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Techniques and Calculation Methods for Lighting Systems of Underpasses and Road Tunnels in Romania

[1] Gheorghe Neamțu, [2] Marinela Ință, [3] Ioan Țincu

[1] Ph.D, Engineer, Associate Professor at "Lucian Blaga" University of Sibiu, 10 Victoriei Street, Sibiu, Romania
[2] Ph.D, Engineer, Lecturer at „Lucian Blaga" University of Sibiu, 10 Victoriei Street, Sibiu, Romania
[3] Ph.D, Mathematician, Lecturer at „Lucian Blaga" University of Sibiu, 10 Victoriei Street, Sibiu, Romania

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Corresponding Author: **Gheorghe NEAMȚU**

Abstract

A good lighting system for underpasses or road tunnels achieves good visibility conditions for road users, where luminance levels are required to match the level of adaptation of the vision of road vehicle drivers. This scientific paper presents the authors' own representation and original point of view on the technical acceptability of lighting in underpasses and tunnels dedicated to road traffic. In this way, those interested can learn about: psychological effects created by light on drivers when entering/exiting to/from underpasses or road tunnels; external factors significantly influencing the methods of realization of lighting systems, lighting motivation, lighting systems calculation, safety lighting, pedestrian evacuation ways, emergency exits, automation of related lighting systems, constructive solutions of dedicated lighting systems and how lighting systems are maintained and serviced, all of them, for underpasses or road tunnels. At the end of the paper, conclusions related to the field are presented.

Keywords: Underpass, Road Tunnel, Lighting System, Luminance, Safety Lighting, Evacuation Route, Emergency Exit, Automation

Introduction

The lighting of tunnels and underpasses for motor vehicles in Romania is an important road safety objective. In daylight there is the probability of road accidents due to the difference in brightness levels of daylight and the relatively dark tunnel space. When entering a tunnel during daytime, vision readjustment takes place, which requires a major strain on the eyes. The tunnel lighting system should be designed in such a way that the traffic safety and visual comfort of drivers is not reduced compared to the road section before the tunnel entrance. It takes about 17 minutes to drive through the Mont Blanc tunnel by car, 20 minutes to travel by train under the English Channel (or la Manche) and only a few minutes to drive through the Brussels Ring tunnels. But lighting them in a safe, sustainable and driver-friendly way is the result of decades of expertise [1]. Over the years, we have seen huge changes in vehicle and road design, we have experienced the LED revolution, and we have seen the priorities and requirements of road infrastructure users evolve, especially when it comes to energy efficiency. Now everything is changing again with the advent of smart controls. LED lighting is now suitable for every part of underpasses or road tunnels, including entrances and exits, so smart systems can be deployed throughout the infrastructure, with real benefits in terms of electricity consumption, emergency systems and driver experience [1]. Compared with general road lighting, the lighting of underpasses and road tunnels requires all-day lighting due to the night-time conditions created by the enclosed space with no other links to the outside other than the entrance or exit. In these road infrastructure elements daytime lighting becomes more complex than night-time lighting. This type of lighting should not only take into account that the road surface should have a certain level of brightness, but should take into account the design speed, traffic volume, linearity and other influencing factors and evaluate in a comprehensive way the effect of lighting on safety and comfort when driving road vehicles, especially in road tunnels. The entrance and surrounding sections should take into account the visual adaptation process of the human eye. At the same time there are clear differences between the visual phenomena occurring in tunnel lighting and those encountered outside tunnels on a normal road. When drivers of road vehicles, enter and pass through a tunnel in a visually bright environment during daylight, various problems with their vision are likely to occur. These effects include the "*black cave"* effect and the ”*white cave”* effect. Tunnel lighting is therefore much more complicated than traditional road lighting. This is why we need to know how the artificial light will interact with pavements, walls (with tiled and without tilled), to create uniformity, to properly calculate reflections and to create safe and linear entrances and exits, so as not to danger the comfort and safety of road users. International Commission on Illumination (ICE) [2] sets the global standards for lighting, and that is why it is important that all authorities in a European country that design, construct and maintain road infrastructure elements, including road tunnels, must fully respect and conform to the requirements of these quality standards.

1. Psychological effects of light on drivers entering/exiting underpass or road tunnel

In the day or night, psychologically speaking, the visual phenomenon of underpass or road tunnel lighting has the following characteristics:

- ***Visual problems when entering the underpass or road tunnel.*** In daylight conditions, because the brightness outside the tunnel is much higher than inside, drivers entering the tunnel will be visually affected by the so-called *"black cave"* phenomenon. This phenomenon is defined by the inadaptation of the human eye (a slow adaptation) from the high luminance of the outside environment at the entrance of the tunnel during daylight to the low luminance inside the tunnel (veil luminance). For this reason, drivers need time to adapt to the low luminance, during which time vehicles at high speeds cover appreciable distances. The phenomenon can also occur at night, when exiting a tunnel with bright lights, or when entering a dark underpass at night;
- ***Visual problems when exiting the underpass or road tunnel.*** In artificial light conditions, because the brightness inside the tunnel is low compared to outside the tunnel, drivers exiting the tunnel will be visually affected by the phenomenon called *"white cave"*. This phenomenon is defined by the maladaptation of the human eye (a poor adaptation) to the transition from low luminance inside the tunnel to high luminance of the outside environment (veil luminance). In this way, when exiting a tunnel, drivers need time to adapt to the brightness of the outside environment. This phenomenon may also occur at night when entering a brightly lit underpass or tunnel or when exiting an underpass or tunnel to a high luminance road or artery.

For both the above mentioned problems, when moving from bright to dim luminance and vice versa, drivers experience those adaptation lags where the human eye does not perceive the area it is in for a short period of time, thus increasing the danger of undesirable road events. The differences between two levels of luminance can be up to 100,000 times in the case of clear skies and east or west facing tunnels;

- ***Visual problems inside the underpass or tunnel.*** Inside tunnels or underpasses that are poorly ventilated or unventilated, due to the confined space, gases accumulate in the form of smoke from the combustion of fuel in the combustion engines of motor vehicles, which is exhausted through the exhaust pipes. Tunnel illumination and headlights are absorbed and scattered (diffused) by the smoke, forming a curtain, a light veil (dense fog effect). This greatly reduces the visibility between road vehicles and possible obstacles, creating the conditions for a potential road accident;
- ***The flicker effect.*** This is due to an incorrect arrangement of the lighting fixtures (when the provisions of the standards and legislation in force regarding the distance between the lighting fixtures are not respected), which causes an uneven or non uniform distribution of the tunnel luminosity, which creates a periodic alternating visual environment (light-dark), and at a certain speed of movement through the tunnel creates the premises for a road accident (Fig 2).

