Ministry of Education and Science of Ukraine
Ternopil Ivan Puluj National Technical University

Faculty of Applied Information Technologies and Electrical Engineering
(full name of faculty)
Electrical Engineering
(full name of department)

QUALIFYING PAPER

For the degree of

Bachelor
(degree name)

topic: **Design of car tunnel lighting**

Submitted by: fourth year student _____ , group IEE-42
specialty 141 Electrical Energetics, Electrical Engineering and Electromechanics
(code and name of specialty)

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Ternopil
2021

Ministry of Education and Science of Ukraine
Ternopil Ivan Puluj National Technical University
(full name of higher education institution)

Faculty Faculty of Applied Information Technologies and Electrical Engineering
Department Electrical Engineering
Educational degree Bachelor

APPROVED BY
Head of Department Tarasenko M.G.

ASSIGNMENT
FOR QUALIFYING PAPER

for the degree of Bachelor
(degree name)

specialty 141 Electrical Power Engineering, Electrical Engineering and Electromechanics

student **Saleh Ahmed Ossama**
(surname, name, patronymic)

1. Paper topic **Design of Car Tunnel Lighting**

Project supervisor Kostyk Liubov, PhD, Associated Professor
(surname, name, patronymic, scientific degree, academic rank)

Approved by university order as of March 3rd, 2021 № 4/7-169
2. Student's project (thesis) submission deadline June 18th, 2021
3. Project (thesis) design basis Materials of scientifically practitioner-driven conference, seminars, periodicals, theoretical and methodological developments of scientist, textbooks, reference books, personal observations and calculations of the author. The initial data for the work are the scheme of traffic, the size of the tunnel, the normative parameters of the light field.

4. Contents of engineering analysis (list of issues to be developed)
Introduction
Analytical section
Calculation and research section
Project designing section
Labour occupational safety and security in emergency situations
General conclusions for qualification work

5. List of graphic material (with exact number of required drawings, slides)
Regulatory requirements for lighting of automobile tunnels
Lighting devices for tunnel lighting
The results of modeling and calculations of the lighting installation for the tunnel
Evaluating the effectiveness of the use of different lighting equipment for tunnel's lighting

6. Advisors of design (thesis) chapters

Chapter	Advisor's surname, initials and position	Signature, date	
		assignment given	assignment accepted
Labour occupational safety and security in emergency situations	Ph.D., Assoc. Prof. Okipnyi I.B.		
Compliance check	Ph.D., Assoc. Prof. Kostyk L.M.		

7. Date the assignment was given January 18th, 2021

PROJECT TIME SCHEDULE

LN	Diploma project stages	Project (thesis) stages deadlines	Notes
1	Literature review in the direction of Diploma project	*20.01.21 – 10.02.21*	
2	Preparation of the Analytical section	*12.02.21 – 14.03.21*	
3	Preparation of the Calculation and research section	*16.03.21 – 18.04.21*	
4	Preparation of the Project designing section	*21.05.21 – 31.05.21*	
5	Preparation of the section Labour occupational safety and security in emergency situations	*03.06.21 – 08.01.21*	
6	Compilation of a schedule reference	*09.06.21 – 11.06.21*	
7	Preparation an introduction, conclusions, content and summary	*09.06.21 – 11.06.21*	
8	Preparation, execution and printing graphic material of Diploma project	*12.06.21 – 20.06.21*	

Student ____________ Saleh Ahmed Ossama
(signature) (surname and initials)

Project (thesis) supervisor ____________ Kostyk L.M.
(signature) (surname and initials)

SUMMARY

This qualifying paper includes: 76 pages, 10 references, 30 figures, 14 tables.

The purpose of the bachelor's qualification work is to analyze the current state of lighting of road tunnels, to model and calculate lighting installations for the road tunnel and to compare their parameters and energy efficiency.

To achieve this purpose we need to solve the following problem:

– to analyze international requirements for lighting of road tunnels;
– to offer lighting devices, schemes of their placement and modes of operation to provide standardized lighting of the tunnel;
– to offer lighting control schemes for motor tunnels;
– on the basis of the offered schemes of lighting installations to provide creation of normative level of brightness and illumination in various zones of the transport tunnel.

The following tasks were solved in the bachelor's qualification work:

– the scheme of illumination of the car tunnel is developed taking into account features of light adaptation of a human eye at various parameters of the tunnel, intensity of automobile traffic, time of day;
– the efficiency of using light devices with LED for outdoor lighting is substantiated;
– schemes of automated control of lighting of car tunnels are offered, which allow to operatively optimize the parameters of the light field in different sections of the tunnel.

Ch.	Sh.	Doc. number	Signat.	Date	DP 17.048.00.000 EN		
Developed		Saleh A.O.			SUMMARY	Letter	Sheet	Sheets
Checked		Kostyk L.M.						
Consultant		Kostyk L.M.				TNTU, FAT, gr. IEE-42		
Compliance		Kostyk L.M.						
HeadofDp.		Tarasenko M.G.						

CONTENT

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HeadofDp.		Tarasenko M.G.						

INTRODUCTION

Relevance of research. Car tunnels are needed to solve communication problems in cities and on highways, so their number and length is constantly growing. In Europe alone, the total length of the tunnels combined is about 2300 km.

Artificial lighting systems account for up to 3–5% of the construction cost and 10–20% of the total operating costs of the road tunnels. Therefore, finding the optimal balance between creating conditions for drivers to reliably solve visual problems (especially when entering the tunnel during the day) and capital and operating costs for the lighting installation is always relevant.

At the end of the last century, two existing approaches to tunnel lighting, which can be called "comfortable" and "economical", were somewhat optimized. Based on the developed general concept, new recommendations of the International Commission on Illumination (CIE), State Building Standards DBN B2.5–28: 2018, and other normative documents of a number of foreign countries were developed.

The purpose of the bachelor's qualification work is to analyze the current state of lighting of road tunnels, to model and calculate lighting installations for the road tunnel and to compare their parameters and energy efficiency.

Task:

– to analyze international requirements for lighting of road tunnels;
– to offer lighting devices, schemes of their placement and modes of operation to provide standardized lighting of the tunnel;
– to offer lighting control schemes for motor tunnels;

– on the basis of the offered schemes of lighting installations to provide creation of normative level of brightness and illumination in various zones of the transport tunnel.

The practical significance of the work. The proposed approaches to the lighting of road tunnels can increase their energy efficiency, improve performance, increase safety and comfort of road traffic.

Work structure. The work consists of an introduction, 4 chapters, conclusions and references. Work presented at 76 pages of printed text. Illustrated 30 drawings, 14 tables. The list of references contains 10 names.

1 ANALYTICAL SECTION

1.1 Types of road tunnels and it's relation with the lighting requirements and their characteristics

Road tunnels have started its appearance by the second half of the 20th century, because they allow an increasing for the capacity of highways, road crossings and streets and other advantages. In addition, they may be necessary for solving the overcoming obstacles and straightening roads.

A tunnel as a section of a street or road that geometrically provides a formed traffic intensity which can be an obstacle to traffic, because of it's presence and properties that change the condition and distracts the eyes of the drivers. In fact, the illumination of the road and the brightness of its coverage in the tunnel is much times lower and harder than the illumination and brightness of the open road. The tunnel isolates the driver from the environment, impairing his orientation, creates a kind of unnecessary sound environment, which complicates the process of driving.

A tunnel is a long cavity that has the properties of a completely dark body in terms of light. Therefore, its entrance on any background will seem black. Any object in the tunnel at some distance from the portal becomes almost invisible to the observer outside the tunnel, in particular to the driver going towards the tunnel. As far as a distance of two or three hundred meters from the entrance to the tunnel, the car going in front is imagined disappeared in the "black hole" of the portal. This phenomenon of disappearance of visibility of objects is called the "black hole effect", which has an impact on drivers not only physiological but also psychological.

When driving under normal conditions, the driver's field of vision is quite large, corresponding to the field created by the windshield of the car, is about 20 °. When approaching the tunnel, the field of view narrows to a value approximately due to the portal of the tunnel up to 2° (fig. 1.1).

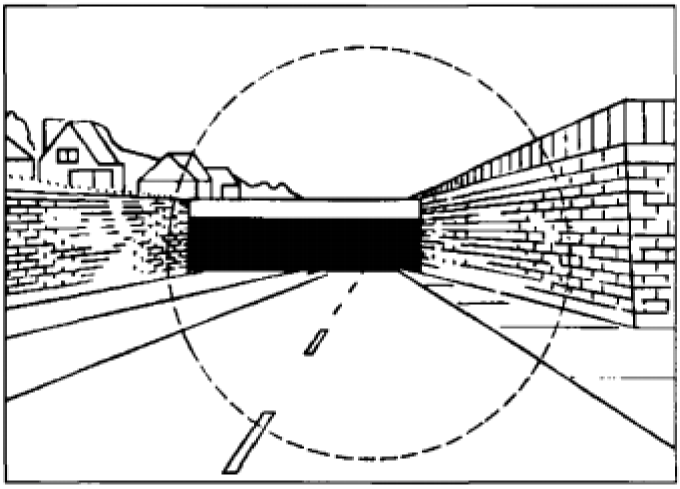


Fig. 1.1 — Tunnel entrance field of view.

The black slit of the tunnel, which increases as you approach it, will take up more and more space on the retina of the driver, which pushes the eyes to adapt to the environment. However, on the way to the portal of the tunnel in the field of view of the driver is occupied by a large part of the brightly lit road and its surroundings. As a result, the process of adapting the eye to the conditions of vision inside the tunnel is very complex. Adaptation of the central part of the retina to the dark, and the periphery to the light causes inductive effects of the states of these areas on each other and the directly opposite reflex of the pupil. The drivers who enter a tunnel with this condition of the visual system may completely lose their sight for some moments.

Therefore, one of the tasks of tunnel lighting is to create a field of view of such brightness and distribution, in which the driver is able to see all the necessary objects both at the entrance to the tunnel(making an easier adaptation to the retina) and when moving inside the tunnel.

The main tasks of tunnel lighting design are:

• minimizing the "black hole effect", which is achieved by using both construction and lighting measures;

• creating a sufficient number of zones and brightness levels that ensure the normal course of the adaptation process from bright sunlight to minimal lighting by the depths of the tunnel;

• proper location of lights;

• elimination of blinding intimacy;

• elimination of the flickering caused by the interrupted arrangement of fixtures and alternation of light and dark zones of surfaces of the tunnel;

• providing orienting action of lighting devices.

The nature of the lighting solution is influenced by the construction choices and design characteristics of the tunnel:

• length;

• cross-sectional dimensions;

• number of lanes;

• speed of movement;

• presence or absence of roundings and slopes;

• lighting characteristics of the material facing surfaces of the tunnel;

• characteristics of the field of view at the entrance to the tunnel (brightness of the immediate surroundings of the portal, its orientation, evaluated in terms of the predominant direction, intensity and duration of natural light, the possibility of building shielding devices).

It should be noted that for tunnels, before entering which traffic stops (control, collection of fees, etc.), there is no problem of lighting the entrance area.

In terms of lighting, tunnels are divided into short and long.

Short tunnels are where the exit of which is clearly visible from the point in front of the entrance. During the day, during the entire time of driving through a short tunnel, the central part of the driver's field of vision is adapted to the brightness of the road during the day. Some reduction in the level of adaptation when overcoming a short tunnel is very low.

Tunnels about 45-60 m long are considered short, although, for example, a tunnel with a length of 100-120 m can be considered short if it is designed to move in two directions with 3-4 lanes in each, otherwise has a significant ratio of width to length.

Short tunnels in most cases do not require special lighting during the day. Penetration of natural light and the ability to see the source portal provide a sufficient level of silhouette visibility. The need for lighting a short tunnel may be needed only in cases where the entrance and exit openings are shielded by houses, plantings or the presence of roundings. In these cases, the data of table 1.1.

Table1.1 – Lighting of short tunnels during the day

Length of tunnel m	Radius of the curve in the plan area	Daylight
Up to 25	Any	Not visible
From 25 up to 75	350 and more	
	Less than 350	50% visible
From 75 up to 125	350 and more	
	Less than 350	Full
More than 125	Any	

Tunnels of short length (20-30 m) may not require special lighting at night, because the appropriate location of street lamps is able to provide enough degree of visibility.

At night, in short tunnels that require special lighting, it is enough to create lighting for its level, which is approximately twice the normal for the road on which it is located.

Tunnels are considered long when the exit of which is not visible from the plane of the entrance portal and any other point inside the tunnel at a distance of 50 m from the entrance. Such a tunnel requires round-the-clock lighting, the mode of which changes according to the change of natural light.

