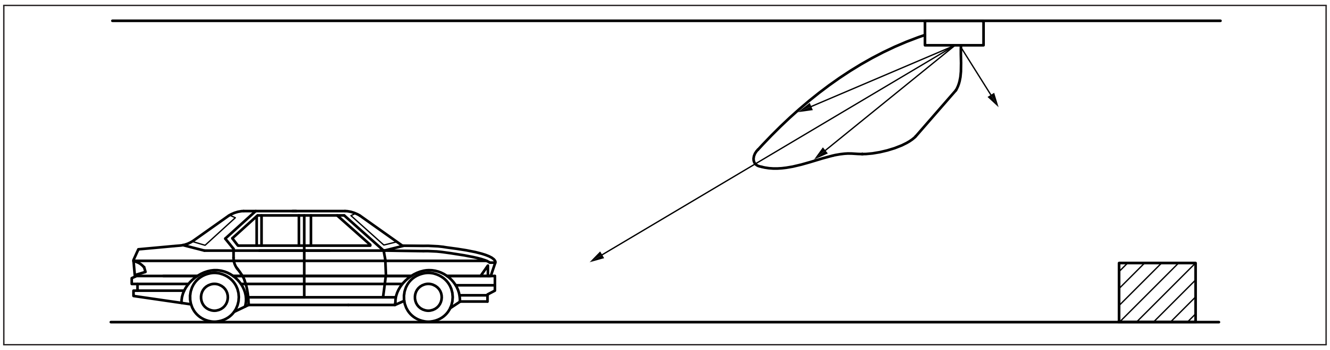


Figure B.2 **Counterbeam lighting system**



Annex C (normative) Daytime lighting of short tunnels

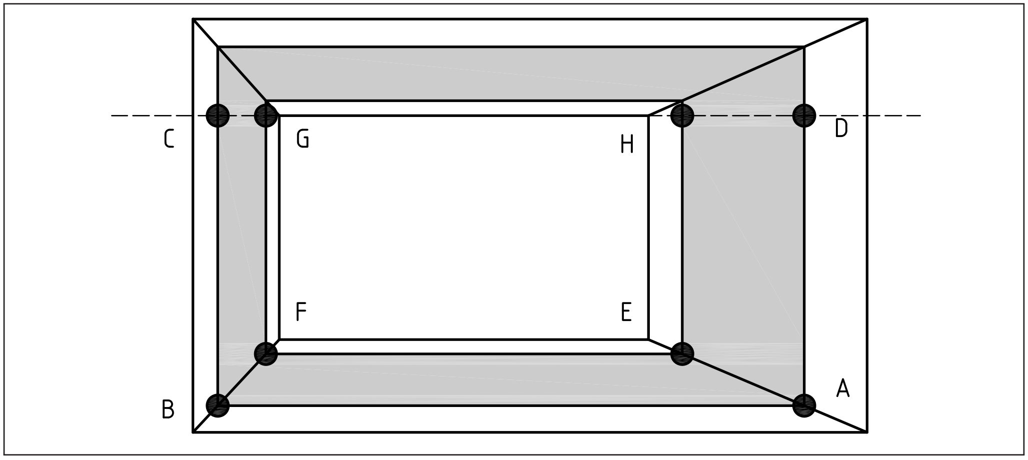
C.1 Determination of look-through percentage

The look-through percentage *LTP* should be calculated using equation (C.1).

$$LTP = 100 \times \frac{\text{surfaceEFGH}}{\text{surfaceABCD}} = 100\frac{EF \times FG}{AB \times BC} \quad (C.1)$$

where A, B, C, D, E, F, G and H are as shown in Figure C.1.

Figure C.1 **Look-through percentage**



Since the angles are small, the *LTP* should then be approximated using equation (C.2).

$$LTP = 100 \times \frac{\beta_u}{\beta_i} \times \frac{\alpha_u}{\alpha_i} \qquad (C.2)$$

where α_i, α_u, β_i and β_u are as shown in Figure C.2.

