SLOVENSKI STANDARD
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Uporaba razsvetljave – Razsvetljava v predorih

Lighting applications - Tunnel lighting

Eclairagisme - Eclairage des tunnels

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93.060	Gradnja predorov	Tunnel construction
93.080.40	Cestna razsvetljava in pripadajoča oprema	Street lighting and related equipment

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EUROPEAN COMMITTEE FOR STANDARDIZATION
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0 Introduction

The aim of tunnel lighting is to ensure that users, both during the day and by night, can approach, pass through, and exit the tunnel without changing direction or speed with the degree of safety commensurate to that on the approach road.

To achieve safe passage through a road tunnel, it is necessary that all users have sufficient information regarding the course of the road ahead, possible obstacles and the presence and actions of other users. Furthermore it is necessary that users,particularly drivers of motor vehicles, have at least an equal sense of security to that experienced on the approach roads.

Principal characteristics required to describe the quality of tunnel lighting are:

– the luminance and illuminance levels of the road surface;

– the luminance level of the walls up to 2 m in height above the road surface;

– the uniformity of the luminance distribution on the road and walls;

– the control of induced glare;

– the avoidance of critical flicker frequencies.

1 Scope

This CEN Technical Report gives guidance on the design of the lighting of road tunnels and underpasses for motorized and mixed traffic. This guidance concerns arrangements, levels and other parameters including daylight, which are related only to traffic safety. Aspects concerning visual comfort should be chosen in agreement with national practice. The guidance in this report may be applied to any tunnel or underpass where the decision to provide lighting has been taken by any authority working within national legislation or other constraints. The report is based on photometric considerations, and all values of luminance and illuminance are maintained values.
The main body of the report covers the common aspects of Tunnel Lighting, and the various methods currently in use in Europe are detailed in the annexes. No single method is recommended.

2 References

This Technical reports incorporates by dated or undated reference, provisions from other publications. These references are cited at the appropriate places in the text and the publications are listed in appendix. For dated references, subsequent amendments to or revisions of any of these publications apply to this Technical Report only when incorporated in it by amendment or revision. For undated references the latest edition of the publication referred to applies.

Not applicable

3 Definitions

For the purposes of this document, the definitions of prEN12665 and prEN13201 and the following apply. The definitions of zones in a tunnel are based on lighting considerations and not on aspects of installation technique or on civil engineering. The lighting terms are in agreement with the CIE Publications.

3.1 Tunnel related zones

3.1.1 entrance portal: the part of the tunnel construction that corresponds to the beginning of the covered part of the tunnel or, when open sun-screens are used, to the beginning of the sun-screens.

3.1.2 exit portal: the end of the covered part of the tunnel or, when open sun-screens are used, to the end of the sun-screens.

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

3.1.4 access zone length : the access zone begins at the stopping distance point ahead of the portal and ends at the portal.

3.1.5 threshold zone: the first part of the tunnel, directly after the portal. The threshold zone begins at the portal.

3.1.6 transition zone: the part of the tunnel following directly after the threshold zone. 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.

3.1.7 entrance zone: the combination of the threshold zone and transition zones.

3.1.8 interior zone: the part of the tunnel following directly after the transition zone. The interior zone stretches from the end of the transition zone to the beginning of the exit zone.

3.1.9 exit zone: the part of the tunnel where, during day-time, the vision of driver approaching the exit is influenced predominantly by the brightness outside the tunnel. The exit zone stretches from the end of the interior zone to the exit portal of the tunnel.

3.1.10 parting zone: the first part of the open road directly after the exit portal of the tunnel. 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.

3.2 Lighting

3.2.1 visual guidance: the optical and geometrical means that ensure that motorists are given adequate information on the course of the road in the tunnel.

3.2.2 threshold zone lighting: lighting of the threshold zone of the tunnel which allows drivers to see into the tunnel whilst in the access zone.

3.2.3 transition zone lighting: lighting of the transition zone which facilitates the drivers' visual adaptation to the lower level in the interior zone.