The main difficulty of daylighting a long tunnel is to eliminate the "black hole effect". This effect is significantly eliminated when the brightness $L_{th}$of the road surface of the entrance part of the tunnel is at least 0,1L_{20}–the brightness of the road in front of the tunnel. Since the brightness of L_{20} corresponds to the illumination of the order of thousands of lux, the value ofL_{20}=10$L_{th}$is achievable only by darkening the road adjacent to the portal.

Reducing the cost of shielding helps to reduce the lightness of the road surface in front of the tunnel and illuminate the surface inside the tunnel. The use of additives to the usual composition of asphalt (reflection coefficient 0.07) allows to achieve the value of the reflection coefficient of the illuminated coating, equal to 0.17-0.20. The length of the shielded area is determined by the value of the allowable speed on the road and the length of time required to adapt the driver's eye. With a brightness of L_{20}=8–10thousand.cd/$m^2$and a difference of L_{20}/L_{th}=10 this time interval is 2–4 sec. To meet these requirements in the entrance of the tunnel, directly adjacent to the portal, it is necessary to create lighting, the values of which are in the range of 1-5 thousand lux.

Sufficient time should be provided in the remote part of the tunnel to adapt to lower brightness. It is believed that the process of adaptation from the brightness corresponding to thousands of lux in the entrance of the tunnel to the brightness corresponding to tens of lux in its depth requires 10-15 seconds. For this purpose, the amount of illumination is gradually gain or gradually reduced from the initial to the accepted for the entire other length of the tunnel. This area is called the adaptive, or boundary zone, because within it the perception of objects by the eye, which is constantly adapting, occurs near the threshold of its sensitivity. The length of this section is determined by the accepted values of the brightness difference and the speed of movement in the tunnel. When determining the number of degrees of change in brightness, the difference in brightness between them and the length of the areas of constant brightness (width of the steps), the following changes in brightness over time are considered acceptable.:

•from 100 to 30 cd/m^2— 1 s;

•from 100 to 10 cd/m^2— 2 s;

•from 100 to 4 cd/m^2— 3 s;

•from 100 to 1 cd/m^2— 4 s.

The values of the average horizontal illumination of the road surface of the carriageway of urban transport tunnels longer than 60 m for the day mode are given in table. 1.2. In the evening and night modes, they should be equal to 50 lux. For tunnel lengths up to 60 m, the average horizontal illumination should be 50 lux in all configurations.

Illumination coverage passages under bridges and overpasses in the dark should not be less than 30 lux at a length of 40 m travel, for longer length the standard should be adapted for it.

Table1.2 – Average horizontal illumination of tunnels

Tunnel length, m	**Tilt of the portal**	**Orien-tation of the portal**	**Average horizantal illumination (lux) at a distance (m) from the beginning of the portal**						
			5	25	50	75	100	125	150 and more
From 1 to 100	Any	Any	750	750	400	150	60	-	-
More than 100	Without slope	North	750	750	400	150	75	60	50
		South	1000	1000	550	250	100	60	50
	With slope	Any	1250	1000	650	350	125	60	50

By the nature of the conditions of vision, and accordingly by the levels of brightness (illumination) of the tunnel can be divided into such zones (fig. 1.2):

1. Access area.

2. Entrance or border area.

3. Transition zone.

4. Inner area.

5. Exit zone.

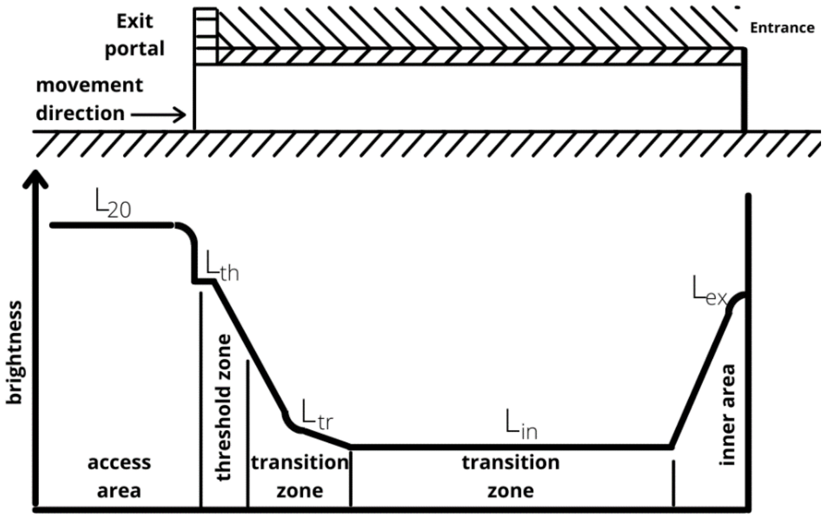


Fig.1.2 — Typical longitudinal section of a one-way tunnel

The solution to the problem of lighting tunnels cannot be unambiguous.

Of great importance for the establishment of normalized values of brightness (illumination) is the "safe braking distance", which means the distance traveled by the vehicle from the moment the driver detects an obstacle to the moment of complete stop (table. 1.3).

Table 1.3 –Safe braking distance.

Speed of movement, km/h	60	80	100	120
Safe braking distance, m	54	88	130	180

Note. Specified in the table safe breaking distance increases by 3% in the presence of descent to the tunnel and decrease by 2% when ascending to the entrance portal.

The brightness of the field of view outside the tunnel (L_{20}) can be very high, especially in clear weather (table. 1.4).

Table 1.4 – Brightness of areas in the field of adaptation

Direction of traffic at the entrance of the tunnel	Average brightness of adaptation field, cd/m^2					
	Sky L_c	Road L_r	Portal environment, L_e			
			Home	Rocks	Grass, leaves	Snow*
North	6	3	8	3	2	15/15
East or west	12	4	6	2	2	10/15
South	16	5	4	1	2	5/15

*In the numerator - on a vertical surface, well, the denominator - on a horizontal surface.

The level of brightness to be created at the beginning of the boundary zone is a value derived from the brightness level of the access zoneL_{20}, duetotheaveragebrightnessofthefieldofviewwhensightingtheportalfromadistanceequ altothe safe breaking distance. The value $L_{20}$is defined as the weighted average brightness within a 20-degree (diameter) adaptation field visible to the driver on the road axis at a safe braking distance in front of the entrance portal, with the driver's line of sight directed to the center of the entrance portal frame. The value ofL_{20}can be calculated by the formula (1.1):

$$L_{20} = K_c L_c + K_r L_r + R_e L_e, \qquad (1.1)$$

Where K_c, $K_r$and K_e — respectively, part of the sky, carriageway and the portal environment in the field of adaptation;

L_c, $L_r$and L_e — the value of their average brightness.

Under the same natural lighting conditions, differentL_{20}values will be obtained for tunnels with different entrances and natural or man-made structures.Naturally, when designing tunnels, the task is to reduce $L_{20}$by reducing the brightness L_r of the road leading to the portal, carried out by shading it (shielding direct sunlight and diffused light) and construction of a powerful lighting installation in the initial part of the tunnel.

The threshold zone is counted from the entrance portal, its length is taken not less than the distance of safe braking.

In the first half of this distance, the lighting is characterized by a constant value of L_{th} and its ratio to the brightness of the entrance zone L_{20}, and then should gradually decrease to the end of this zone to 0,4L_{th}. L_{th}/L_{20}values are regulated depending on the selected tunnel lighting system (table. 1.5).

Table1.5 – Normalized values of the ratio of the average brightness of the road surface of the boundary zone to the brightness of the adaptation

Intensity per lane	Value L_{th}/L_{20}, %							
	Symmetrical lighting system				Counter lighting system			
	Speed of movement, km/h				Speed of movement, km/h			
	60	80	100	120	60	80	100	120
> 1200	4	5	7	8	2.5	3.2	4	4.5
< 1200	3.5	4.5	6	7	2	2.7	3.5	4

Note. The given values of the ratio L_{th}/L_{20}refer to tunnels characterized by such conditions:

a) one-way traffic;

b) there are no side entrances and exits in the border and transition zones;

c) the entrance is located on a straight section of the route.

In cases where at least one of these conditions is not met, the L_{th}/L_{20} ratio should be increased by at least 30%.

The average brightness of the tunnel walls up to a height of 2 m is taken to be at least 0.7 of the average brightness of the road surface. The nature of the recommended reduction is shown in fig. 1.3.

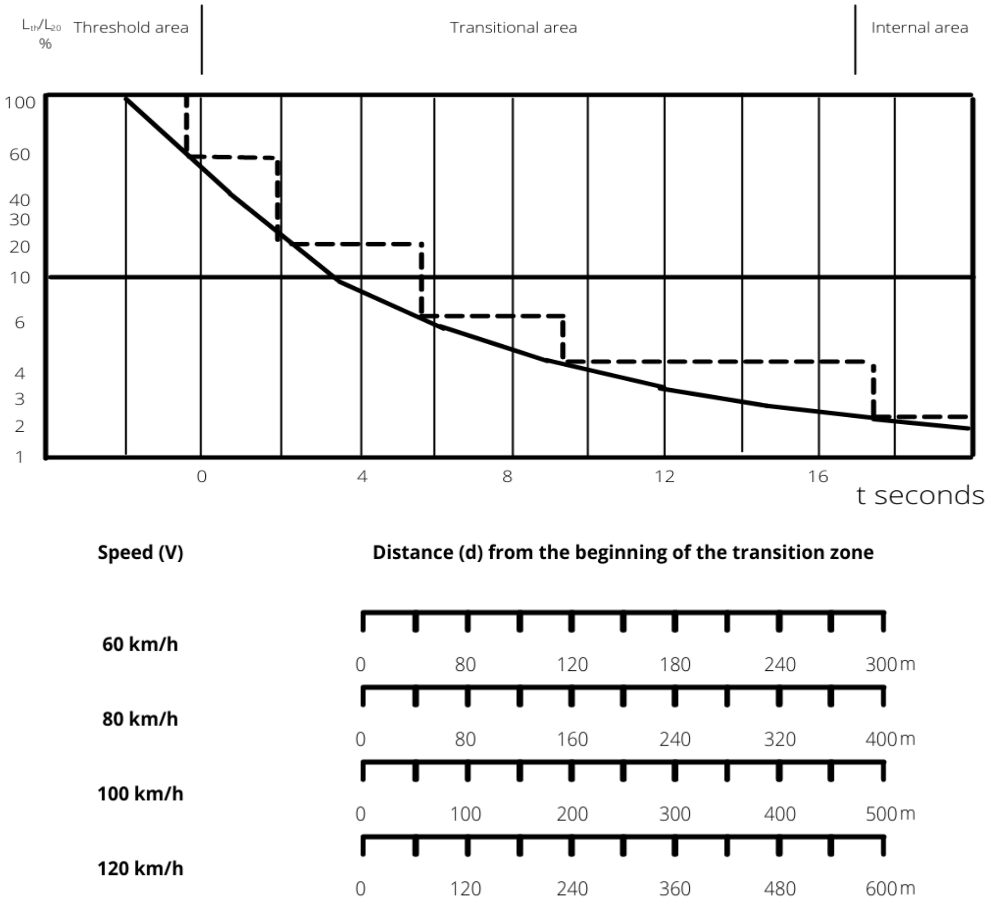


Fig. 1.3 — The curve of the decline in the brightness of the road surface in the transition zone

In the transition zone, the brightness gradually decreases from the brightness level of the boundary zone to the brightness level of the inner zone.

Obviously, it is impractical in long tunnels to maintain the high brightness of the surfaces required at the beginning of the tunnel along the entire length. Tunnel lighting should be constructed in such a way that the brightness of its surfaces in a limited area after entry gradually decreases and by the end of the section reaches a value that provides the desired degree of safety and efficiency. It is natural to assume the need to slightly increase the brightness of the surfaces of the exit part of the tunnel in order to mitigate the conditions of adaptation at the exit.

The data in table 1.4 indicate the brightness of the road surface immediately before entering the tunnel in 3–5 kcd/m^2.

It has been experimentally established that the driver's eye can adapt to a brightness ten times lower within 1-2 seconds when approaching the tunnel. This allows you to set the required for the initial part of the tunnel values of brightness and light, as well as, taking into account the allowable value of the speed of entry into the tunnel, the length of the road that requires shielding. Experience in the construction and operation of tunnels and experiments have shown that with very heavy traffic, the brightness of the road surface in the depth of the tunnel should reach 10-20 cd/m^2, with moderate traffic, this value can be reduced to 5 cd/m^2. Setting this level makes it possible to determine the magnitude of the brightness difference from the initial part of the tunnel to its middle, as approaching 100.