NOTE 1 The centre for the perspective drawing in Figure C.1 is:

a) a point on a horizontal line 1.2 m above the road surface;

b) in the middle of the traffic lane (if more lanes are used, to be determined for each lane);

c) at the stopping sight distance, SSD, from the daylight influenced apparent entrance portal, taken from Table 1.

NOTE 2 Where the tunnel approach sight lines are short, for example the approach is on a bend or the tunnel is part of a grade separated junction, the centre for the perspective drawing in Figure C.1 is the point furthest from the apparent entrance portal from where there is a reasonably straight view through the tunnel.

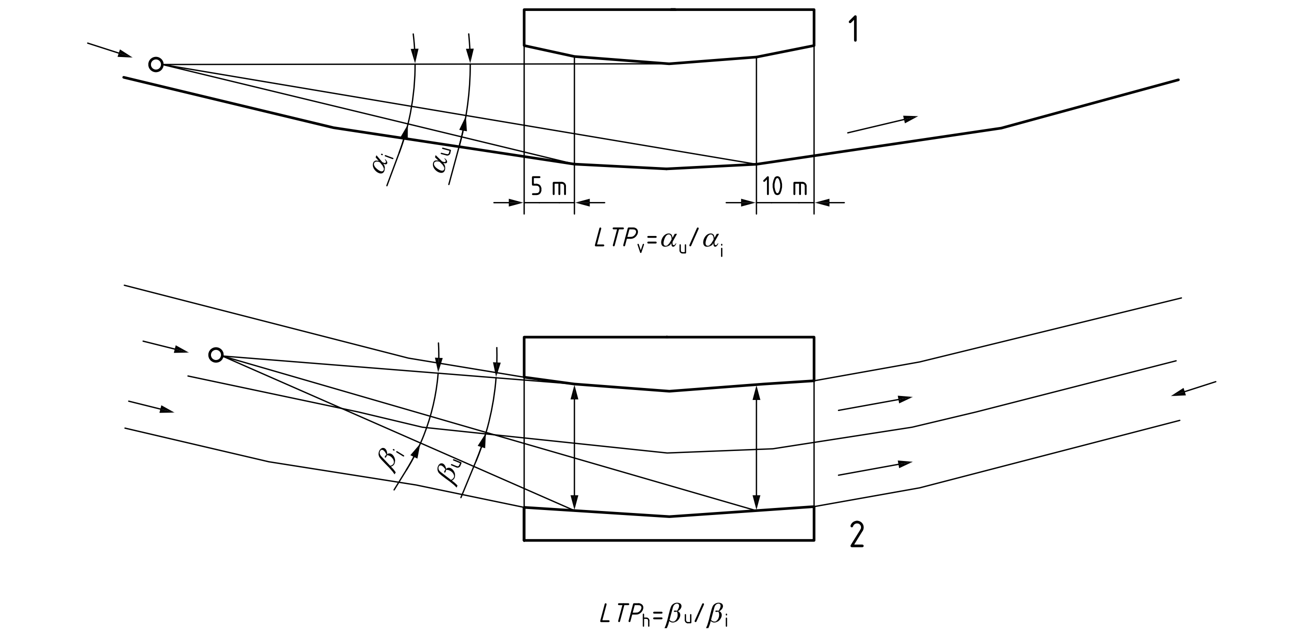
NOTE 3 The ceiling is not taken into account, because it is not normally a background against which other road users or obstacles can be hidden.

NOTE 4 Daylight penetration shortens the apparent visual length of the tunnel. Therefore, an apparent entrance and exit portal is used when determining LTP. For a box section tunnel the apparent entrance portal is normally inset about 5 m inside the tunnel and the apparent exit portal about 10 m inside the tunnel. In practice it is difficult to estimate or measure the inset distances; the 5 m and 10 m figures represent good practice. For an open abutment tunnel or where the area admitting daylight is significantly larger than for an equivalent box section tunnel, these distances may be increased to 10 m and 20 m respectively.

NOTE 5 The perspective situation can be based on drawings of the tunnel or on a photograph of an existing tunnel.

NOTE 6 In some cases a perspective drawing of the tunnel cannot be readily produced, especially when the tunnel has both a vertical and horizontal curve. In such cases, sufficient accuracy is given when the dark frame is based on drawings of the horizontal plane and vertical cross-section.