3.2.4 interior zone lighting: lighting of the interior zone of the tunnel which provides adequate visibility in the interior of the tunnel, irrespective of the use of vehicle headlights.

3.2.5 exit zone lighting: lighting of the exit zone which improves the visual performance during the transition from the interior zone to the open road beyond the tunnel.

3.2.6 emergency lighting: lighting provided for use when the supply to the normal lighting fails. [prEN 12665]

3.2.7 fire emergency guidance lighting: lighting providing visual guidance in the event of fire and smoke.

3.2.8 daylight screens, louvres: devices that transmit (part of) the ambient daylight. They may be applied for the lighting of the threshold zone and/or the entrance zone of a tunnel.

3.2.9 sun-tight screens: screens that are designed in such a fashion that direct sunlight cannot reach the road surface under the screen.

3.3 Luminances, illuminances

3.3.1 access zone luminance : the eye adaptation luminance in the access zone.

3.3.2 L20 access 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 tunnel mouth. L_{20} is assessed from a point at a distance equal to the stopping distance from the tunnel portal at the middle of the relevant carriage-way or traffic lane.

3.3.3 equivalent ocular veiling luminance (Lseq): the light veil as a result of the ocular scatter L_{seq} is quantified as a luminance.

3.3.4 atmospheric luminance (Latm): the light veil as a result of the scatter in the atmosphere expressed as a luminance.

3.3.5 windscreen luminance (Lwinds): the light veil as a result of the scatter in the vehicle windscreen expressed as a luminance.

3.3.6 threshold zone luminance (L_{th}): the average road surface luminance of a transverse strip at a given location in the threshold zone of the tunnel (as a function of the measurement grid).

3.3.7 transition zone luminance (L_{tr}): the average road surface luminance of a transverse strip at a given location in the transition zone of the tunnel (as a function of the measurement grid).

3.3.8 interior zone luminance (L_{in}): the average road surface luminance of a transverse strip at a given location in the interior zone of the tunnel (as a function of the measurement grid).

3.3.9 vertical illuminance (E_{v+}): the illuminance at a particular location at a height of normally 0,1 m above the road surface, in a plane facing the direction of oncoming traffic. The height of 0,1 m above the road surface is meant to represent the centre of an object of 0,2 m x 0,2 m.

3.3.10 contrast revealing coefficient (q_c): the quotient between the luminance of the road surface, and the vertical illuminance E_{v+} at that point.

$$q_c = \frac{L}{E_v}$$

where q_c is the contrast revealing coefficient in $cd.m^{-2}lx^{-1}$

3.3.11 threshold zone luminance ratio (k) at a point: the ratio between the threshold zone luminance L_{th} and the access zone luminance L_{20}.

$$k = \frac{L_{th}}{L_{20}}$$

3.3.12 overall uniformity (of road surface luminance, wall surface luminance) (U_o): ratio of the lowest to the average luminance on the reference field of calculation or measurement.

3.3.13 longitudinal uniformity (of road surface luminance of a carriageway) (U_l): ratio of the lowest to the highest road surface luminance found in a line in the centre along a driving lane. The longitudinal uniformity is considered for each driving lane.

3.3.14 veiling luminance (Lv): the luminance that, when added by superposition to the luminance of both the adapting background and the object, makes the luminance threshold or the luminance difference threshold the same under the two following conditions:

– glare present, but no additional luminance;

– additional luminance present, but no glare.

3.4 Traffic related concepts

3.4.1 carriageway: that part of the road normally used by vehicular traffic.

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

3.4.3 emergency lane (hard shoulder): a lane parallel to the traffic lane(s), not destined for normal traffic, but for emergency (police) vehicles and/or for broken-down vehicles.

3.4.4 traffic flow (british) or volume (american): the number of vehicles passing a specific point in a stated time in stated direction(s). In tunnel design, peak hour traffic, vehicles per hour per lane, will be used.