The process of adapting to such a change in brightness takes a few seconds. Taking into account this and the value of the allowable speed in the tunnel, you can determine the length of the adaptation zone, within which the illuminance should be reduced (smoothly or stepwise) from the value taken at the beginning of the tunnel to the minimum.

Thus, the purpose of lighting transport tunnels is to provide the ability to see day and night with the same degree of reliability and comfort as on the road. Deviation from this goal may result in a reduction in the capacity of the tunnel and the road, as well as a decrease in the degree of traffic safety, which reduces the efficiency of the structure.

The practice of designing lighting installations on the basis of Swiss standards SN 150915 should be considered in more detail. In fact, finding the coefficient of proportionality K between L_{th} and L_{20} according to this document is based on the sum of evaluation indicators in points, which determine the class LI according to the lighting requirements, which reflects the degree of complexity of the driver's visual work. This is, firstly, an indicator of traffic intensity from 0 to 7 points depending on the number of transport units per hour per lane, as well as, divided or movement in directions; the maximum indicator for the divided movement is 6 points (at traffic intensity more than 1200 units/h), and at movement in both directions (counter) - 7 points at the same intensity. Secondly, it is an indicator of the composition of traffic - 0.1 or 2 points, depending on the share of freight transport, as well as the presence of non-motorized traffic. 2 points are added for poor visual marking of the direction of movement. Finally, if the average brightness of the lower part of the walls (up to a height of 2 m) <0.4 L_{th}, 4 points are added, and at its value of 0.4-0.8 L_{th} –2 points. The following sums of points are set for high classes LI: for the 4th - 8-9 points, for the 5th - 10-11, for the 6th - 12-13 and for the 7th - 14-15 points, respectively.

For visual marking of the direction of movement in AT one-row arrangement of fixtures on walls and satisfactory visibility of dividing lines on a pavement which is usually provided is enough, however points to this indicator are not added. Thus, almost the maximum amount of points is not more than 12-13, i.e. corresponds to the Class 6.

A slightly different approach is demonstrated by the latest edition of the US Society of Lighting Engineers, although tunnel lighting requirements are divided into the same zones and lighting levels in the threshold and transition zones and depend on entrance orientation, surrounding landscape and buildings, estimated vehicle speeds and intensity of its movement.

As can be seen from table 1.6, accepted in the US safe braking distances depending on the speed is significantly higher than in Europe.

Table 1.6 shows that the lengths of the threshold and transition zones of the tunnel come from the length of the braking distance, but the length of the threshold zone is 15 m less than the braking distance, because ~ 15 m in front of the portal entrance tunnel completely dominates the field of view the driver.

The minimum brightness of the road surface in the inner zone should be 5 $cd/m^2$with a ratio of average brightness to a minimum of 3:1.

Table 1.6 – The length of the adaptation zones depending on the speed of vehicles

Speed of traffic, km/h*	Minimum braking distance, m	The length of the coastal zone, m	The length of the transition zone, m
48	60	45	60
64	90	75	90
80	140	125	140
88	165	150	165
96	200	185	200
104	220	205	220

* it is assumed that at the direct and equal entrance to the tunnel, the average prevailing speeds are approximately equal to the maximum permitted speed.

Throughout the threshold zone must be maintained a constant value of L_{th}, which is selected according to table. 1.7.

The transition zone should be divided into sections of equal length. In the first section after the threshold zone, the brightness of the road surface must be at least 25% of L_{th}. In each subsequent section, the average brightness of the road surface must be at least 33% of the brightness level in the previous section, the road surface should not exceed $2L_{inner}$

Features of the new Japanese standard JIS Z 9116-1990 "Lighting of tunnels for motorized traffic" and the British BS 5489, p.7 - 1992 "Outdoor lighting. Part 7. Practical guide to lighting tunnels and overpasses" in comparison with the recommendations of the International Commission on Illumination (CIE) are related to the desire to guide designers to more moderate levels of lighting, as well as the practical absence of Japanese and English AT backlight systems, as seen in tables 1.8 and 1.9.

Table 1.7 – Recommended values of the average brightness of the road surface in the threshold zone of the tunnel during the day (USA)

Characteristics of the tunnel	Vehicle Speed, km/h	Brightness, cd/m^2, traffic density, cars/time*			
		<25000	25000-89999	90000-150000	>150000
Mountain tunnels with gentle slopes, where snow can depend, or tunnels through river barriers with small surrounding buildings. Orientation of the east-west tunnel	81	210	250	290	330
	61-80	180	220	260	300
	60	140	185	230	270
Mountain tunnels with steep, dark slopes or in climatic conditions when the snow does not occur. The environment of the portal is moderately bright all year round	81	145	175	205	235
	61-80	130	160	190	220
	60	105	140	170	200
Hidden portals; dark surfaces or buildings surrounding the entrance area to the portal. Special measures taken to reduce the brightness outside the tunnel. Orientation of the tunnel north - south	81	80	100	115	130
	61-80	70	90	105	120
	60	60	80	95	110

* the average annual number of cars per day in both directions

Table 1.8 – Normative indicators of illumination of threshold and internal zones according to the Japanese JIS 9116 standard -1990 *.

Estimated speed, km/h	Coefficient of proportionality $c = L_{th} / L_{20}$ (only)	Average brightness of the road surface in the inner zone, cd/m^2
100	0,07	9,0
80	0,05	4,5
60	0,04	2,3
40	0,03	1,5

Note. The entrance part of the AT is divided into threshold, transition and relaxation zones. At a speed of 100 km / h, the length of the threshold zone with a constant brightness L_{th} – 55 m, transitional with a decrease in brightness to 0,5 L_{th} – 125 m; in the relaxation zone, the decrease in brightness to 0,1 L_{th} should occur within ~ 150 m. The design speed > 100 km/h for tunnels is not considered.

Required by the British standard BS 5489, Part 7 (1992) values of $k = L_{th} / L_{20}$ and the brightness of theinnerzone L_{inner} .

Table 1.9 – Category of road lighting according to the speed of the vehicle.

Maximum speed, km/h	Category of road lighting	Coefficient c (single)	L_{inner}, cd/m^2
>110	Freeway	0,07	10
80-100	Category 1 and 2 roads with this speed limit	0,06	5
50-70	Category 2 roads with such speed limit, category 3 roads	0,05	3

1.2 Ways to increase the efficiency of lighting tunnels

By the end of the 1990s, there was again a tendency to pay more attention to the economic side of the issue when designing the tunnels. Thus, a new version of European standards is being prepared under the leadership of D.A.Schroeder, which adopts the size of the critical object 0.3×0.3 m instead of 0.2×0.2 m, and the critical contrast 0.3 instead of 0.2, which will to reduced values of L_{th} D.A.Schroeder testified that the implementation of the Swiss standards of backlighting of the entrance areas of the AT provide very good visibility. But these norms are much lower than the norms of CIE. However, he noted that this system requires more accurate "light control", otherwise it creates increased blinding effect. It is recommended to use formula to calculate the veiling brightness in tunnel, which gives higher values of brightness. In a number of recent works, the question of reducing the levels of illumination of the pavement while maintaining the level of visibility due to increased quality characteristics of lighting.

The issue of preventing the flicker effect caused by brightness differences when driving along a number of luminaires is not controversial. This effect is practically absent when the step of the lamps at a given speed creates a flicker with a frequency of less than 2.5 Hz or more than 15 Hz (the flicker frequency is determined by dividing the speed in m/s by the step of the lamps in meters. For example at 60 km/h = 16.6 m/s and a step of 10 m blink frequency 16.6/10=1.66 Hz, i.e. outside the discomfort zone.

All norms and recommendations emphasize the need to take known measures to facilitate adaptation in the entrance section of the tunnel: use as possible dark materials for facing or painting all external surfaces in front of the portal - pavement, the portal itself, ramp walls, etc. and vice versa, light pavements and wall cladding inside the tunnel. If a significant part of the driver's field of vision is occupied by the sky, it is recommended to use vertical panels, eyelets or tall trees that shield the entrance to the tunnel.

Also, in all these documents, it is recommended to adjust the brightness levels in the tunnels depending on the levels of natural light, as the most difficult conditions from the point of view of the driver approaching the tunnel, for which, for example, CIE standards, are only a few hundred hours. year even in the southern countries. For example, in Italy, more than half of the daytime brightness outside the tunnel is 20-25%, and about a third of the time - 10% of the maximum. Therefore, the vast majority of lighting installations of tunnels with a calculated brightness $L_{nop.}$ >100 cd/m^2 or illumination above 1200-1500 lux, accepted for the threshold zone, have several modes of operation during the day.

The control system is often controlled by a computer on a differential basis: the executive signal in the control unit is proportional to the difference in brightness levels inside and outside the tunnel.

In countries where there are particularly stringent requirements for levels X in the maximum mode, tunnel designers and their lighting are trying to use every opportunity to save electricity and other resources. Thus, in Germany, after the release of DIN 67524. 1987, new and reconstructed tunnels are usually equipped with a system of backlighting of the entrance sections and one or another system regulates the lighting levels. For example, in the entrance area of the tunnel with a length of 600 m on the motorway in Karlsruhe in the system of backlight is automatically a step-by-step transition to one of the 8 lighting modes with levels L_{th} 160, 140, 120, 100, 80, 60, 40 and 20 cd/m^2. The most common lighting installations with 5 modes of operation: 3 day, one twilight and one evening; sometimes at night an additional reduced mode is introduced.

An important aspect in the design of lighting fixtures is also the stock ratio. In recent years, the level of air pollution in cars has decreased in developed countries; at the same time, the tunnels use luminaires with a degree of protection of IP65, and their regular maintenance is established. Therefore, for example, in Belgium when using such lamps even in tunnels of the II category of pollution the stock factor is accepted on ~ 20% lower, than and so low at lamps of degree of protection IP54.

Sometimes the level of illumination in the inner zone is dependent on the normalized attenuation factor. Thus, according to the norms of PIARC (Permanent International Association of Road Congresses), at a attenuation factor of $5\times10^{-2}m^{-1}$ the braking distances of 160, 100 and 60 m correspond to the norms of average brightness of 10, 5 and 1 cd/m^2; at the attenuation coefficient 9×10^{-3} m^{-1}(1/m) braking distances of 100 and 60 m correspond to average brightnesses of 15 and 2 $cd/m^2$and at so polluted air in tunnel the speed demanding braking distance of 160 m is not allowed.

The analysis of the basic concepts in the field of lighting of entrance zones of transport tunnels allows to draw the following conclusions:

• over the past 15 years in developed countries there has been a significant convergence of approaches to the standardization of lighting entrance sections of tunnels. However, the brightness levels recommended by various documents in the threshold and subsequent zones of the tunnels vary in a very wide range, especially at speeds>100 km/h; the highest requirements for brightness levels in the threshold zone are set in the recommendations of the CIE and the norms of Germany;

• more attention is paid to the cost-effectiveness of lighting in the standards of England, the United States, Japan and especially Switzerland;

• the effect of the application of the backlight system is taken into account only in European practice and in the recommendations of the CIE; while the recommendations of the CIE allow a moderate decrease in brightness in the threshold zone by 20-38%, while the Swiss recommendations reduced compared to the norms of the CIE threshold values for traditional systems in the counter system are reduced by about 2 times In Germany and several other countries leave the norms the same, taking into account only the higher utilization factors for the brightness of the luminous flux of backlight fixtures;

• the length of the threshold zone, where the maximum brightness is constant, at a speed of ~100 km/h varies from 55 min Japan to 185 min the United States; in the recommendations of the CIE it is 80 m;

• the total length of the transition zone at a speed of ~100 km/h is from ~200 min the US to 220-365 m depending on the intensity of traffic on the recommendations of the CIE (if you include the second half of the threshold zone, where the brightness of the road begins to decline);

• for the counter lighting system the most important point is strict control of light distribution of fixtures that provides exclusion of dazzling.

1.3 Conclusions to section 1

1. Based on the analysis of the international standards of lighting of motor transport tunnels the generalization of the basic directions of increase of economy, safety and comfort of lighting is carried out. The normative indicators of illumination and brightness in different zones of the tunnel depending on its parameters and characteristics of road traffic taking into account features of light adaptation of a human eye are systematized.
2. Different types of lighting of motor tunnels depending on the purpose of lighting, location of lighting fixtures, direction and intensity of road traffic are analyzed.

2 CALCULATION AND RESEARCH SECTION

2.1 Lighting devices for road tunnels

Lighting fixtures used to illuminate tunnels can be divided into groups:

– general lighting fixtures;
– side lights;
– lighting fixtures for local lighting;
– emergency lighting.