2. External factors significantly influencing the methods of realization of lighting systems for underpasses or road tunnels

When designing a lighting system for tunnels or underpasses, a number of factors have to be taken into account which influence their cost and size.

These factors include [3, pp. 76-77]:

- ***Entry or exit orientation:*** An orientation towards sunrise or sunset creates high veil luminances (the luminance perceived by the driver when entering or exiting the tunnel) which can lead to high installed powers;
- ***The existence of shading on the external entrance or exit area:*** These shadings create a natural decrease in the luminance of the veil and thus a natural luminance reduction zone;
- ***Speed limit in the area:*** The distance traveled by the vehicle during the adaptation time of the human eye is directly proportional to this type of speed. The speed to be taken into account when designing the lighting systems in this case will be 20 km/h higher than the maximum legal speed in the area, in order to avoid road accidents in particular cases of adaptation of the human eye to the luminance of the veil;
- ***Visibility of the tunnel exit from the entrance area:*** Eliminates much of the “*black cave”* phenomenon;
- ***Reflective wall surfaces:*** The more these surfaces reflect light, the higher the luminance level produced by the same light source;
- ***Weather conditions:*** (difficult traffic conditions). Fog, rain, snow, ice, wet or slippery road conditions have a direct influence on braking distance and the possibilities of detecting a potential obstacle in road traffic.

3. Motivation for lighting underpasses and road tunnels

For the correct and safe circulation of road vehicles through underpasses or tunnels, designers and specialists in this field propose lighting systems for installation in these tunnels and underpasses that meet the latest technical requirements in accordance with the quality standards, provisions and regulations in force. For this reason, lighting systems in underpasses and road tunnels during daylight hours should eliminate the phenomenon of *”white cave”* (at the exit) and *”black cave”* (at the entrance), thus making a gradual transition between the natural luminance of the outside environment and the artificial luminance inside the underpass or tunnel, while allowing drivers' eyes to adapt to the changing conditions.

Fig 1: Underpass on DN 7, Bascov (Pitesti), Romania, connecting to the A1 - Highway [4]

In view of the variation of lighting in the outdoor environment, the motivation for the realization of the lighting system for underpasses or road tunnels derives from the need to create flexible and properly automated systems, so that they meet the requirements of the created environment and users [3, p. 77].

Fig 1 shows an underpass on DN 7, Bascov commune (Pitești city), Argeș county, Romania, which connects with the A1 highway, and Fig 2 shows the Capra - Bâlea road tunnel, Trasfăgărășan, Romania.

Fig 2: Capra - Bâlea road tunnel, Transfăgărășan, Romania [5]

In the diurnal environment the lighting system in a road passage or tunnel will have to create a quick adaptation of the human eye between the different luminances of the access arteries and their interior area. The standards in force for the lighting of underpasses and road tunnels are [3, p. 78]:

- ✓ The Romanian standard SR 13433/1998 – *Road lighting;*
- ✓ ICE Report 88/2004 *Guide for the road and underpasses*.

4. Calculating lighting systems for underpasses or road tunnels

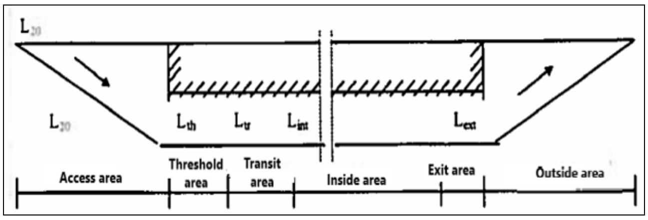


Fig 3: Cross-section with characteristic areas of a road tunnel [3, p. 79]

In a road tunnel, the lighting system must be designed and realized in such a way that it does not create a feeling of insecurity and comfort for the users. For this reason, there should be no difference between driving a vehicle inside the tunnel and driving on an open road where visibility, comfort and safety are maximized. These aspects presuppose that the tunnel users must have all the appropriate information regarding the course of the road (visual guidance), the positions of the other traffic participants in the tunnel, as well as the necessary data on obstacles on the road. When designing lighting systems suitable for road tunnels, **five zones are considered** (Fig 3). In each zone specific problems arise. The calculation methodology for lighting systems for road tunnels is specified in the technical report ICE88/2004.

The five zones of a road tunnel are [3, pp. 79-82]:

a) Access area also called the near zone is that area of road outside the road tunnel in the immediate vicinity of the road tunnel entrance, where drivers of road vehicles must be able to observe obstacles in the tunnel. It is in this area that the human eye's ability to adapt is affected and it is in this area that the necessary lighting at the tunnel entrance and in the threshold area will be designed. During daylight hours, the eyes of drivers of road vehicles are adapted to the relatively high illuminances typical of this area and inadequate illumination of the road tunnel entrance can create the effect of a *"black cave"* where no object is visible. At night drivers' eyes are adapted to the darkness and the same entrance can appear very well illuminated;

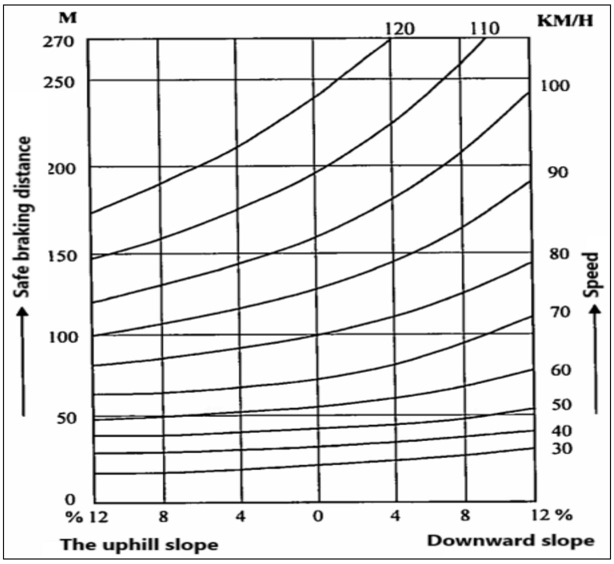


Fig 4: Braking distance determination diagram [3, p. 79]