Figure C.2 **Visual angles**



Key

1 Vertical plane

2 Horizontal plane

C.2 Determination of need for daytime lighting

C.2.1 General

Daytime lighting should be provided according to the *LTP* value, as follows:

- where *LTP* < 20%, artificial daytime lighting should always be provided;
- where *LTP* > 80%, artificial daytime lighting is generally not needed;
- where 20% < *LTP* < 80%, the need for artificial daytime lighting should be determined in accordance with **C.2.2**.

C.2.2 Daytime lighting for LTP values between 20% and 80%

Where the LTP value is between 20% and 80%, a critical object representing a car, pedestrian or cyclist should be observed against the apparent exit portal of the tunnel.

For tunnels intended for motor vehicles only, a critical object representing a car should be used. This should be a rectangle 1.6 m in width and 1.4 m in height.

For tunnels intended for mixed traffic, a critical object representing a pedestrian or cyclist should be used. This should be a rectangle 0.5 m in width and 1.8 m in height.

The longitudinal position for the observer should be the same as used for the determination of look-through percentage. The longitudinal position for the object should be at the apparent entrance portal ABCD.

The transverse position of the object and observer should be in accordance with Table C.1 for the appropriate type of road.

Table C.1 **Transverse position of object and observer**

Type of road	Position of object	Position of observer
Multi-lane with emergency lane	Left-hand side, emergency lane	Centre line, traffic lane 1
Multi-lane with no emergency lane	Left-hand side, traffic lane 1	Centre line, traffic lane 1

The need for daytime lighting should be determined according to the percentage of the critical object that can be seen against the apparent exit portal. Artificial daytime lighting should be provided when either:

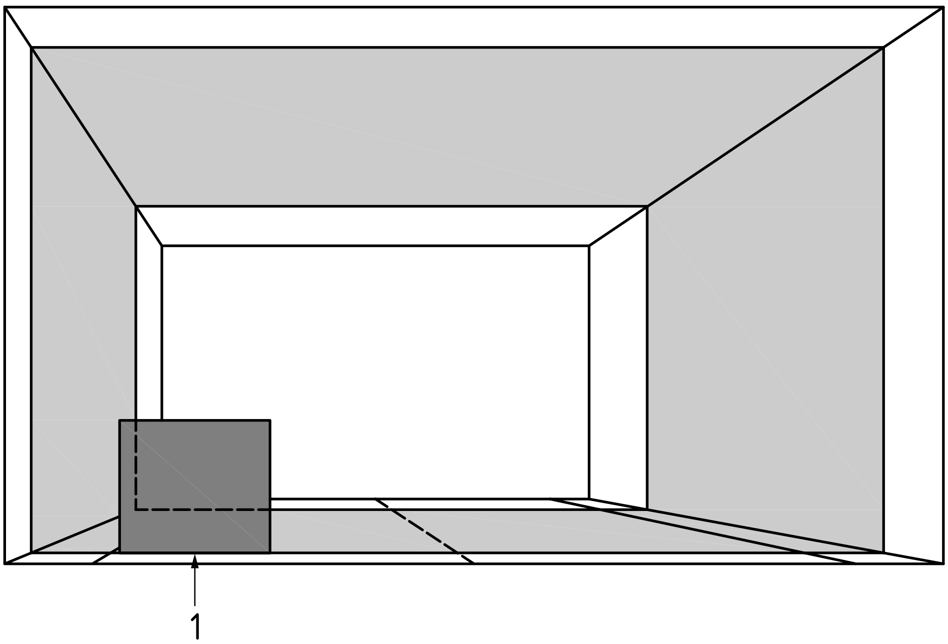
a) less than 20% of the critical object representing a car can be seen against the apparent exit portal (see Figure C.3); or

b) less than 30% of the critical object representing a pedestrian/cyclist can be seen against the apparent exit portal (see Figure C.4).

The visibility of the object in bi-directional tunnels should be calculated for both directions of travel.

NOTE For examples of types of daytime lighting see Annex D.