General lighting of the road tunnel is created by lamps installed on the walls at certain intervals. Luminaires must provide sufficient light flux for uniform illumination of floors, walls, carriageways of road tunnels. In addition, they must be compact, safe to handle, have a dust- and moisture-proof housing that is easy to clean and wash.

Luminaires with a protection angle of at least 10 ° must be used in transport tunnels. The height of their location must be at least4 m.

Side lighting lines provide even lighting and eliminate flicker. At the same time, they support optical movement.

In addition to the general lighting of the transport zone, more intensive local lighting of certain zones of road tunnels is provided: cameras, niches, extensions.

Another important task is to provide lighting in accidents and emergencies to evacuate people to safe places and save their lives and health. The evacuation lighting system is responsible for this. It must provide a level of illumination in the tunnel of at least 10-12 lux.

The main approach in the development of evacuation lighting system is determined in each case and depends on the length of the tunnel, its design features, configuration, presence of centralized control systems in the event of an emergency.

In long tunnels, emergency exits may be located far from each other and out of sight. There is a task to direct the evacuees to the nearest evacuation exit. This problem is solved with the help of direction indicators. There is a gradual transition from the use of reflective stickers on the walls to light static indicators and controlled LED dynamic indicators of the direction of movement.

Evacuation lighting should be controlled centrally from the control room. In operating mode, all emergency lighting fixtures are in working condition and powered from the external 220 V mains. In the dynamic direction indicator, one of the arrows (which shows the nearest output in a normal situation) is also constantly illuminated when powered from the 220 V mains.

In emergency mode, all luminaires switch to battery power (24-36 V). In the dynamic direction indicator, the glow of one of the arrows is maintained when powered by a battery. An arrow in the opposite direction (depending on the source of the fire) can be switched to active mode according to the external control signal.

As light sources for general lighting, as a rule, high-pressure discharge lamps are used, which are placed in closed glass housings, which protect them from possible damage. In addition, you can create lamps that contain several lamps of different wattages, which can be turned on separately or simultaneously. This provides a gradual and fairly smooth light transition.

Luminaires are divided into 3 groups according to their lighting characteristics: symmetrical, asymmetrical light distribution and "counter beam". Luminaires of symmetrical light distribution (fig.2.1-2.2) can be installed both on walls, and on partitions. They are used to illuminate interior areas, evening lighting, as well as single-track tunnel, used for traffic in both directions.

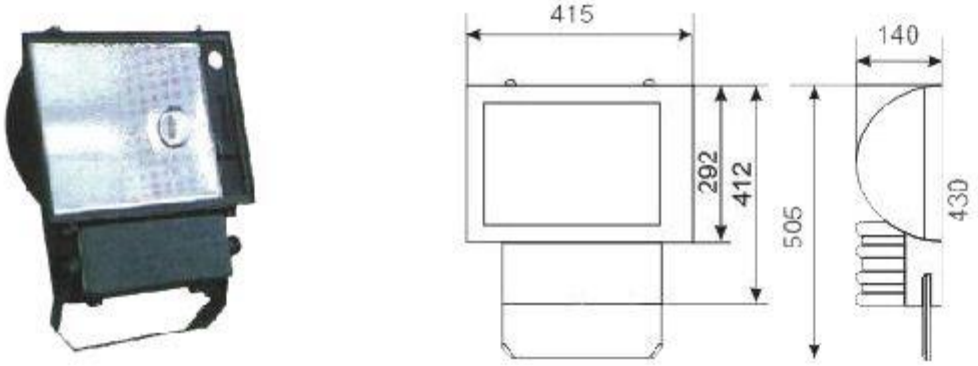


Fig.2.1 - Spotlight of symmetrical light distribution with the sodium lamp.

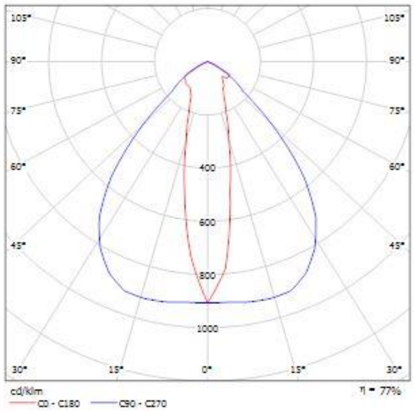


Fig.2.2 - Light distribution of the luminaire with symmetrical light distribution.

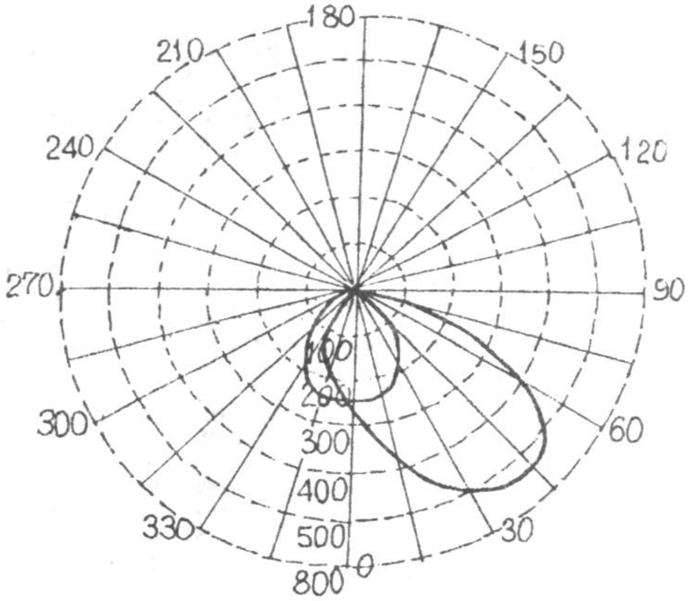
Luminaires of asymmetric light distribution (fig.2.3) are installed on walls or in corners between walls and partitions in systems of traditional lateral lighting.

Figure 2.3 - Floodlight with asymmetric light distribution

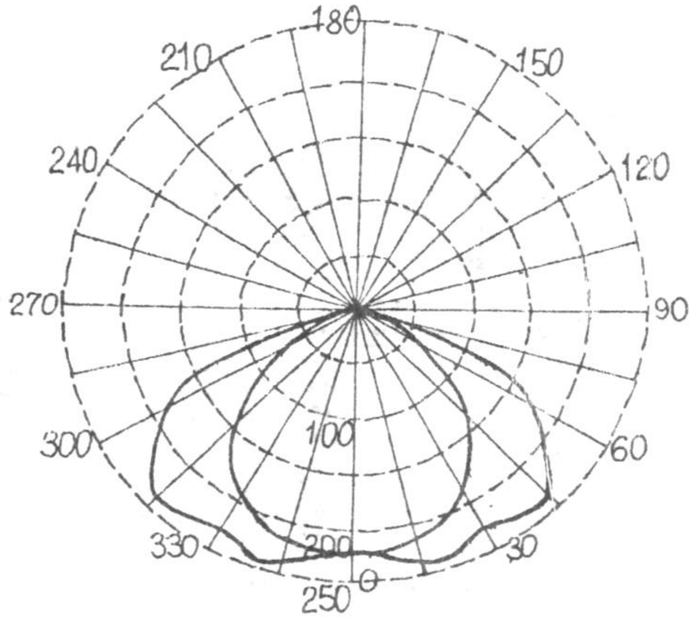
Luminaires with light distribution "counter beam" for backlight systems of the entrance areas of the tunnel are installed on the partitions in one or more rows, depending on the width of the tunnel and the required illuminance (brightness) of the tunnel section.

In fig.2.4, a the characteristics of luminaires for the complete equipment of the tunnel lighting installation are presented: type "counter beam" with sodium lamps with a power of 400 and 250 W and symmetrical light distribution for illumination of the inner zone and evening (night) mode. Two-lamp lamps (fig.2.4, b) allow you to change the lighting mode, alternately turning on a light source.

The main design requirements for lighting fixtures are high tightness of any luminaires for the tunnel (degree of protection IP65 optical compartment and ballast compartment, which provides the possibility of washing luminaires with a hose and protection of internal elements), as well as special measures for easy maintenance and replacement of luminaires lamps with their exact fixation relative to the reflector. The case and heat-resistant protective glass must be resistant to the environment, the convenience of installation and dismantling of luminaires on special brackets must be provided and sufficient vibration resistance of fastening of internal elements and the whole structure must be ensured. Therefore, tunnel luminaires are distinguished by the use of high-quality materials and components (aluminum alloy or stainless steel housing and fasteners of high chemical resistance, sealing with silicone rubbers and sealants, especially reliable lamps and ballasts, sealed plugs and connectors.). Luminaires are usually replaced without depressurizing the connection of the protective glass to the housing, and the ballast unit is placed on an easily removable panel in a separate compartment.



a) luminaire of asymmetric light distribution



b) luminaire of symmetrical light distribution with two lamps

Fig. 2.4 - Light distribution of luminaires with sodium lamps for traditional "symmetrical" lighting system

Developed by Schreder, the outdoor luminaire has a number of advantages: optimal photometric characteristics, adjustable lamp position, energy savings, low operating costs and long service life. The luminaire uses the so-called "Silife" system, which is a hermetically sealed optical unit consisting of a reflector, protective glass and a removable lamp holder. The use of this system, which has a degree of protection IP66, allows you to maintain the initial photometric performance throughout the period of operation. This allows you to reduce the power of light sources in the lamp and increase the distance between the supports in the lighting installation. A high degree of protection avoids its internal cleaning and reduces operating costs to a minimum.

The considered light devices are intended for work with high-pressure discharge lamps. A promising direction in the development of street lighting, as indicated in the previous section, is the use of LED light sources.

Tunnel lighting can be realized with the use of special LED lamps for tunnel lighting. An example of such a luminaire is the LED luminaire for lighting tunnels TONNEL 65. A feature of this luminaire is a special device (bracket) for installation on the walls of the tunnel.

In fact, you can create LED lighting in the tunnel and ordinary lamps, installing LED lamps in them. Such luminaires include TLVP luminaires with a polycarbonate diffuser and the appropriate protection class (Fig. 2.5.). Such luminaires usually use T8 fluorescent lamps. But replacing them with LED lamps T8 will be an LED lamp to illuminate the tunnels. The lamp is overhead and can be easily installed on the tunnel wall.

Fig.2.5 – Luminaire with LED on the basis of TLVP 2x36

You can also use lamps for lamps with E40 base. At present, LED lamps for street lighting are mass-produced (Fig.2.6). Such luminaires can be mounted on a support or attached to a wall or ceiling.

Fig.2.6 - LED lamps for outdoor illumination

The body of the luminaire is made of aluminum alloy, the surface is anodized, the protective glass is made of impact-resistant optical polycarbonate.

In the table 2.1 the basic parameters of lamps of the MMZ series are resulted

Table 2.1- The main parameters of lamps of the MMZ series

Type of SP	Power, W	Luminous flux, lm	IDC type	Weight, kg	Dimensions, mm		
					length	width	height
MMZ 15-03	15	1600	Cosine	2.6	320	200	65
MMZ 35-03	35	3200	Cosine	3.6	520	200	65
MMZ 70-03	70	6000	Cosine	4.6	720	200	65
MMZ 90-03	90	7700	Cosine	4.6	720	200	65
MMZ 130-03	130	11000	Cosine	4.6	720	200	65

The use of LED lamps has a lot of advantages over lighting with discharge lamps (table 2.2).

Table 2.2 - Comparison of characteristics of luminaires with different lamps

Comparison parameters	LED luminaire type MMZ 70-03	Luminaire with lamp HVL-250	Luminaire with lamp SON 250
Service life of a light source (light of a radiating element)	Up to 100 thousand hours	Up to 10 thousand hours The actual service life does not exceed 1 year	Up to 10 thousand hours
Electricity consumption, W	70	Up to 320	Up to 330
Starting current, A	0.30	4.50	
Consumer current, A	0.30	2.10 · 2.20	
Use of luminous flux (efficiency) in street lighting,%	95-98	30-50	65
Loads on city and municipal power grids	Low	Large starting currents at the time of heating (heating time up to 15 minutes) high operating temperature	
Vibration resistance of luminaires during operation	High	Low	
Resistance to voltage drops, V	120-270	180-250	Not stable
Stability of street lighting systems at low temperatures	High	Low	
The presence of a stroboscopic effect	No	Present	
Contrast and color rendering	High	Low	
Ecological safety of the lamp	Environmentally friendly	The lamp contains up to 100 mg of mercury vapor	The lamp contains sodium-mercury amalgam and xenon
Special conditions for disposal of light sources	Does not need	Needs	
Degree of protection	IP64	IP54	
Weight of the luminaire, kg	Maximum 8	10-12 (without lamp)	
Time of entering the operating mode of lighting of light sources	Maximum 1 second	From 10 to 15 minutes (lamp lighting period)	
Temperature mode of operation during operation, °C	From -40 to +40	From -40 to +40 (at low temperatures start of systems is difficult)	

2.2 Placement of luminaires in tunnels

Placing lighting devices in the tunnel and eliminating their blinding effect is an important and quite difficult task. In the initial part of the tunnel, where high illumination is required, the ceiling area may be insufficient to accommodate, for example, lamps with fluorescent lamps, and the use of lamps with discharge lamps such as mercury, metal-halide, sodium due to the small height of their installation may be accompanied by significant blindness. The solution to this problem can be based only on careful study and selection of lighting characteristics of luminaires, which is further complicated by the need to create fairly high values of vertical illumination.