b) Threshold area is the first of the four proper zones of the road tunnel. Drivers who are still in the access area should slightly distiguish the obstacles in this area before entering the tunnel. The length of this zone is dependent on the maximum permissible speed for the specific traffic in this zone and should be equal to the braking distance, as the road surface at the end of this zone should depict the detection background of the obstacles when observed by drivers close to the tunnel entrance. The diagram shown in Fig 4 shows how the braking distance is determined as a function of the maximum design speed of the vehicle and the situation on the ground. The length of the threshold area is equal to the braking distance thus determined;

c) Transition area. After approximately high illuminance levels in the threshold area, the illuminance in road tunnels shall be gradually reduced to a level corresponding to the inner area. The length of this zone shall be approximated by the maximum permissible speed of road traffic in the tunnel and the difference between the illumination level at the end of the threshold zone and the inside area; the length of this zone shall be approximated by the maximum permissible speed of road traffic in the tunnel and the difference between the illumination level at the end of the threshold zone and the inner area;

d) Inner area is the part of the road tunnel that is least exposed to daylight. In this area drivers' vision is exclusively influenced by the light emitted by the luminaires mounted in the tunnel. The interior area will be characterized by a constant flow of light throughout. The visual adaptation of drivers in this area is not fully achieved and therefore it is necessary to provide strong illuminances. The exact values of the illuminances will be chosen according to the speed of road traffic in the area (or braking distance) and density;

e) Exit area, is the last area of a single way road tunnel. It is the part of the tunnel where the vision of the drivers of road vehicles approaches the exit and is influenced proportionally to the natural light brightness of the outside environment. The visibility problems arising here are related to the fact that drivers need to be able to intuit and judge the maneuvers of the vehicles in front of them, which are perceived by them as a black silhouette against the background of a large vehicle ahead.

4.1 Specific quantitative and qualitative aspects. Additional components determined

Any tunnel lighting system shall be designed and constructed to provide a luminous microclimate to ensure the smooth and safe movement of road vehicles. In doing so, specific quantitative and qualitative conditions shall be met. The level of luminance and illuminance in the road plane form the necessary foundation in four characteristic zones. A judicious distribution of illuminances in the field of vision and on the road surface leads to the avoidance or reduction of blinding of road users in various ways.

The color of light chosen by the designers of lighting systems in underpasses and road tunnels, as well as reflective surfaces, without specific rendering conditions, can create a comfortable and pleasant ambience for users. A regulated visual guidance creates safe conditions for the movement of road vehicles, and the avoidance of flicker is a requirement imposed precisely by the requirement for visibility comfort.

4.1.1 Quantitative aspects

The ambient luminance level on different sections determined by the external luminance requires a horizontal illuminance level. The level of illuminance in the horizontal plane of the road is spatially variable (along the tunnel) according to the luminance level of the natural (outside) light [3, p. 83].

A) ***During the day*** an underpass or road tunnel does not need an additional light (taken in comparison with normal night lighting) if the exit occupies a large part of the field of vision when observed from a distance equal to the braking distance before the entrance. For this reason, road tunnels need additional daylight if, observed from the same position, the exit appears as a black spot in which obstacles (vehicles) are hardly recognizable. Table 1 shows the requirements for the level of daytime illumination according to the length of the tunnel according to ICE.

Table 1: SIL parameters for tunnels as a function of: length, exit view, daylight access, wall reflectance and traffic type [3, p. 84]

Tunnel length [m]	Is the output visible from SSD distance?	Natural light floods into the tunnel?	Wall reflectance is high (>0.4) or low (<0.2)	Traffic is heavy or light (including cyclists and pedestrians)	% required level/ day of luminous flux in the limit zone
< 25					0
25 – 75	Yes			Easy	0
				Hard	50
	No	Sufficient	Big	Easy	0
				Hard	50
			Small		50
		Insufficient			50
75 – 125	Yes			Easy	50
				Hard	100
		Sufficient	Big	Easy	50
				Hard	10
			Small		10
		Insufficient			10
>					10

Note: SSD stands for safe braking distance; BS-5489 has 4 classes for tunnels: < 25 m - no lighting; 25-50 m - daylight limited to 15 cd/m^2 or 3 times the level of interior lighting as per the above table for long tunnels, whichever is greater. It will apply when ambient lighting has been reduced to 10% of the maximum L_{20}; 50-100 m - constant level of luminous flux throughout the tunnel length as boundary areas for long tunnels; < 100 m - class A with full lighting as for long tunnels. BS recommends that the illuminance at night should be 3 times the illuminance on the streets outside the tunnel.

- ***Access area***

The specific luminance to which the human eye adapts during the travel time corresponding to this zone determines the luminance of the threshold zone. The adaptation luminance taken into account is divided into: the *luminance in the access area* and the *equivalent weil luminance*.

Luminance in the access area. Everyday experience shows that the access zone adaptation luminance specific to an observer within braking distance of the entrance to a road tunnel is defined by the average of the luminances contained in a conical field of view corresponding to a 2 x 10º plane angle centered at the middle of the tunnel and one quarter of its height. This is called the access zone luminance, L_{20} (Fig 3). In areas where it is not possible to measure luminance (tunnels under construction) L_{20} can be determined from the data presented in Table 2, using the mathematical relationship [3, p. 85]:

$$L_{20} = yL_S + pL_R + eL_B \quad (1)$$

Where, *y, p* and *e* is the percentage of the considered field of view that is occupied by that element;
L_S- the luminance of the sky;
L_R– the road luminance;
L_B - the background luminance.

Table 2: Luminance types by material type [3, p. 86]

Direction of entry into the road tunnel	L_{sky}	L_{road}	$L_{background}$			
			Stones	Buildings	Snow	Meadows
North	8	3	3	8	15	2
East - West	12	4	2	6	10-15	2
South	16	5	1	4	5-15	2

ICE 88/2004 resents another calculation method L_{seq} which involves using a digital automatic, a digital camera with a normal lens. Through the camera lens, a photograph of the tunnel entrance can be taken, with the camera positioned at the calculated braking distance from the road tunnel entrance at a height of 1.25 m. The camera lens will be oriented with the sensor towards the center of the tunnel entrance (Fig 5). The resulting photo will be superimposed on the polar diagram shown in Figure 6.2.2, page 9 of the publication [3, p. 87].