3.4.5 speed limit: the maximum legally allowed speed.

3.4.6 design speed[1]: a speed adopted for a particular stated purpose in designing a road.

3.4.7 reaction time[1]: the minimum time interval between the occurrence of an event demanding immediate action by the driver and his response. The reaction time includes th time needed for perception, taking a decision and acting.

3.4.8 stopping distance SD: the stopping distance SD is the distance needed to bring a vehicle, driving at design speed, to a complete standstill. The SD is usually defined in national legislation or regulation. The concept "Safe stopping distance" is not used in this standard.

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1) The terms indicated conform to the "Vocabulary of traffic engineering terms", published by Traffic Engineering and Control, London, 1960.

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

3.4.10 motor traffic (motorized traffic): traffic that consists of motorized vehicles only. It depends on national legislation which vehicle types are included in this classification. In some countries it only includes vehicles which are capable of maintaining a minimum speed. In others, mopeds are not considered as motorized traffic.

Remark concerning traffic flow : 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 on rural areas 10% and in urban areas 12% of ADT. On undivided roads, 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, assumption 1:2 can be made. Then the higher flow will be divided by the number of lanes of this carriageway.

4 General aspects of tunnel lighting

4.1 Tunnel conditions

Road and traffic conditions in tunnels may differ considerably from those that prevail on the open road. The design of tunnel lighting installations should take these different conditions into account, in particular as regards the traffic safety aspects.

It is desirable to measure tunnel lighting installations after completion to ensure that the design requirements have been met. Advice on measurement is given in section 9.

4.1.1 Stopping Distance

Important parameters for the design of tunnel lighting installations include the speed, volume and composition of traffic flow entering, and passing through.

There is a strong, but non-linear relationship between the traffic flow and the accident risk: higher volumes show a higher accident risk (with the exception of very low or very high traffic volumes). The extra risk can be counteracted, at least in part, by increasing the light level. This relationship is established for many types of open roads, and it is assumed that it also holds for tunnels.

One of the most important factor is speed. In practice, road and tunnel designs are such that speed and flow usually are interrelated, as a high design speed is selected for roads for which a high flow is expected. High speeds require better visibility and therefore generally a higher luminance level.

The stopping distance SD that often has to be evaluated for the correct design of the lighting is the sum of two stretches of road:

- the x_o distance covered during the reaction time
- the x distance covered during the braking time

If u is the travelling speed, constant at the beginning of the stopping action,

$$x_o = u \cdot t_o \qquad (1)$$

where t_o is the reaction time.

The x distance can be calculated comparing the impulse for a dt time with the momentum

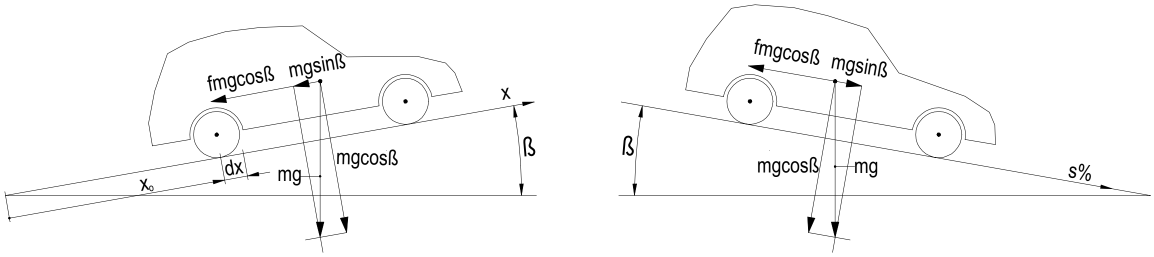

Figure 1: forces acting on a vehicle with different slopes.

$$-(f\cdot m\cdot g\cdot \cos\beta 6 m\cdot g\cdot \sin\beta)\cdot dt = m\cdot du \qquad (2)$$

where:

f = friction coefficient tire-pavement

m = mass of the vehicle

g = gravity acceleration

the **+** sign must be considered for ascending slope; the **–** sign for descending slope.