The placement of luminaires should eliminate the possibility of monotonous flicker due to the interrupted location of the luminaires (flicker effect), and ensure the creation of an orienting effect of the lighting installation (Table 2.3).

Table 2.3 - Select the step of installing the luminaires to prevent the flicker effect

Speed of cars, km/h	60	80	100	120
Minimum distance from the entrance portal, mm	500	660	830	1000
Step, m not less not more	 1,3 6,7	 1,7 8,9	 2,1 11,1	 2,6 13,3

The most common layouts for lighting long tunnels:

• two-row on the upper part of the walls;

• two-row on each of the axes of motion;

• single-row along the axis of the tunnel.

Depending on character of light distribution and orientation of fixtures, distinguish symmetric and asymmetric systems of illumination of tunnels.

The symmetrical system is divided into transverse and longitudinal.

The luminaires used in this system have a symmetrical light distribution in two main planes: longitudinal and transverse. In the transverse system, the longitudinal axes of the luminaires (usually with fluorescent lamps and low-pressure sodium lamps) are oriented along the axis of the tunnel, which provides the predominant direction of light flow across the tunnel. At such lighting good light orientation, low blindness, high uniformity of illumination of a carriageway and walls are created. The disadvantages of such a system include a small step between the lamps, which means a large number of them, increased capital and operating costs.

In a longitudinal system, the longitudinal axes of the luminaires are oriented across the axis of the tunnel, which provides the predominant direction of luminous flux along the tunnel, while providing a higher luminous flux utilization rate and a larger pitch between the luminaires. But such a system is characterized by worse uniformity of brightness distribution of the carriageway, especially the walls.

The asymmetric system is divided into counter and passing. The luminaires used in this system have a pronounced maximum light intensity in the main transverse plane at angles of 50º – 65º relative to the optical axis of the luminaire.

The oncoming system is characterized by a high level of brightness of the road surface and low brightness of the vehicle in front, the associated system, on the contrary, provides good lighting of vehicles in front, against the background of low brightness, and therefore it is not practical. Recently, the asymmetric counter-system for the boundary and transition zones has become widespread. The symmetrical longitudinal system is applied to internal and exit zones in the day mode and all transport zone in the night mode.

In the night mode, the brightness of the coating throughout the tunnel is maintained the same, at the level of 2-5 cd/sq.m. Sections of the road before entering the tunnel and directly behind the exit portal in the evening and at night should be well lit to the level maintained in the tunnel.

Particular attention is paid to the lighting of the road coming out of the tunnel. It should exclude a sharp difference in brightness and give the chance to be guided in an environment and to specify the direction of the further movement.

2.3. Methods of light control

Transport tunnels play an important role in solving the transport problems of the modern city. At the same time, road tunnels are very difficult and dangerous areas. This is due to the lack of natural light inside the tunnel and a sharp change in lighting at the entrance and exit, which negatively affects the visibility of the road and makes it difficult to identify obstacles and conditions on the road. Therefore, the lighting of tunnels is subject to strict requirements.

Sufficiently high brightness in the entrance areas of the tunnels are provided by installing a large number of luminaires, their use in full is not always advisable. For example, on a cloudy day, as well as with changing weather conditions during the day, very bright light in the tunnel leads to visual discomfort in drivers. This can lead to accidents.

The main way to create favorable conditions for visibility of the environment, which provides the necessary degree of safety and visual comfort of the driver, is to adjust the lighting during the day and when switching from day to night.

As sources of information about the desired mode of operation can be used:

- autonomous controller of the power supply point, in which the annual schedule of sunrise and sunset is laid down;

– commands from the control point;

- photometric devices that control the brightness inside and outside the tunnel.

You can use the following methods to adjust the light level:

- step automatic adjustment by sequential disconnection of groups of daytime running lights (according to the annual schedule);

- step adjustment according to photometric sensors (brightness meters);

- smooth regulation of a luminous flux of lamps due to change on them of supply voltage (application of dimmers);

- a combination of the above methods of regulation.

2.3.1 Stepwise adjustment of the light level

At present, in the tunnels of the post-Soviet space, step adjustment is mainly used by the method of switching on and off part of the luminaires automatically according to the annual schedule or according to the readings of the brightness meters.

The most advanced technical achievements are widely implemented in Germany, Switzerland, Italy and other developed countries of Europe. For example, as photometric sensors use brightness meters of the German firm "Electric-special" which are established before entrances to portals and in threshold zones of the tunnel. Such a system should implement the following links of control and management:

"Brightness meter ⇨ control cabinet ⇨ stage contactors ⇨ luminaires »

The creation of tunnel lighting networks provides for the possibility of adjusting the power of lighting installations by turning on the network in the evening (all lighting is included) and night (part of the lighting is included) modes of operation. For this purpose networks have contactors of evening (KB) and night (KN) operating modes (fig.2.7). These contactors are installed in outdoor lighting cabinets. The most common power supply for outdoor lighting is the box I-710. It is an intermediate element between the power supply (0.4 kV busbars of urban transformer substations) and sections of the lighting network.

The operation of the outdoor lighting box complies with all regulations. However, when part of the luminaires are switched off at night, one of the phases of the three-phase lighting network is switched off, which causes voltage asymmetry, which is additional losses in lighting networks and reduction of supply voltage quality at outdoor lighting connection points. In this case, individual circuits for adjusting the power of the discharge lamp-ballast kit are used.

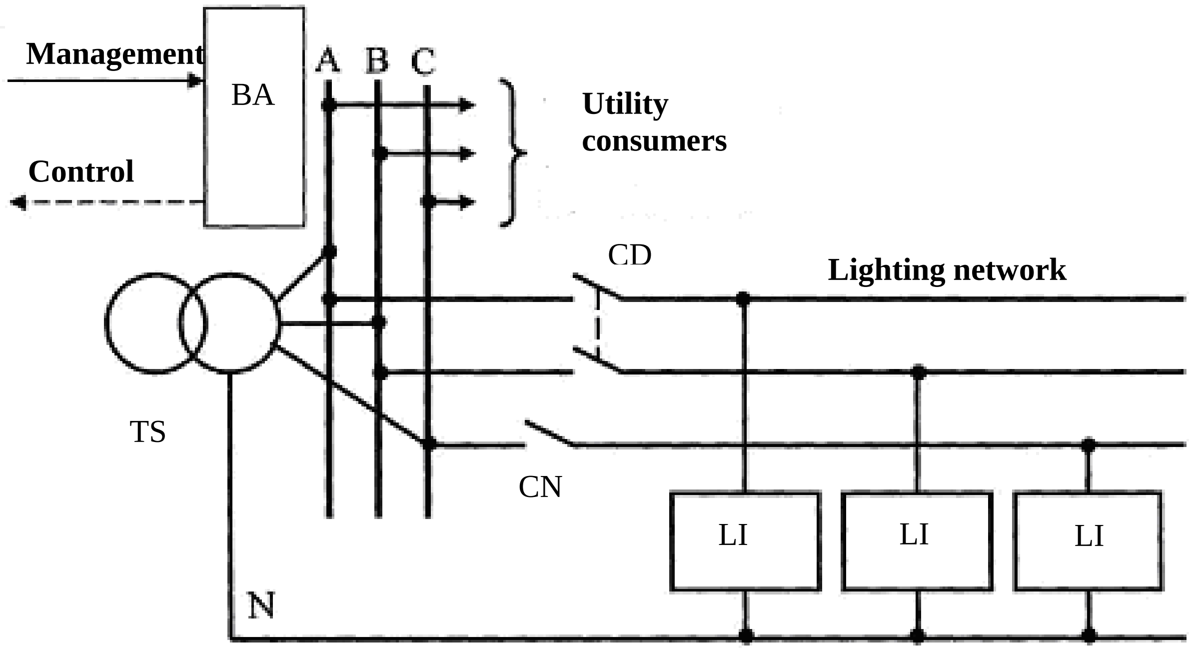


Fig.2.7 - Scheme of the lighting network of external lighting of the tunnel with the automation unit:

TS - city transformer substation;

BA - automation block;

LI - lighting installation;

A, B, C, N - transformer substation busbars;

CD, CN - AC contactors, respectively, day and night modes.

2.3.2 Smooth adjustment of light level

The most promising is the introduction of continuous automatic control - dimming. At dimming constant comparison of the set and actual parameters received from brightness meters in pre-tunnel and threshold zones of the tunnel is carried out. This allows the regulator to apply a voltage to the lamps, which provides a smooth change in the level of illumination in the entrance area in accordance with the change of natural light outside. The voltage on the lamps can vary in the range of 230-180 V. As a result, the luminous flux of the luminaires can change by 20% from the initial value.

This system implements the following links of control and management:

"Brightness meter ⇨ regulator ⇨ luminaires "(dimming).

It is obvious that in comparison with step adjustment in "day" mode (manual, timer or on a brightness meter) dimming allows to reach illumination adequate to necessary intensity and safety of movement at the minimum operational expenses. At the same time the continuous control over electrical installation from the computer of the dispatcher with a possibility of management is carried out. Thus, the change in voltage of the lamps is carried out in accordance with the signal of the luminance meter, proportional to the brightness of the adaptation in the access zone.

This achieves energy savings by stabilizing the voltage in the evening, when due to the decline in power consumption may exceed the voltage in the network. Together with dimming, depending on the typology and modes of operation, energy consumption can be reduced from 20 to 50%.

In addition, additional savings in operation are obtained by increasing the service life of lamps. However, the data obtained from the lamps on the actual installations indicate a significant deterioration of the luminous flux on average in the range of 8.00-12.00 during working hours, which leads to early replacement of luminaires.

By stabilizing the voltage, the power regulator protects the lamps from any voltage surge, especially in cases where the lamps are installed immediately after the transformer and the voltage loss in the network is minimal, therefore, the voltage in the evening can reach values above nominal. Undervoltage leads to a significant reduction in excessive heat loss, thus significantly increasing the service life of the lamp.

The controller stabilizes the operating voltage using a fully digital system, ensuring an accuracy of ± 1% and no overvoltages.

Voltage regulation is carried out by including in the circuit of additional voltage transformers that add the value of the load voltage. The process is controlled by a powerful controller, which is responsible for the control process and for all external communications of the controller.

Fig.2.8 shows a decrease in the power of the lighting installation at night when using dimming.