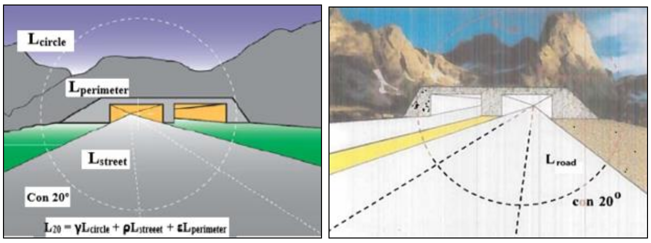


Fig 5: The significance of the luminance values taken into account for the determination of L_{20} [3, p. 86]

The calculation procedure described, as follows [3, p. 87]: The external illuminances, which together define the luminance in the access zone of the road tunnel, differ strongly for different types of tunnels. In mountain road tunnels the luminance in the access zone is basically determined by the brightness of the mountainous surroundings in the tunnel entrance area. For viaducts and underpasses, the luminance is partly dependent on the shadow of buildings (or other constructions) and partly on the luminance of the sky, because in urban areas the sky is partially seen by a ground observer (the sky is seen through a reduced part of the field of view). Thus the total outdoor luminance becomes:

$$L_{20} = \gamma L_{circle} + \rho L_{street} + \varepsilon L_{perimeter} \quad (2)$$

Where,
L_{20} is the luminance in the access zone;
γL_{circle} – luminance outside the circle;
ρL_{street} – road (street) luminance;
$\varepsilon L_{perimeter}$ – perimeter luminance of the circle.

For many types of road tunnels, special measures can be made for the lighting of the access area. Such measures include using dark (non-gloss) materials for the road surface near the tunnel entrance, the face of the tunnel entrance and (for underwater tunnels) the vertical walls before the tunnel entrance; planting trees and shrubs adjacent to and above the entrance to block the sky glare; and making the entrance as high and wide as possible. In practice, the highest luminance in the tunnel access area (consistent with a horizontal illuminance of approximately 100,000 lx) varies depending on the type of tunnel and measurements in the range [3,000 - 8,000 cd/m^2].
Equivalent veil luminance, Lv. This type of luminance is determined according to disability blindness. It is the basic factor in the adaptability of drivers' vision. It would seem logical to use it to determine threshold luminance requirements and this is still being discussed to this date by the ICE. At the time of the last ICE publication, there was not enough information to finalize a method by which the threshold luminance could be determined. The CIE still today specifies this luminance value using a practical method based on the luminance in the L_{20} access area [3, p. 88].

- ***Threshold area***

The brightness of this area should be approximately one high at the start to maintain safe driver visibility performance. It can be determined by L_{20}, the luminance of the access area.
Threshold luminance, L_{th}, required can be determined according to the ratio [3, p. 88]:

$$\frac{Lth}{L20} \quad (3)$$

This ratio is presented in Table 3, for different types of braking distances and for two types of lighting system.

Table 3: Luminance of the threshold area [3, p. 89]

Braking distance [m]	IL symmetric L_{th}/L_{20}	SIL "counter beam" L_{th}/L_{2n}
60	0.05	0.4
10	0.06	0.5
160	0.1	0.7

- ***Transition area***

Drivers of road vehicles entering a road tunnel need some time to adapt visually to the low light levels inside. The purpose of the transition zone is to be able to create this gradual transition. Fig 6 shows the lighting of underpasses and road tunnels: a) threshold area; b) transition area.

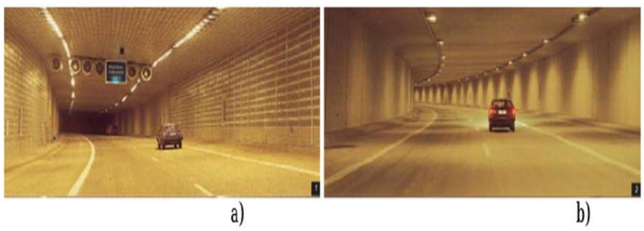


Fig 6: Lighting of underpasses and road tunnels: a) threshold area; b) transition area [6]

The luminance of the transition area, represented by a decreasing value, is calculated with the mathematical relation [3, p. 91]:

$$L_{tr} = L_{th} (1.9 + t)^{1.4} \quad (4)$$

Wehere,
L_{th} represents threshold luminance;
t – time traveled in the transition area.

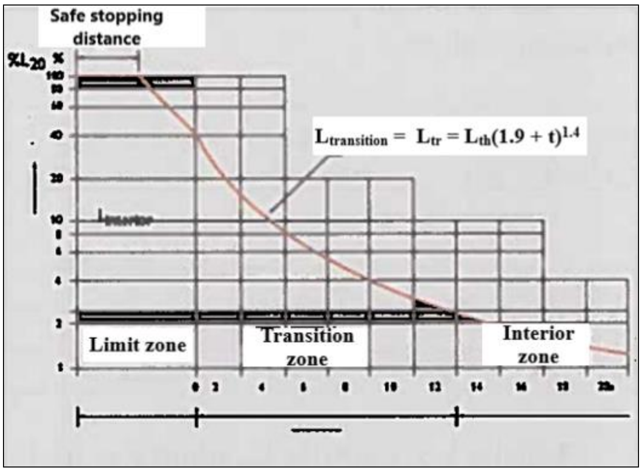


Fig 7: Theoretical variation of luminance in the transition zone as a function of the time traveled in this zone [3, p. 91]

Fig 7 shows the theoretical variation of the luminance in the transition zone as a function of the time traveled in this zone. Using this curve and knowing the traffic speed it is possible to calculate the *ideal luminance gradient* for any type of road tunnel.
From analyzing the data shown in Fig 7, we can see that the curve can be approximated by a number of steps, the maximum accepted decrement for a step is 3:1, and the luminance level never falls below the limit indicated by the curve. From this it follows that, identical to the threshold area, the average luminance of the 2 m high walls must be at least equal to the average luminance of the road surface.