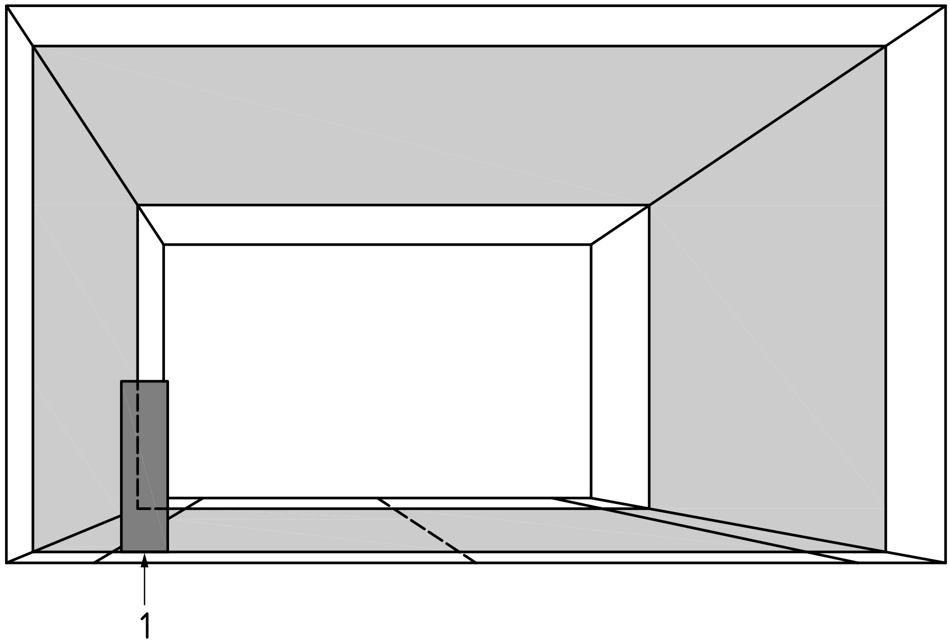
Figure C.3 **Visibility of a car**



Key

1 Vehicle 1.6 m × 1.4 m

Figure C.4 **Visibility of a pedestrian/cyclist**



Key

1 Pedestrian/cyclist 0.5 m × 1.8 m

Annex D (informative) Types of daytime lighting for short tunnels

COMMENTARY ON ANNEX D

Artificial daytime lighting for short tunnels can take many different forms. The appropriate type of lighting for each tunnel is a matter for the highway authority, taking into consideration local conditions and all relevant matters of safety and amenity.

Examples of the type of lighting that can be used for short tunnels are:

a) full daytime lighting in accordance with Clause **5**;

b) 50% of full daytime lighting;

c) limited daytime lighting of 10 cd/m² to 30 cd/m², operated when traffic flow is likely to be high, during the periods immediately before dusk and after dawn and on very overcast days;

NOTE 1 Limited daytime lighting can be controlled by a photocell and timer unit, adjusted to meet the required switching conditions.

d) reduced limited daytime lighting, as above but using the night-time lighting to achieve 0.5 to 1.5 cd/m²;

NOTE 2 The night-time lighting can be operated permanently if it is desirable to avoid having a control system.

e) A "light pool" consisting of a short high luminance section in the centre, the tunnel either side being lit to a much lower luminance.

NOTE 3 Details of this type of lighting are given in DIN 67524-1:2008-02.

f) direct illumination of one or both tunnel walls.

NOTE 4 Illumination of walls can be particularly effective where the tunnel is horizontally curved.

The following measures can significantly reduce the lighting requirement for short tunnels:

1) segregation of pedestrians and cyclists from motorized traffic;
2) light coloured walls.

Annex E (normative) Determination of access zone luminance by direct measurement

COMMENTARY ON ANNEX E

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 in Britain, but it is possible for a tunnel in winter, covered in snow, to reach a higher L_{20} value.

E.1 Apparatus

E.1.1 *Luminance meter*, preferably accepting a 20° circular field of view (see Note 1), mounted on a tripod.

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

NOTE 2 An imaging luminance measurement device can be used instead of a luminance meter.