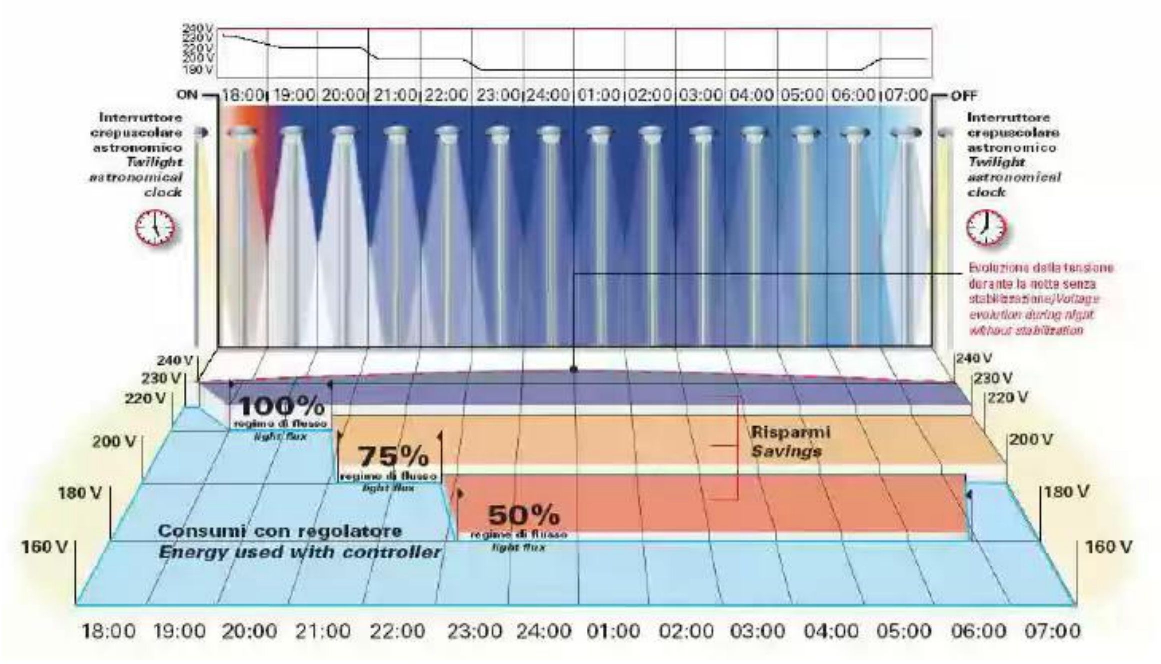


Fig.2.8 - Reducing the power of the lighting installation at night when using dimming

The advantage of such system is that no special calibration or maintenance is required except for standard visual inspections, which are usually performed on control panels. The system allows you to very quickly stabilize the micro-oscillations in the network due to fast feedback. The controller can simply be installed on an existing electrical installation in the power supply gap of daytime running lights.

The dimmers can be used with different types of lamps, even if they work simultaneously in a lighting installation. Operating temperature range from -20 to 50 °C. Regulators have a high efficiency - up to 98%.

The required level of dimming is calculated on the basis of data on the brightness of the road surface. To do this, before each entrance to the tunnel, a light meter is installed at a distance80 m from the portal. The luminance meter is set so that its axis almost coincides with the line of sight of the driver entering the tunnel. Another brightness meter is installed inside the tunnel in a similar way. That is, we obtain data on the brightness of the road surface in the open area just before the entrance to the tunnel, which is created by natural light. And the brightness from the artificial lighting inside the tunnel, which can be adjusted. The task of the system is to maintain a given comfortable ratio, which, on the one hand, ensures smooth adaptation of the driver's eye to the brightness created in the long part of the tunnel, and on the other hand, eliminates excess light and saves electricity.

The successful implementation of the control system of lighting installations depends on the perfection of methods and devices for power control and voltage limitation in lighting networks. The creation of the executive element of the control system of the lighting installation depends on the method of control, the type of lighting load, the range of regulation. As a rule, in lighting networks voltage instability with predominance of positive deviations is noted. It is known that the service life of light sources at high voltage as incandescent and discharge lamps is reduced compared to the operation of the light source at rated voltage.

In order to limit the voltage in lighting networks, it is recommended to install in the networks of thyristor limiters - voltage stabilizers, which limit the mains voltage at mains voltage fluctuations up to 30%, thereby increasing the service life of light sources and save electricity.

Thyristor voltage regulators include thyristor regulators and thyristor voltage limiters in lighting networks. Thyristor regulators are used for both incandescent and discharge lamps, and on the principle of phase control for incandescent lamps, they provide brightness control of lamps 10 times or more, but the use of thyristor regulators for discharge lamps is somewhat limited due to the stability of its operation at large control angles . Therefore, in outdoor lighting networks, where discharge lamps are mainly used, thyristor regulators are used mainly as voltage limiters. Moreover, the use of thyristor voltage limiters leads to a number of restrictions on their use in outdoor lighting networks with discharge lamps.

Installation in the box of external lighting thyristor with phase cut-off means the introduction into the power supply circuit of external lighting semiconductor switch, which operates in phase control mode, which switches half-waves of alternating voltage with a given angle of thyristors. Thus, a non-sinusoidal voltage is applied to the section of the lighting network equipped with this type of regulators, the negative effect of which can be manifested in various forms. The most serious violations include the instability of the discharge light sources, the formation of radio interference, the complexity of cascade control circuits.

It is known that in the phase control of the power of the discharge lamp in the case of inductive ballast, varying the opening angle of the thyristors, you can smoothly change the current of the lamp. However, the current pause characteristic of this mode limits the range of regulation due to the attenuation of the lamp at large cut-off angles. At deep regulation of several lamps their burning is unstable, there is a flickering of lamps.

Luminaires for outdoor lighting is equipped with compensating capacitors. Arbitrary time-out of the discharge lamp, which in some cases occurs during operation of networks, or its failure removes the influence of inductive ballast and automatically translates the lamp into a capacitive receiver, i.e. the network changes the impedance, which makes adjustments to the thyristor regulator, different from the specified mode. At short-term attenuation or short-term burning of several fixtures with discharge lamps due to increase in size of a capacitive component in the thyristor regulator the phenomenon of "overregulation" can be observed. The predominance in the line of the capacitive component leads to the fact that the thyristor device with a phase control law may be completely inoperable. To prevent such situations, it is recommended to install capacitors in the thyristor regulator. For an outdoor lighting network, this recommendation provides for the withdrawal of individual capacitors from the circuit of each luminaire and their replacement with a battery with equivalent capacity, which is installed in the outdoor lighting cabinet and connected to the buses of this lighting supply network.

Powering the outdoor lighting network with non-sinusoidal voltage leads to an increase in the current amplitude of the discharge lamp, which in turn reduces their service life. Thus, when the lamp power is reduced to 50%, the amplitude factor of the SON lamps increases to 1.6-1.8, which reduces the actual service life by 20%.

Outdoor lighting networks are powered by general purpose substations, so the voltage level in these networks is usually unstable, and there are both deviations and voltage fluctuations. Experience of operation of thyristor devices in networks with discharge lamps shows that at voltage fluctuations up to 20% reliability of work of regulators with phase cut-off cannot be guaranteed. Non-sinusoidal operating current of the lighting line forms a wide range of harmonic components. Low-order components reduce the power factor of the devices, and high-frequency components, even at small amplitudes, create interference to radio reception. This fact is especially important given that the outdoor lighting networks are mostly made in a wired version with an air strip and can serve as an antenna circuit. Equipping a thyristor controller with a filter that protects against the spread of radio interference is problematic due to the wide change in load impedance during operation of the network with discharge lamps. Recommendations for the use of phase regulators located in the power supply points of lighting networks and functionally combined with them, while maintaining a system of cascade control of installations also raise doubts. The control phases to which the contactor coils of the cascade power points are connected are the power wires of the outdoor lighting network. During the operation of the regulator in the mode of the reduced power to the coils of the contactors calculated for work on a sinusoidal current, half-wave of the voltage limited by phase cut-off is brought. This leads, firstly, to a decrease in gravity electromagnet, secondly, to the unacceptable overheating of the coil due to the action on the magnetic system of higher harmonics.

Thus, when creating a system for regulating the power of the outdoor lighting network with discharge lamps, the use of group thyristor regulators with phase cut-off is not always justified.

However, phase regulators are used for lighting installations with incandescent lamps. In these installations, thyristor regulators can perform both the functions of voltage stabilization and the starting current limiter.

The second group of regulators are automatic control devices. When using automatic feedback regulators, you can compensate for the aging of discharge lamps, which allows you to maintain the luminous flux of the lamp throughout its life. Automatic control of artificial lighting saves up to 50% of electricity. Devices of group execution on thyristor and triac circuits provide automatic adjustment depending on necessary illumination and the performed functions. However, the use of dimmers for lighting systems is not always economically feasible. Thus, when using regulators for incandescent lamps with a power of 100 W when creating a luminous flux to a level equivalent to a lamp of 40 W, the power consumption is 70 W.

Lighting installations that use thyristor regulators create radio interference, and to reduce the level of radio interference, it is proposed to perform electrical wiring with shielded wires, or their length should not exceed 50 m.

Analysis of publications on thyristor regulators shows that regulators are mainly used for special installations, but their use in lighting networks, where discharge lamps make up the majority, is problematic. Therefore it is necessary to stop on simpler ways of regulation of power of digit light sources.

In the literature, it is proposed to use as a regulator additional ballast, which is included sequentially in the main. When turning on and off the additional ballast, the power of the light sources is regulated.

In the 70-80s of the last century with the development of semiconductor technology began to develop and semiconductor ballasts for discharge lamps. The first developments in this direction were mainly focused on fluorescent lamps. On the basis of semiconductor technology began to create equivalents of discharge lamps to measure the parameters of ballasts, but such models are designed only for fluorescent lamps up to 80 watts.

There are developments for powering discharge lamps of high pressure, the scheme of the converter is developed. For metal halide lamps, the frequency range varies from a few kHz to 40 kHz, for sodium lamps - up to 30 kHz, for mercury lamps - up to 70 kHz. The problem of ignition of lamps is solved. The converter has an efficiency of up to 80%. Experimental studies of high-pressure discharge lamps complete with these transducers show their stable operation during operation, with an increase in luminous flux, for example, for sodium lamps by 12%. The use of semiconductor ballasts can reduce power consumption by 12-29% and power losses in the device by 56-67% compared to electromagnetic ballasts.

2.4 Conclusions to section 2

1. Based on the analysis of lighting and electrical parameters of light sources, the expediency of their use for different types of tunnel lighting is substantiated.
2. The characteristics of luminaires with discharge lamps of high pressure and LED are compared.
3. Methods of light regulation in tunnels are analyzed, their advantages and disadvantages are established, recommendations on use for different types of lighting installations are given.

3 PROJECT DESIGNING SECTION

3.1 Lighting calculation of a lighting installation for a transport tunnel

We set the size of the road tunnel: length 100 m, width 13.5 m. The tunnel has two opposite sides with 2 lanes on each side. The height of the tunnel is 5 m. The two strips are separated by columns 0.5 m wide and another 2 columns 0.5 m on each side of the lane Fig 3.1 shows a general view of a given tunnel.

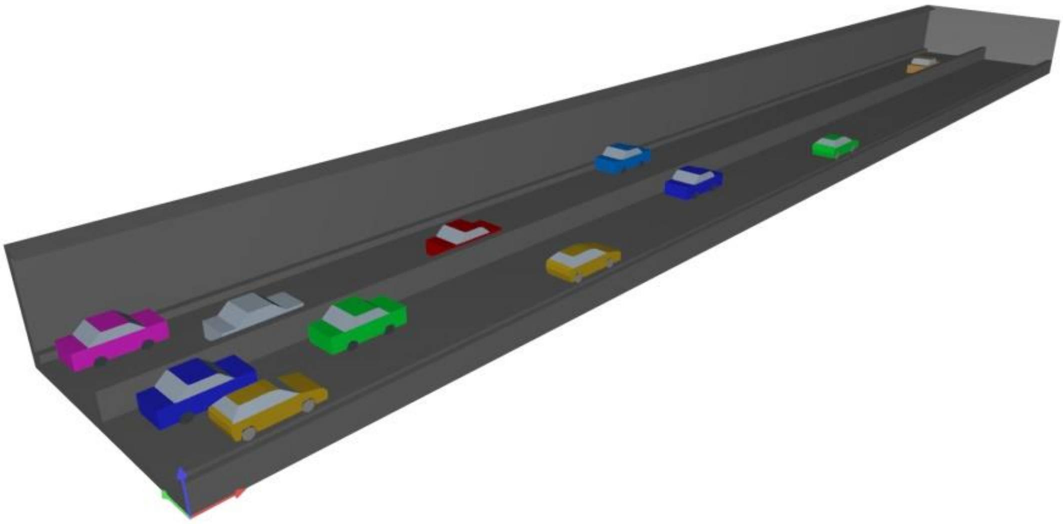


Fig. 3.1 - General view of the car tunnel

According to the requirements of DBN 2.5-28-2018, the level of illumination in the tunnel up to 100 m long and the speed of traffic 50-80 km/h must be at least 625 lux for the threshold zones and 370 for the internal zone during the day, and 50 lux at night. For a tunnel with a length of 100 m there are three zones: threshold (at both sides of tunnel) and internal.

In the event of an emergency shutdown of the main lighting of the tunnel, evacuation lighting must be provided. The level of illumination during the evacuation should be 10-12 lux. The luminaires must be powered by 24-36 V from an independent generator.

For the general illumination of a tunnel we choose fixtures Havells Sylvania 0039826 SYLVEO2 SON 250 W, Havells Sylvania 0039911 SYLFLOOD1 150 W and Schréder GL2 COMPACT 5 124 W**.**

Figure 3.2-3.3 shows the general appearance and light distribution of luminaires.