- ***Indoor area***

In this area, the adaptation does not necessarily have to be carried out entirely at the entrance to the indoor area. Here it is necessary to ensure a sufficiently high luminance level compared to that of an open road in a field at night. The main reason for ensuring high luminance is that drivers' visibility is significantly reduced due to exhaust pollution. For this reason the recommended luminances for this area are given in Table 4. They are shown in relation to the traffic density.

Table 4: Values L_m for the indoor area [3, p. 92]

Braking distance [m]	Road traffic density		
	< 100 veh/hour	100 < veh/hour < 1,000	> 1,000 veh/hour
60	1	2	3
100	2	4	6
160	5	10	15

- ***Exit area***

În during daylight periods, exits from an underground passage or road tunnel create a *"white cave"* phenomenon for drivers of road vehicles, where possible obstacles can be easily distinguished as silhouettes. Human vision adapts more quickly to the bright light outside the road tunnel, but it is important to consider additional light in this context [3, p. 93].

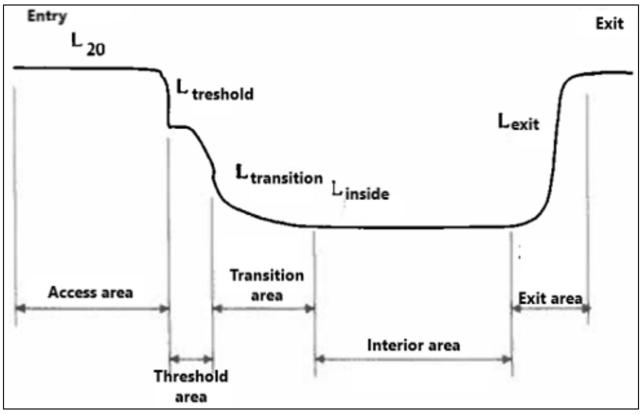


Fig 8: Luminances distribution along a road tunnel [3, p. 93]

For observation of small vehicles against the background of large ones, a higher luminance level is required in the tunnel exit area. This impediment can be solved by placing a larger number of luminaires at the tunnel exit, which will provide a five times higher level compared to the interior area. Fig 8 shows the light distribution along a road tunnel.

B) In the night time

If the road tunnel is located on a road whose carriageway is illuminated, the lighting system used shall ensure a uniform luminance level on that road. If daylight shielding devices are to be used, the lighting system shall be continuous under them, and if the access road is not illuminated, the road tunnel lighting system shall be provided to ensure an average luminance of 1 cd/m2, a general uniformity $UO = 0,4$ and a longitudinal uniformity $UL = 0,6$ for each traffic lane in the tunnel. This rule can also be applied to level crossings during daytime [3, p. 94].

4.1.2 Qualitative aspects

The distribution of luminance in the field of vision and in the road plane is the basic condition for the quality of the achievement of visibility comfort. It can be controlled in the same way as for other roads, by checking the uniformity of illumination and the maintenance of the factors E_{min}/E_{max} within the limits set by the standards, as follows:

$$E_{min}/E_m > 0.4 \quad (5)$$

$$E_{min}/E_{max} > 0.2 \quad (6)$$

The road through the tunnel is considered to be a main traffic route.
The advantages over the luminance are specific to underpasses and road tunnels and are due to reflective surfaces and enclosed spaces. In this case the luminance distribution is much more balanced compared to outdoor roadways and is due to the reflective component. The uniformity of the luminances in the plane of the roadway shall be checked by means of the uniformity coefficients mentioned to avoid discomfort blinding.
It should be noted that the presence of reflecting surfaces (walls, ceiling, and sometimes the roadway, if it has a

reflection coefficient $p > 0.3$) has a positive role in the uniformity of the luminance in the useful plane [3, p. 95].
In order to prevent incapacitating blindness, it is necessary to provide visual protection by fitting tunnel or underpasses lighting lamps with protective angles or equipping them with dispersers. In order to eliminate discomfort blindness in the field of vision, specialists recommend determining the threshold increase index TI by means of mathematical relations [3, p. 95]:

$$TI = 65Lv/Lm^{0.8} \text{ (pentru } Lm \leq 5 \text{ cd/m}^2) \quad (7)$$

$$TI = 95Lv/Lm^{1.05} \text{ (pentru } Lm > 5 \text{ cd/m}^2) \quad (8)$$

Where,
Lm is the average luminance of the walls and roof;
Lv – the veil luminance of sources appearing at the spatial angle corresponding to that 20º plane.

Comfort is ensured if:

$$TI < 15\% \quad (9)$$

Reducing the contrasts due to the reflection of the enclosure makes a substantial contribution to reducing the blinding of drivers on public roads, which is a common psychological and physiological phenomenon on public roads.
Due to the fact that luminaires in road underpasses or tunnels are mounted at a lower height compared to public street lighting, they will have a specialized construction to illuminate the roadways in the underpass or tunnel at certain angles. This will provide increased protection by better masking the light sources from the direct view of drivers. This aspect is quite important, especially in the central area of the lens where the luminance level is low. In the access and even transit areas the luminance of the luminaires can be higher with asymmetric light distribution and with a maximum intensity that will be directed against the direction of vehicle movement through the underpass or tunnel *(counterbeam)*. This highlighting of the luminance at the transition from natural to artificial light in the passage or tunnel helps to warn drivers of the entrance. The effect of a *"black cave"* at the entrance, or a *"white cave"* at the exit, is to create an uncomfortable contrast of luminances which may cause road accidents if the level of illuminance is not adjusted as indicated above [3, p. 96].
Light color can manifest itself in road tunnels as [3, p. 96]:
- ✓ Color of light sources;
- ✓ Color of reflected surfaces.

Correct reproduced at color is not indispensable in this case. For this reason no restrictions can be imposed from this point of view, but the economic constituency becomes important when choosing light sources. In this case it is advisable to choose light sources with high efficacy. The warm color of sodium-vapor lamps creates a pleasant ambience and is conducive to the visual comfort of users. More recently, LED lamps are being used which have the same color characteristics, but are more energy efficient, economical and environmentally friendly.