E.2 Procedure for existing tunnels

E.2.1 The luminance meter and tripod (**D.1.1**) should 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 20° field centred on the tunnel entrance. The meter and tripod should be positioned at a distance from the portal equal to the stopping sight distance. Where this is impractical, this measurement should be taken from the position where the photometer is to be located.

NOTE Differences in results are generally negligible.

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

NOTE In practice, drivers mitigate the effects of this situation by lowering their visors.

E.2.3 A series of measurements should be taken at both ends of the tunnel around the times when the maximum L_{20} values are reached, and should 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 it is advisable 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.

E.3 Procedure for planned tunnels

E.3.1 Where a tunnel is yet to be constructed, L_{20} measurements should be made from positions corresponding to where the new road will be. The luminance meter should 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 F.

E.3.2 Measurements should be taken in accordance with **E.2.2**.

NOTE Measurements made on the site of an unbuilt 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 F.1 (see Annex F). 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 20° field of view.

Annex F (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 sight distance, *SSD,* before the entrance portal should be constructed in perspective using drawings, or a computer model, or obtained directly with a photograph. Whichever method is used the observation point should be 1.5 m above the road surface at the centre of the carriageway, at a distance from the portal equal to the stopping sight distance, *SSD*.

The angular extent of the view should be determined so that a circle subtending 20° at the observer's eye can be superimposed. If a photograph is used, there should 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 *SSD*, an angular calibration of the photograph should be determined using equation (F.1).

$$\theta_{\mathrm{H}} = \tan^{-1}\frac{H}{SSD} \qquad (F.1)$$

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 should be calculated using equation (F.2).

$$\theta_{\mathrm{p}} = 2\tan^{-1}\frac{h}{2f} \qquad (F.2)$$

With the use of an overlay, the tunnel portal should 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 should 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 should be carried out as follows.

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

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

c) A schedule of the segments should be made up (an example is shown in Table F.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} should then be calculated using equation (F.3).

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

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 F.1 **Perspective view of a tunnel entrance with superimposed 20° subtense circle**

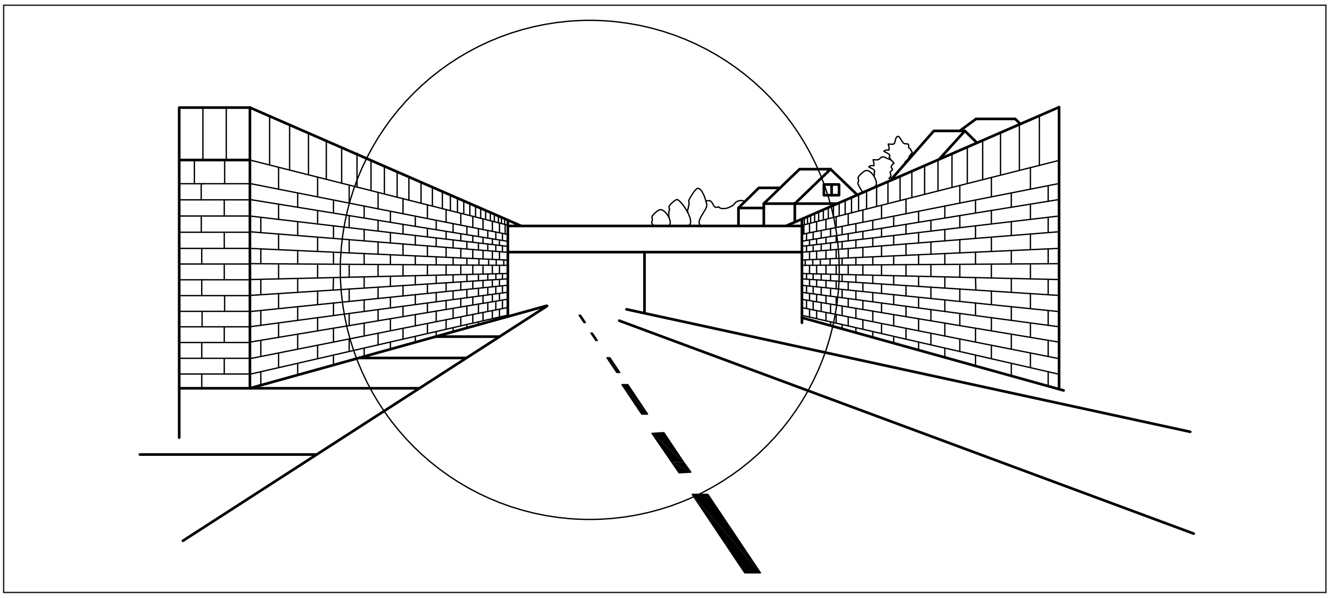
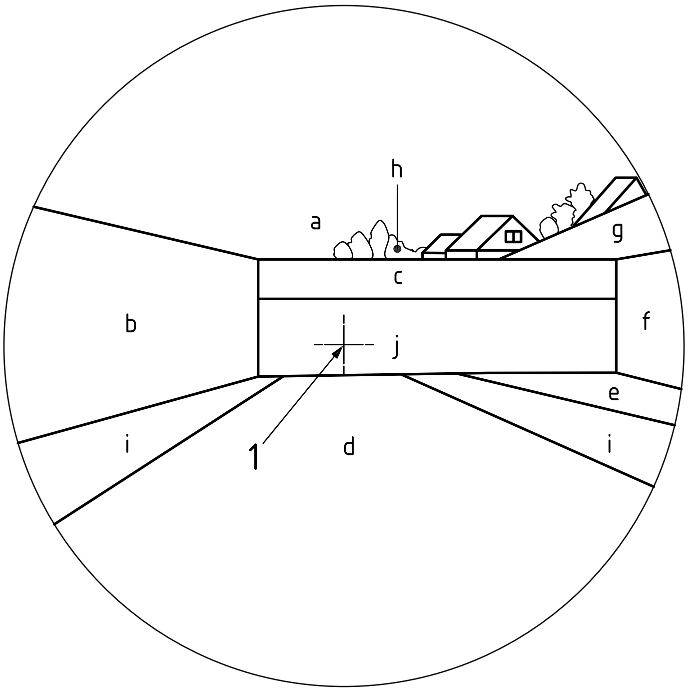