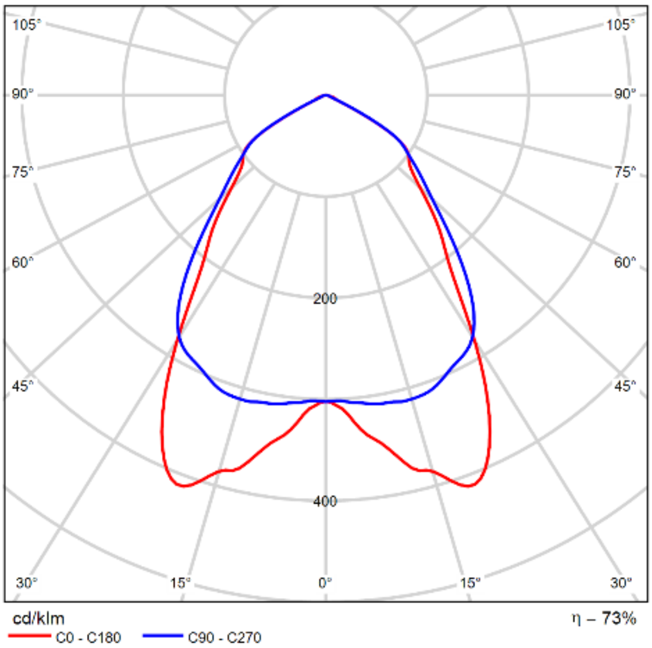


Fig. 3.2 - General view of the luminaire Havells Sylvania SYLVEO2 SHP-TS 250W and its light distribution

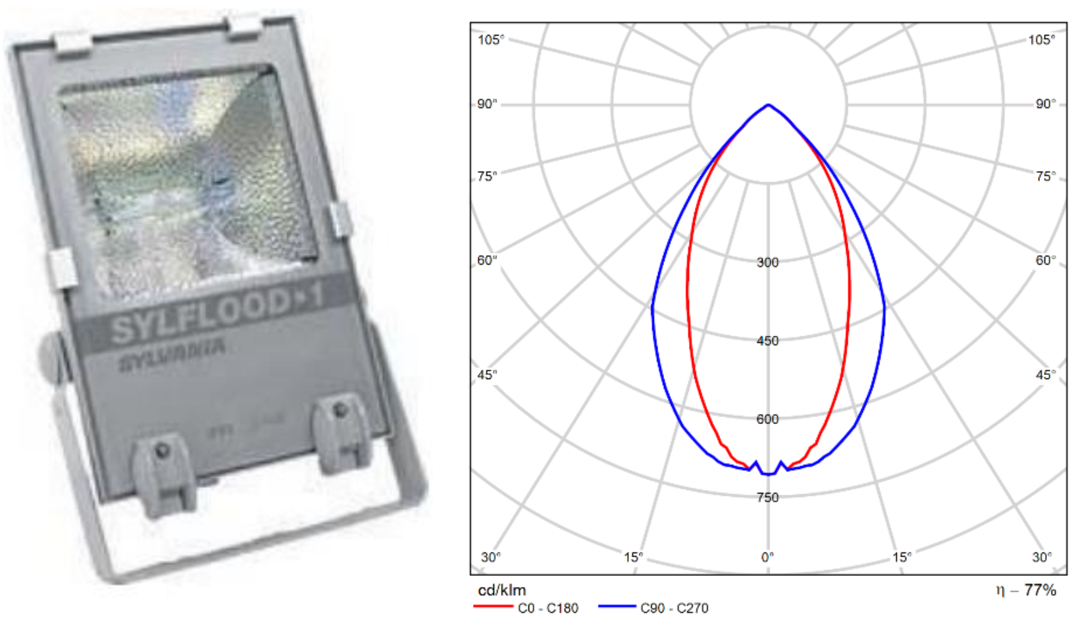


Fig. 3.3 - General view of the luminaire Havells Sylvania SYLFLOOD 1 HSI-TD 150W and its light distribution

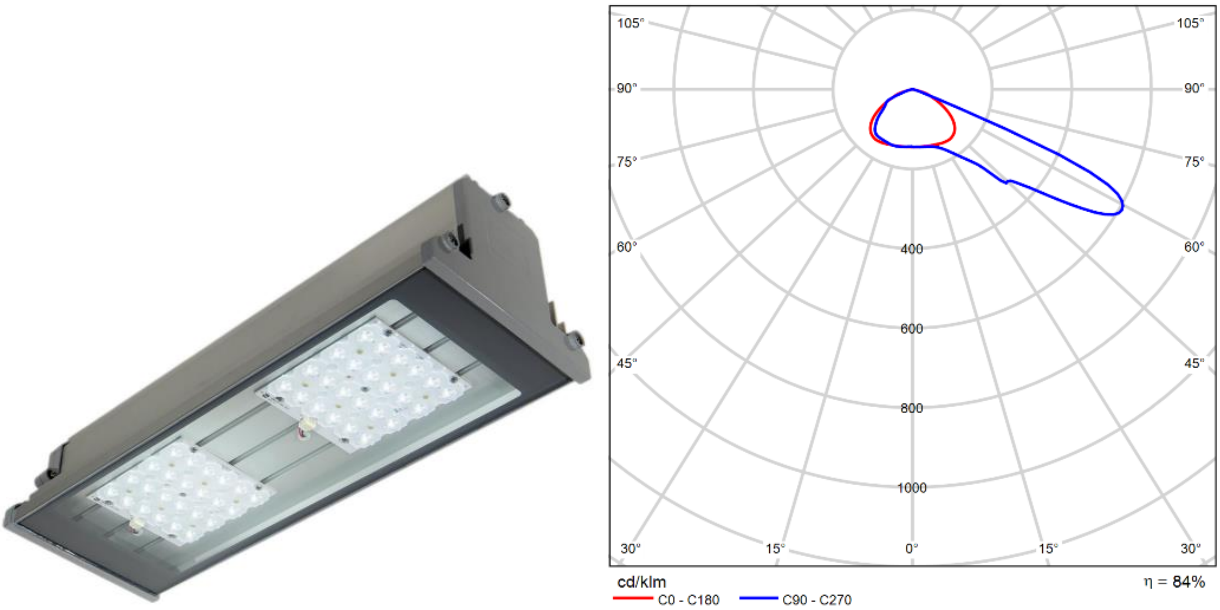
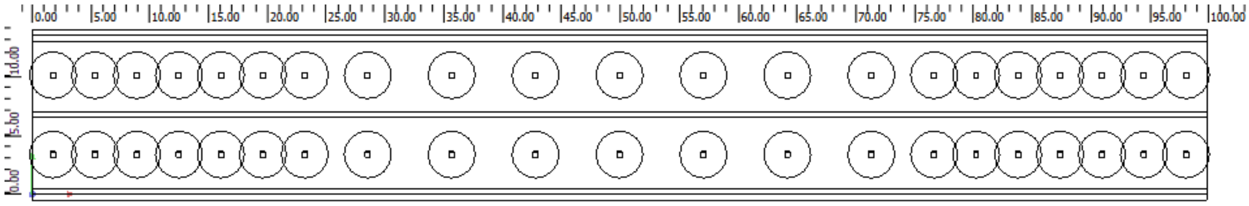


Fig. 3.4 - General view of Schréder GL2 COMPACT 5 124 W and its light distribution

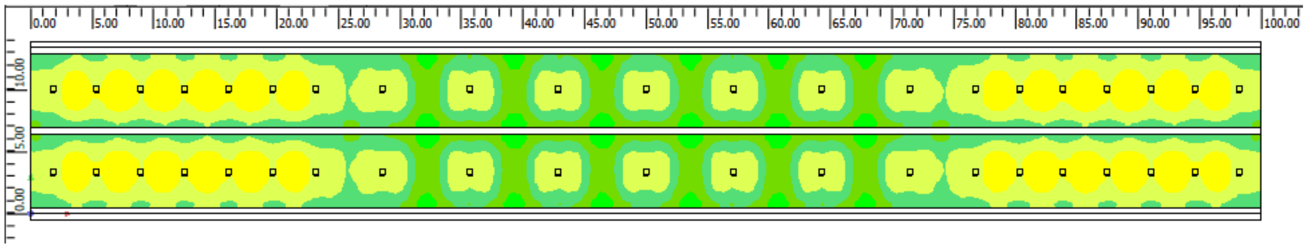
To ensure a normalized level of illumination, we use 42 luminaires Havells Sylvania 0039826 SYLVEO2, fixed in the center of the lane at a height of 4 m. Figure 3.5 shows the layout of these lighting devices, taking into account the normalized level of illumination of different areas of the tunnel.



pcs.	Manufacturer	Article No.	Article name	P	Φ	Luminous efficacy
42	SYLVANIA	0039826	Sylveo 2 SHP-TS 250W, Extensive Beam, 2050k	284.0 W	20529 lm	72.3 lm/W

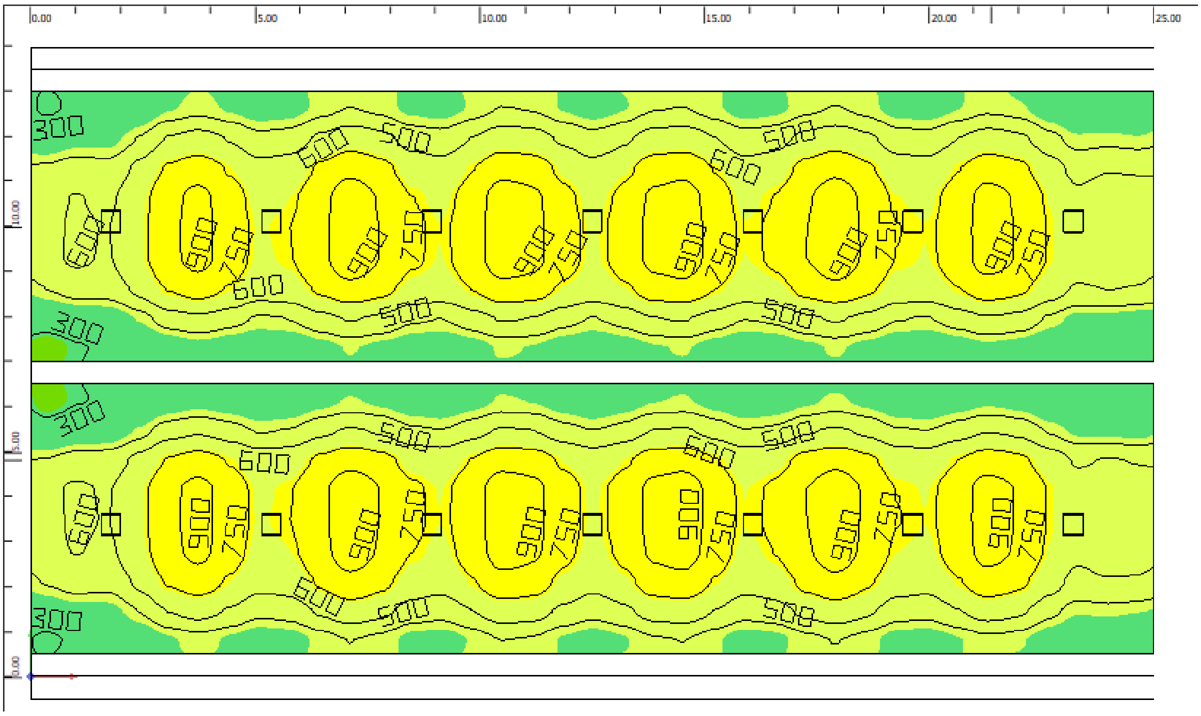
Fig. 3.5 - Layout of luminaires Havells Sylvania 0039826 SYLVEO2 SHP-TS 250W

Figure 3.6 shows the curves of equal illumination of the tunnel in the general case, as well as for individual zones of the tunnel.