Reflective surface of walls and roof contributing to a comfortable ambience should be light-colored, warm, faded, with a high reflectance factor (0.7), which will also contribute to a judicious distribution of the lighting as well as to the "silhouette" switching of vehicles when exiting the underpass or the road tunnel [3, p. 97].
Visual guidance is also a qualitative condition in achieving safe road traffic that supports the profiling of the roadway perspective. Efficient guidance is achieved by placing the luminaires in rows parallel to the road axis. If the road passage or tunnel is provided with two vehicular traffic lanes, at least one row of continuous or discontinuous luminaires shall be used for each lane, and if the level of illumination is high, the luminaires shall be arranged on the roof above each lane axis.
Flicker effect is created by strings of luminaires that catch the user's eye with a rapid succession of images, similar to the effects of shiny car surfaces.The phenomenon is strongest in the central area of the road passage or tunnel, where the luminaires are more sparse (the example shown in Fig 2).
The discomfort effect generated by this phenomenon is dependent on the frequency given by the mathematical relation [3, p. 97]:

$$f = v/d \text{ [Hz]} \quad (10)$$

Where,
v represents speed (m/s);
d – distance between luminaires (m).

To $f = 2{,}5$ *Hz* și $f = 15Hz$, the phenomenon becomes negligible, with no negative effects on drivers' vision.

5. Safety lighting in underpasses or road tunnels
Safety lighting becomes mandatory for any underpass or road tunnel longer than 500 m and is recommended for high volumes of vehicle traffic through them.
The main purpose of safety lighting in such objectives are the following:
- ✓ Evacuate people and the vehicles they are in;

Pedestrian evacuation of people without vehicles.
All these types of lighting shall be realized by means of uninterruptible power supplies, with the switch-on time of the emergency lighting to be 0.30 seconds and a minimum operating time of 30 minutes.
In addition, the safety lighting system of these road infrastructure targets should be combined with a speed limit sign (indicator) placed 100-150 m before the entrance to the underpass or road tunnel.
The luminance levels in the threshold and transition areas must be in accordance with the speed limitation prescribed in such cases and their level in the interior area must be at least equal to the night time level [3, p. 98].
The following requirements are necessary for the emergency lighting of these road infrastructure objectives:
- ✓ For vehicular traffic lanes it is required to achieve a minimum average road tunnel illuminance threshold of 10 lx and a minimum value of 2 lx;

- ✓ Pedestrian traffic lanes are required to achieve three times the level of illumination of the neighboring roadways, with double the level of illumination allowed if a different light source is used. In this case, the uniformity may not be less than that of the adjacent roadway, and the luminaires must have a color rendering index R_a above 60;
- ✓ For intersections or roadway connections within these road infrastructure objectives, the average illuminances and uniformities to be maintained shall be greater than or at least equal to those of the area within the tunnel.

Fig 9: Example of intersection lighting in a road tunnel [3, p. 93]

În Fig 9 shows an example of intersection lighting in a road tunnel.

6. Escape routes for pedestrians evacuation from underpasses or road tunnels

In the event of a road accident, fire with smoke or toxic exhaust fumes or other life-threatening hazards, the traffic lanes in underpasses or road tunnels become pedestrian evacuation routes to emergency exits. These escape routes shall be adequately marked with marker lamps placed at a distance of at least 10 m apart and at h = 1 m in relation to the road surface, on both sides of the tunnel.

7. Emergency exits from underpasses or road tunnels

7.1 Emergency exit lighting

Emergency exits from underpasses or road tunnels shall be marked with specialized lighting to guide users to leave them as necessary. In this case, the lighting shall be positioned 2 m from the emergency doors towards the tunnel.

Fig 10: Example of lighting in a tunnel and marking emergency exits [3, p. 102]

The average vertical illuminance level at all times at the emergency exit shall be 3 to 5 times the vertical illuminance level of the tunnel walls up to 2 m high in daylight. The lighting uniformity in this area shall be greater than 0,6 and the light sources shall have a color rendering index *Ra > 60* [3, p. 101].

7.2 Marking emergency exits

Marking of emergency exits from underpasses or road tunnels shall *be carried out by green coloured lighting fixtures*, which shall be placed in close proximity to them and shall have a floating, flashing (flashing) operating mode with a frequency of 1-2 Hz, and the light intensity shall be greater than 150 cd with emission in all directions [3, p. 101]. Fig 10 shows an example of lighting in a tunnel and marking emergency exits.

7.3 External evacuation

The evacuation of persons to the outside of an underpass or road tunnel shall, if necessary in an emergency, be from the inside to the outside.

For these pedestrian circulation routes, an average horizontal level maintained higher than the level of the tunnel interior in daylight conditions shall be provided with a uniformity of at least 0,2 (minimum/average). The rendering index of the light sources used shall be *Ra > 40* [3, p. 102].

8. Automating lighting systems for underpasses and road tunnels

In order to adapt an automation system to these road infrastructure elements, the starting point will be to determine the L_{20} canopy luminance which is always dependent on external climatic factors. The variation of the requirements of the artificial lighting system of the road tunnel is generated by the variation over a wide range of outdoor illuminances. In this respect, in order for the lighting system of the road tunnel or passageway to meet the requirements of quality standards, the equipment depends on the external lighting, which is variable during daylight, and specialists recommend *stepless or continuously variable systems*.

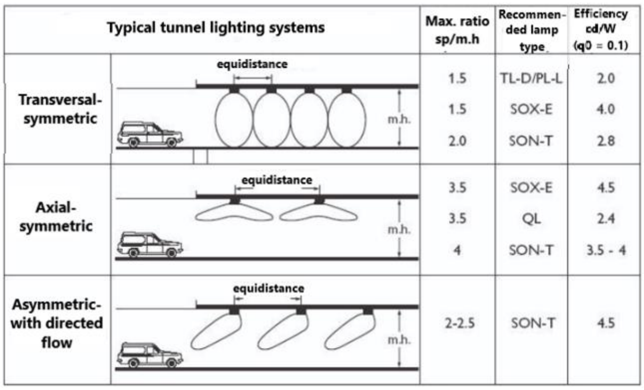
The calculation of such a system is required in at least five situations, as follows [3, p. 103]:

- ✓ clear skies in the morning;
- ✓ cloudy skies in the morning;
- ✓ clear afternoon skies;
- ✓ cloudy skies in the afternoon;
- ✓ at night.

The automation method of the tunnel lighting system will be designed and implemented by meeting the requirements of all these situations (minimum 5) and will take into account the advantage of energy saving which will be realized by reducing the emitted luminous flux and the power consumed during the diurnal periods when the exterior luminance is lower in relation to the maximum luminance.