The time dt can be expressed as dx/u. Introducing the slope s = tanβ the (2) becomes:

$$-\cos\beta\cdot g\cdot(f6s)dx/u = du \qquad \text{or}$$

$$dx = -\frac{u}{\cos\beta\cdot g\cdot(f\pm s)}du$$

Being cosß always close to the unit, it can be neglected.

Integrating the left-hand member between the distance 0 and x, the right-hand member must be integrated between the speed u and the speed 0. So:

$$\int_0^x dx = -\int_u^0 \frac{u}{g\cdot(f\pm s)}du \qquad (3)$$

The integration of the right-hand member is impossible because the friction coefficient f is an unknown function of the speed and other parameters depending on the speed, such as the atmospheric conditions, the tires condition and so on.

But assuming f as a constant versus u the (3) gives:

$$x = \frac{u^2}{2\cdot g\cdot(f\pm s)} \qquad (4)$$

With this hypothesis the formula (4) can be used to determine x if the friction coefficient is assessed by practical tests and reported in a graph as a function of the speed.

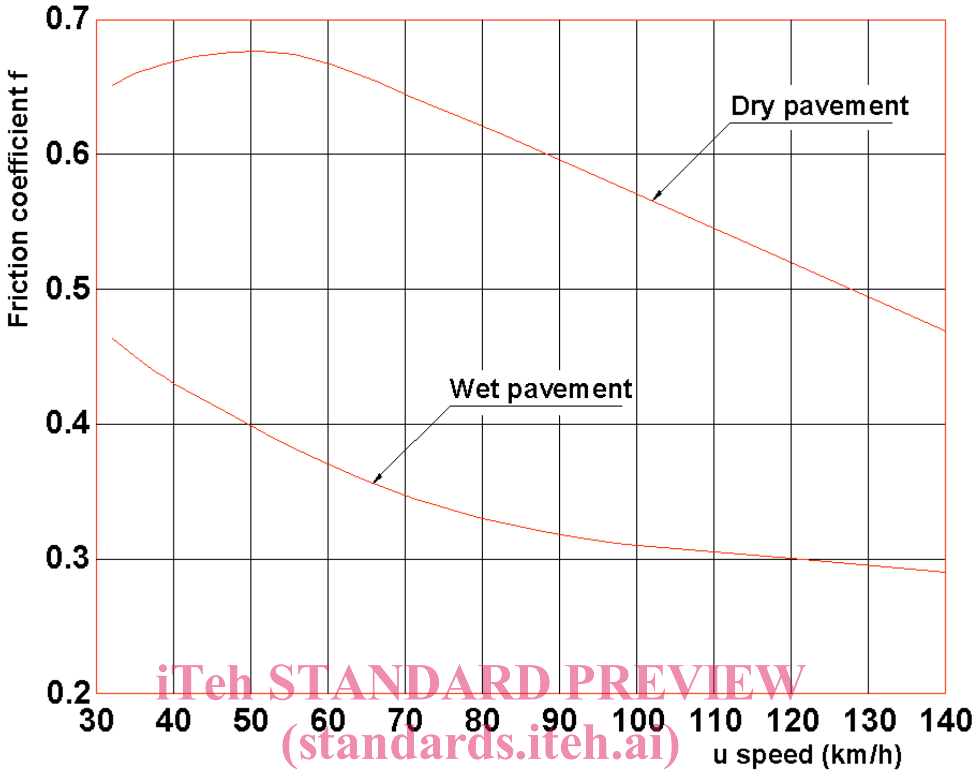

Fig 2: typical diagrams of the friction coefficient as a function of the speed for dry and wet pavement.