Figure F.2 **20° field of view divided into assessment areas**



Key

1 Centre of entrance portal

Table F.1 **Typical luminance values**

Background	**Luminance, *L*** cd/m²
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 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 F.2 **Example of determination of access zone luminance**

Segment[A)]	**Background**	**Area,** ***A***[B)]	**Luminance,** ***L*** cd/m²	**Product of** ***A*** **×** ***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/m²

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.

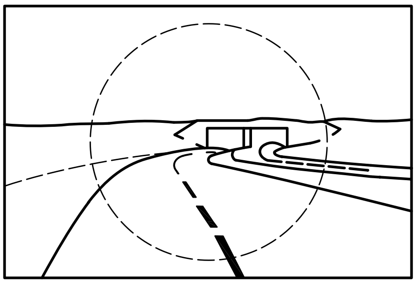
C) Where daytime lighting is to be provided to short tunnels where the exit portal is visible at the stopping sight distance, SSD, before the entrance portal (see Annex C), due to light penetration the tunnel interior "j" will have a luminance value. This luminance value should be entered as a negative value in Table E.2, and will give a slight reduction in the value of L20.

Annex G (normative) 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 G.1, which 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 sight 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 E and Annex F.

Figure G.1 **Examples of tunnel approaches giving access zone luminances to be used** *(1 of 2)*