9. Design solutions of lighting systems for underpasses and road tunnels

The lighting systems dedicated to these elements of the road infrastructure must meet the quality and quantity requirements outlined above. This can be achieved by a logical arrangement (positioning) of the luminaires and a concordant selection of light sources.



Typical tunnel lighting systems	Max. ratio sp/m.h	Recommended lamp type	Efficiency cd/W (q0 = 0.1)
Transversal-symmetric	1.5	TL-D/PL-L	2.0
	1.5	SOX-E	4.0
	2.0	SON-T	2.8
Axial-symmetric	3.5	SOX-E	4.5
	3.5	QL	2.4
	4	SON-T	3.5 - 4
Asymmetric-with directed flow	2-2.5	SON-T	4.5

Fig 11: Lighting systems for tunnels [3, p. 104], [6]

In terms of light distribution, lighting systems fall into three broad categories [3, p. 104]:

- ✓ transversal;
- ✓ longitudinal;
- ✓ against the line of sight *(counter beam).*

În Fig 11 shows all these types of lighting systems, including data and *sp/m.h* ratios and the type of light sources recommended.

Transversal lighting system radiates light mainly perpendicular to the longitudinal axis of the underpass or road tunnel, is the most common system and is characterized by a continuous string of tubular fluorescent lamps. LED tube lighting technology has now become increasingly widespread, providing clearer ambient lighting and substantial electricity savings.

- ***Advantajes:*** Blindness reduced; better light penetration between vehicles and switching/variation of luminous flux; clearer visual glare.
- ***Disadvantages:*** Small distances between luminaires; flickering.

Longitudinal lighting system radiates light mainly parallel to the longitudinal axis of the tunnel.

- ***Advantajes:*** Large distances between luminaires; high efficacy.
- ***Disadvantages:*** Reduced wall illumination; shadow spots possible.

Lighting system against the line of sight (counter beam) is a lighting system for underpasses and road tunnels with asymmetric luminaires and directed maximum light intensity, arranged against the users' view (as opposed to the direction of vehicle movement). This type of lighting system shall be installed exclusively in the entrance/exit area to/from the tunnel in order to reduce the black/white cave effect. From this derives the main *advantage* of this type of lighting system, but also some disadvantages, such as: reduced illumination of the tunnel walls; reduced brightness at the tunnel entrance; risk of overshadowing by the small vehicles. Data on the mounting of a luminaire in a *"counter beam"* lighting system is shown in Fig 12.

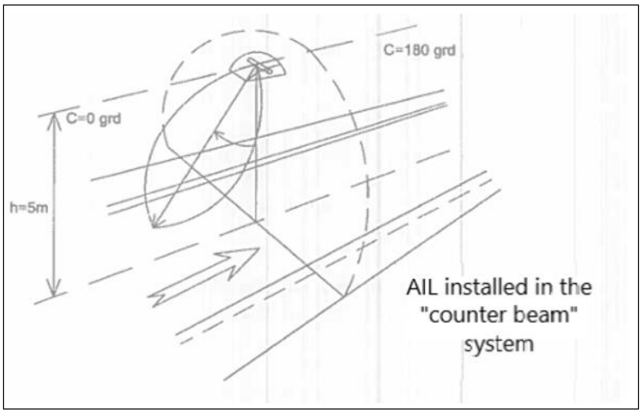


Fig 12: Luminaire mounted in *"counter beam"* lighting system [3, p. 106]

The following types of systems are commonly used [3, p. 106]:

- ✓ Discontinuous strings within the flicker avoidance limit;
- ✓ Continuous rows mounted as normal, one in each direction;
- ✓ Parallel bands mounted on roof or walls, oriented horizontally or vertically;

Continuous light strings made of light tubes, mounted on the lateral walls of the underpass or road tunnel.
The most commonly used lighting equipment are [3, p. 107]:

- ✓ Those equipped with fluorescent lamps;
- ✓ Those equipped with high-pressure sodium vapor discharge sources;
- ✓ Hose with asymmetric *"counter beam"* distribution (in the sill areas of tunnels, in a false roofs created for soundproofing purposes - a functional and aesthetic solution);
- ✓ Light tubes that work on the principle of light transmission through the sky, by means of an optical film of the OLF (Optical Lighting Film) type, which covers the inside of the tube and ensures high refractive coefficients (98%) and which ensures the transportation of light over long distances. By means of these light sources, *point light sources* can be transformed into *linear light sources* and are used in the central area of the tunnel.

Additional requirements for tunnel lighting sources:

- ✓ Robustness;
- ✓ Degradation and failure (reliability);
- ✓ Tightness;
- ✓ Smooth outside;
- ✓ Visual protection in compliance with the regulations in force;
- ✓ Ctrical short-circuit protection;
- ✓ Easy maintenance;

Criteria for choosing light sources for underpasses and road tunnels:

- ✓ *High luminous efficacy* (use of high pressure sodium, fluorescent, metal halide or LED sources). Optimum -

in the threshold area use sodium vapor lamps, and in the transit area use sodium vapor discharge lamps, tubular fluorescent lamps, combined; in the central area use fluorescent lamps alone or in combination with other high life discharge lamps;
- ✓ *Proper operation at various ambient env ironment temperatures;*
- ✓ *Reduced priming time when changing power supply* (in the case of electricity supply, when switching to own back-up power supply;
- ✓ *Dynamism* characterized by permanently adapted illuminance/ luminance levels according to the illuminance/ luminance levels of the external environment (clear sky, cloudy sky, day, evening, night).

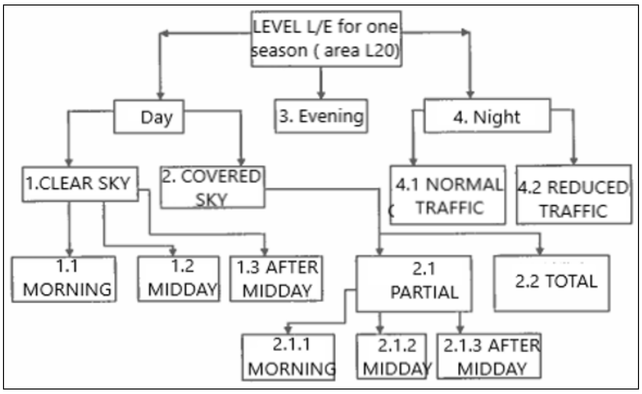


Fig 13: SIL operating regimes for underpasses or road tunnels [3, p. 109]

Fig 13 shows the lighting system operating regimes (SIL) for underpasses or road tunnels.