Summing the reaction distance (1) and the braking distance (4) the general formula of the stopping distance is obtained.

$$SD = u \cdot t_o + \frac{u^2}{2 \cdot g \cdot (f \pm s)}$$

In all the hereabove formulae's (except in the figure 2 where u is expressed in km/h), u is expressed in m/s, x in m, t_0 in s and g is equal to 9,81 m.s-2

Without any particular value, t_o can be assumed equal to 1 sec and f taken from the curve of fig. 2 for wet pavement as a function of the design speed.

4.1.2 Tunnel lighting requirements

The lighting of a tunnel entrance should be adequate:

– to avoid the 'black hole effect' when a driver is unable to see into the tunnel;

– to reduce the likelihood of a collision with another vehicle (or bicycle or pedestrian);

– to enable a driver to react and stop within the SD if an unexpected hazard appears.

4.1.3 Traffic composition

The traffic composition is relevant for the tunnel lighting in several aspects:

– the percentage of trucks;

– the presence/absence of pedal bicycles and/or mopeds;

– the presence/absence of pedestrians (non emergencyconditions);

– the presence/absence of authorization to allow the transit of hazardous material.

The lighting has to be adapted to these circumstances. Higher levels or better quality lighting for the walls or the road are necessary for the visual task when the conditions are more difficult or more hazardous.

4.1.4 Road and tunnel conditions

Driving comfort is an important aspect of the quality of the lighting installations of road traffic tunnels. Tunnels, constructed to overcome traffic obstructions, should not become a traffic obstruction by themselves. The design should be such that the traffic flow in and through the tunnel must be just as fluid as on the open road. As a result of feelings of anxiety, drivers are likely to slow down near the tunnel entrance. Sudden drops in speed reduce the traffic capacity and easily might lead to traffic jams and even to accidents. So, a good lighting that helps to overcome any feeling of anxiety is not only a matter of driving comfort but also a matter of road capacity and of traffic safety.

This may be explained as follows. Driving a car safely is mainly a matter of attention. On long stretches of motorway, attention may waver and the level of arousal is low. Drivers are not well prepared to cope with emergencies should they occur unexpectedly. Near tunnels, the attention must be higher to cope with additional hazard factors. Tunnels, being low and narrow, might cause concern or even fear, but also will lead to an increase in arousal. The fear and the arousal are likely to cancel out each other to a large extent, so that the more dangerous tunnel entrance need not to lead to more accidents. However, what happens to the driving comfort is another matter.

The object of installing lighting in a road tunnel is to enable the traffic to pass through with the same degree of safety and comfort, as is customary on the open road, and with an acceptable speed. The difficulty of the driving task when approaching and passing through a tunnel is mainly 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. To enable a road user to drive safely when a tunnel is on his route, it is pertinent to give him adequate and relevant information, which allows the driver to situate himself in space and time, to foresee a "model" of his future position and to adapt his behaviour to this anticipated "model".

When making the lighting design for a tunnel, the following aspects should be taken into account:

a) Altered perception

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

b) Overall perception

1. Before entering a tunnel

   – the layout should clearly show that one is approaching a tunnel - this should be supported by relevant signs;

   – portals should be constructed with dark materials in order to reduce the access zone luminance;

   – there should be a black asphalt surface for the road up to the portal.

2. Entering the tunnel

   – East-West orientations may cause more problems than North-South orientations;

   – avoid light coloured surfaces in the immediate surround of the portal such as buildings, walls, etc.;

   – adopt trees or other screens to avoid direct glare from the sun.

3. Inside the tunnel

   – if discontinuities, ramps and intersections in the geometric design, it is advised to treat them specifically by an ad hoc lighting system;

   – adopt a light coloured road surface that should be near diffuse for symmetric lighting and more specular for counterbeam lighting;

   – adopt and maintain good guiding facilities (road markings, delineators etc.) along the road;

   – adopt separate sign lighting when the tunnel is lit by monochromatic light-sources.

4. At the exit

   – adopt, when a glaring situation may be expected outside the exit, civil engineering works or planting that will screen off the direct sunlight.