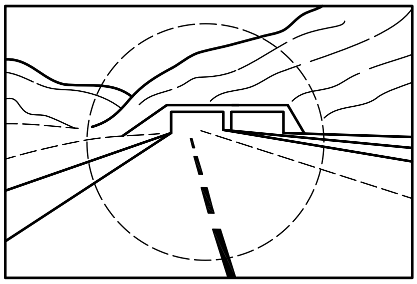


160 m distance

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

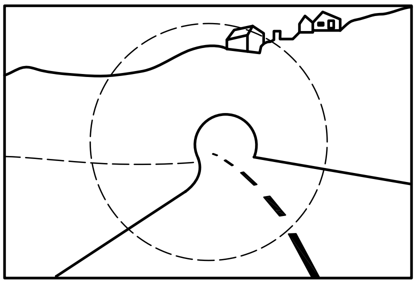


90 m distance

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

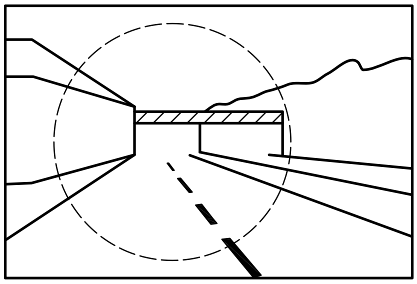


90 m distance

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



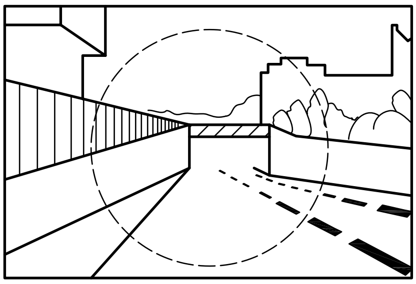
90 m distance

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

Figure G.1 **Examples of tunnel approaches giving access zone luminances to be used** *(2 of 2)*

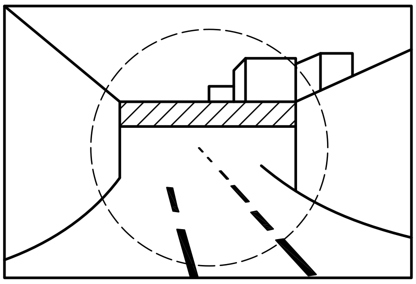


90 m distance

L_{20} driving north 3 500 cd/m²

L_{20} driving south 5 500 cd/m²

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

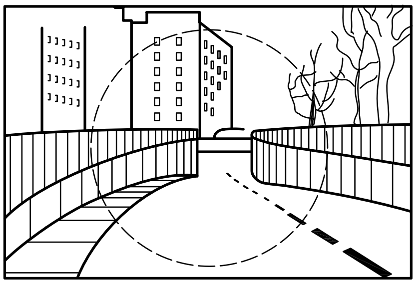


50 m distance

L_{20} driving north 3 000 cd/m²

L_{20} driving south 4 000 cd/m²

f) Low speed urban underpass

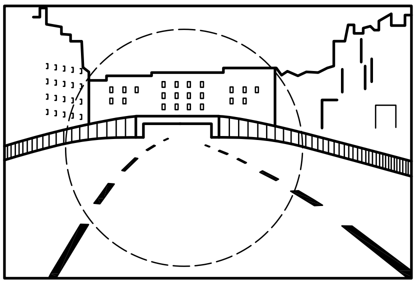


90 m distance

L_{20} driving north 3 000 cd/m²

L_{20} driving south 4 000 cd/m²

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



160 m distance

L_{20} driving north 4 500 cd/m²

L_{20} driving south 6 500 cd/m²

h) High speed urban road, high-rise buildings

Annex H (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 the minimum illuminance, 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 H.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 can 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 BS 667 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 H.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 might be:

$$\sqrt{5^2+6^2+2.5^2} = \pm 8\% \qquad (H.1)$$

Table H.1 **Typical uncertainties in parameters and examples of their effect on illuminance values** *(1 of 2)*

Factor	Uncertainty	Suggested value	Example effect on:	
			Average illuminance	**Minimum illuminance**
			%	%
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% LED ±10%	±6 ±4 ±2 ±5 ±10	±6 ±4 ±2 ±5 ±10
Luminaire output (not applicable to LED luminaires)	Variation in light distribution and output due to manufacturing tolerances on luminaire.		±2	
	Variation in intensities (HID reflector optic).	±10%		±10
	Variation in light output due to variation in HID arc tube position within optic.	±2% light output		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 (average illuminance 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 or LED drivers). 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

Table H.1 **Typical uncertainties in parameters and examples of their effect on illuminance values** *(2 of 2)*

Factor	Uncertainty	Suggested value	Example effect on:	
			Average illuminance %	**Minimum illuminance** %
Light meter	Where applicable, use of a field illuminance meter conforming to BS 667.	±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

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