10. Maintain lighting systems for underpasses or road tunnels

Within road lighting systems, the lighting of underpasses and tunnels define distinct particularities, regulated by dedicated quality standards and regulations. In this respect, specific techniques, methods and actions are required for the maintenance or repair of these systems in order to keep them operating at their designed parameters throughout their lifetime.

The particularities of these systems are [3, p. 109]:
- ✓ The existence of electronic equipment in automation systems - requires maintenance at yearly intervals by checking their functioning within the parameters, as well as functional tests;
- ✓ Excessive pollution with exhaust gases inside underpasses or tunnels - cause chemical corrosion, oxidation, dulling of the diffusers and physical degradation of appliances, luminaires, electrical and electronic circuits and lamps (bulbs). This aspect implies the use of a maintenance factor of maximum 0.8 in the design, but also a 50% shorter cleaning interval of the diffusers than that proposed for the lighting of adjacent roadways;
- ✓ Existence of back-up lighting - this involves checks in accordance with the manufacturer's specifications of the back-up anchorage system and, in the case of generator sets used as back-up source, start-up tests with or without load. Within the time periods specified by the manufacturer, not to exceed 4 years, the existing batteries in the emergency lighting/ centralized battery systems shall be completely replaced;
- ✓ Influence of reflected light from underpass or road tunnel walls - the designed situation considered the case where the tunnel walls are clean and the reflected light component is about 25%. There is a requirement that the walls of these road infrastructure elements must be maintained in an appropriate state of cleanness in order to respect the light reflectance properties.

Maintenance of lighting systems for underpasses or road tunnels is carried out under special conditions due to:
- ✓ Working conditions that are unfavorable due to lack of natural light, air flow and abundance of chemical or noise from road vehicles;
- ✓ Difficult cleaning of reflective surfaces with the restriction of road traffic and transportation of the necessary substances over long distances;
- ✓ Heavy access to lighting equipment positioned at height or on the sides of tunnels, for which it is necessary to divert or restrict vehicle flows in one direction only by means of alternative traffic or temporary road traffic stops.

Expert recommendations on maintaining lighting systems for underpasses and road tunnels:
- ✓ The choice of luminaires that have a special construction for this type of use, that have a high degree of protection (IP66), mechanical shock resistance (IK10), chemical corrosion and vibration resistance. For this purpose, non-ferrous metals such as cast and corrosion-treated aluminum or stainless steel shall be used;
- ✓ Locating, as far as possible, luminaires in places that allow easy access to them, without restricting road traffic;
- ✓ The choice of construction materials for the reflective surfaces of the walls of underpasses or road tunnels that do not retain dust, soot, PM 10, PM 2.5, etc, so that maintenance is as rare as possible;
- ✓ Creating a project-based maintenance system in which all maintenance, repair and commissioning of systems will be integrated for correct and compliant operation.

Conclusions

In the case of the threshold area, the average luminance on the road tunnel walls up to h = 2 m shall be at least equal to the luminance of the road surface. For ½ of the threshold area the luminance shall be equal to Lth. For the other half it is recommended that the luminance level should decrease linearly to $0,4\ L_{th}$.

The silhouette effect at the exit of road tunnels can be accentuated by covering the walls with highly reflective materials.

At night, when exiting the road tunnel outside the road tunnel, for a distance equivalent to five seconds of driving, the road shall be illuminated to at least 1/3 of the luminance level provided for the exit area. The distance may be calculated in relation to the maximum permissible speed in the tunnel area.

For adequate illumination of a road passage or tunnel, continuous or strip lighting is recommended (preferably LED, as it is more effective and more technically and economically efficient). Using this type of lighting eliminates flickering.

For redundancy of the emergency lighting system, two independent power supplies are recommended and normally at least 1/7 of the normal lighting should be connected to an uninterruptible source. For this purpose, the re-ignition time of the lamps used in the main lighting system shall be taken into account when calculating the back-up lighting system.

The safety systems of the underpasses will include mandatory warning signs at the tunnel entrance, in order to reduce the speed of road vehicles in the area, when adverse weather conditions (fog, rain, sleet, snow) occur and manifest themselves, affecting the visibility of users and increasing braking distances.

When choosing the lighting system to be used in an underpass or road tunnel, the access area must always be taken into account. For this purpose trees should be planted trees to reduce the contribution of the sky luminance which will create a lower luminance value for the threshold area.

References

1. Winkel KV. Underground: Why tunnel lighting is important. 17 November, 2022. [Interactiv]. Available: https://ro.schreder.com/ro/blogs/iluminarea-tunelurilor-pentru-asigura-siguranta-cu-costuri-operationale-minime. [Accessed February 13, 2025].
2. cie.co.at. International Commision on Illumination. About the CIE. International Commision on Illumination, 13 February, 2025. [Online]. Available: https://cie.co.at/about-cie. [Accessed February 13, 2025].
3. Vătăjelu D, Opincaru A, Chihai L, Tebeșel și S R. Vidis, Road Technical Bulletin, vol. First Edition, C.N.A.D.N.R., Ed., Bucharest, Romania: Monthly publication, 2012, 166.
4. foto.agerpres.ro. Underpass on DN 7, Bascov (Pitesti), Romania, connecting to the A1 highway. foto.agerpres.ro, 14 February, 2025. [Interactiv]. Available: https://foto.agerpres.ro/foto/detaliu/2899387. [Accessed February 14, 2025].
5. transfagarasan.travel. Capra - Bâlea road tunel. Building the tunnel. Transfagarasan.travel, 2024. [Interactiv]. Available: https://transfagarasan.travel/ghid/locatie/tunelul-capra-balea/. [Accessed February 14, 2025].
6. Ciobanu și CN. Codreanu. Underpass and road tunnel lighting," în VII International Technical-Scientific Conference Current Problems of Urbanism and Spatial Planning. U.T.M., November, 13-15, 2014, Chișinău, Republic of Moldova, 2014.