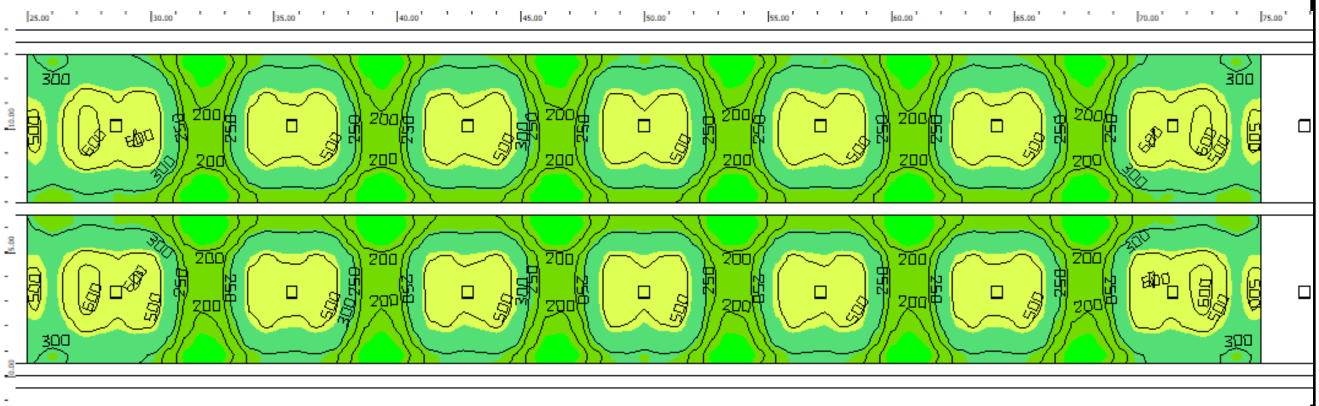
Properties	Ē	E_{min}	E_{max}	g_1	g_2
	500 lx	148 lx	992 lx	0.30	0.15

a)



Properties	Ē	E_{min}	E_{max}	g_1	g_2
	642 lx	259 lx	991 lx	0.40	0.26

b)



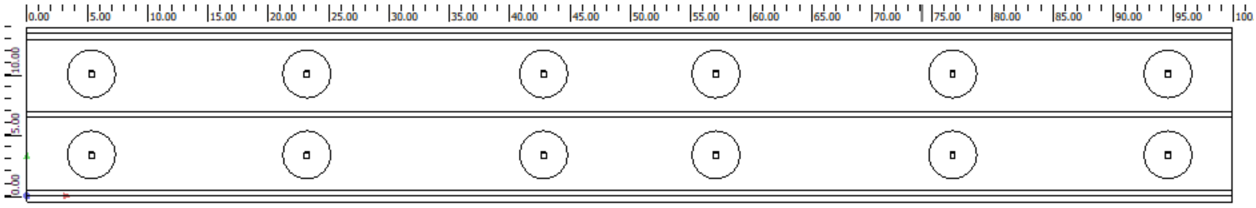
Properties	Ē	E_{min}	E_{max}	g_1	g_2
	357 lx	147 lx	637 lx	0.41	0.23

c)

Fig. 3.6 - Curves of equal illumination of the tunnel during the day:
a) general view; b) isoluxes of the threshold zone; c) isoluxes of the inner zone.

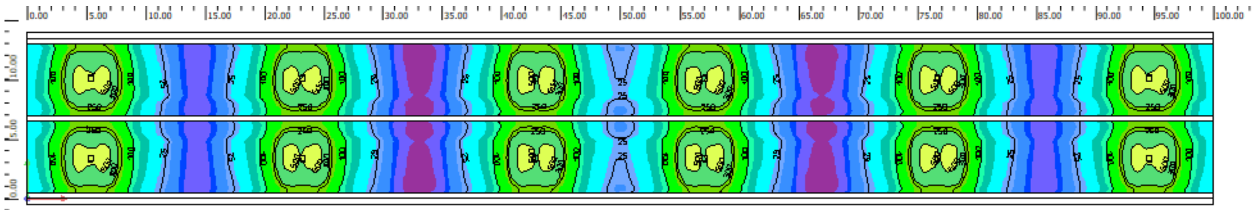
To illuminate the tunnel at night, we use a stepped method of dimming. Thus for maintenance of illumination of 50 lux we apply switching off of separate light devices. In our case from 42 luminaires we disconnect 30 luminaires. Fig. 3.7

shows the location of lighting luminaires that operate at night. Figure 3.8 shows the curves of light levels.



pcs.	Manufacturer	Article No.	Article name	P	Φ	Luminous efficacy
12	SYLVANIA	0039826	Sylveo 2 SHP-TS 250W, Extensive Beam, 2050k	284.0 W	20529 lm	72.3 lm/W

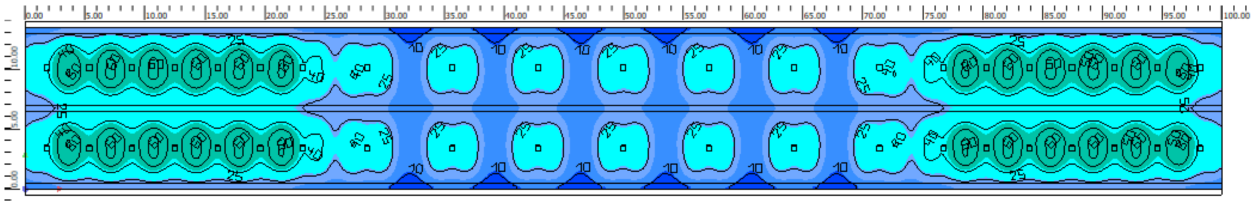
Fig. 3.7 - Placement of luminaires that work at night



Properties	Ē	E_{min}	E_{max}	g_1	g_2
	145 lx	4.22 lx	554 lx	0.029	0.008

Fig. 3.8 - Curves of light levels at night

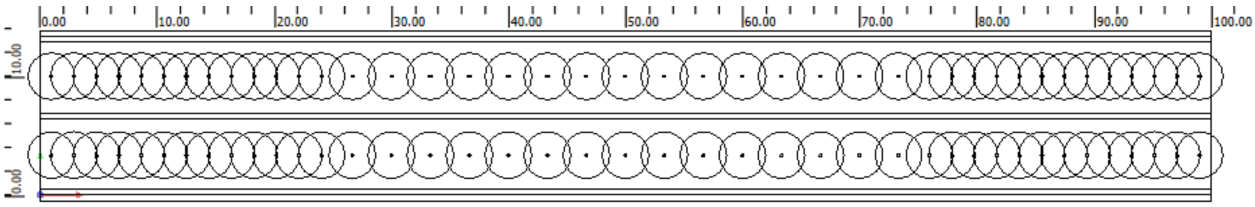
Figure 3.9 shows the curves of the levels of luminous of the road surface during the day with lamps Havells Sylvania 0039826 SYLVEO2 SHP-TS 250W.



Properties	Ø	min	max	g_1	g_2
	30.4 cd/m²	6.95 cd/m²	63.1 cd/m²	0.23	0.11

Fig. 3.9 – Luminous levels of the road surface during the day

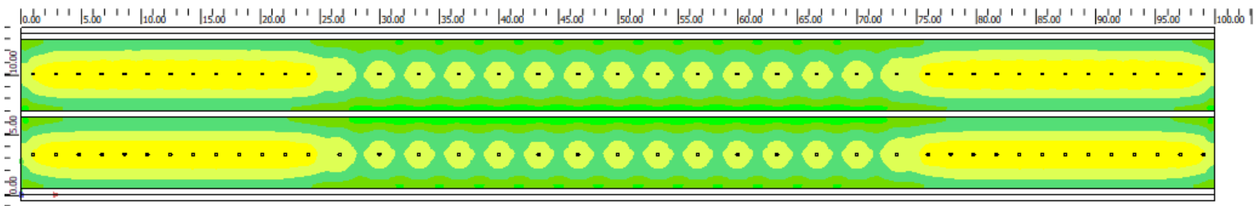
To ensure a normalized level of illumination, we use 82 luminaires Havells Sylvania 0039826 SYLFLOOD 1, fixed in the center of the lane at a height of 4 m. Figure 3.10 shows the layout of these lighting fixtures, taking into account the normalized level of illumination of different areas of the tunnel.



pcs.	Manufacturer	Article No.	Article name	P	Φ	Luminous efficacy
82	SYLVANIA	0039911	SYLFLOOD 1 Extensive + bulb HSI-TD 150W 4K	173.0 W	9959 lm	57.6 lm/W

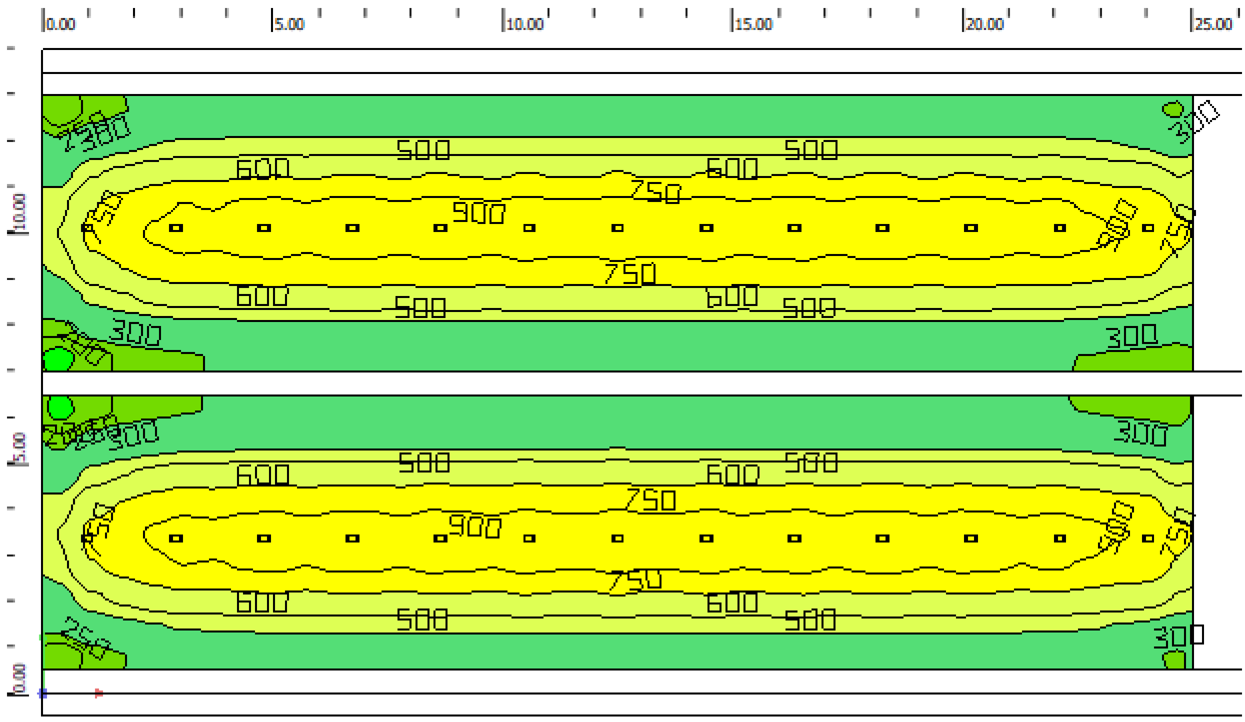
Fig. 3.10 - Layout of lamps Havells Sylvania 0039911 SYLFLOOD1 HSI-TD 150W

Figure 3.11 shows the curves of equal illumination of the tunnel in the general case, as well as for individual zones of the tunnel.



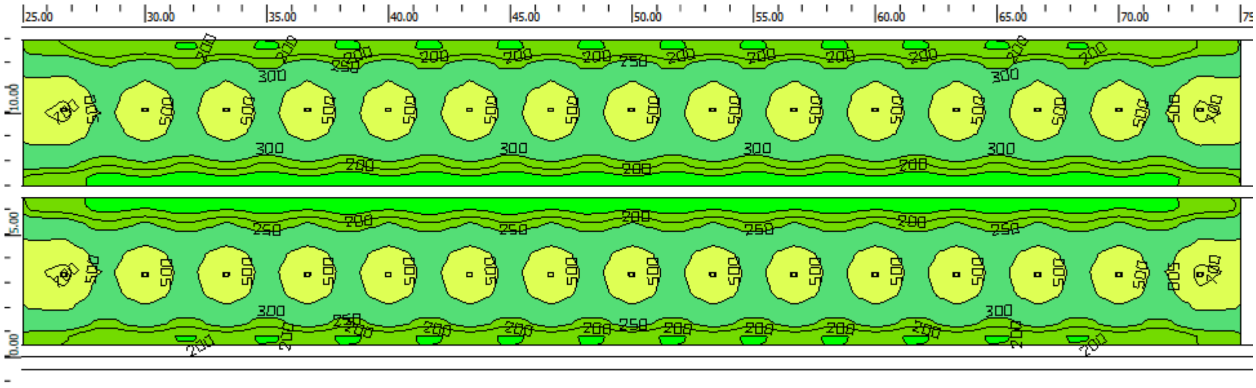
Properties	Ē	E_{min}	E_{max}	g_1	g_2
.	508 lx	174 lx	992 lx	0.34	0.18

a)



Properties	E	Emin	Emax	g1	g2
.	629 lx	182 lx	991 lx	0.29	0.18

b)



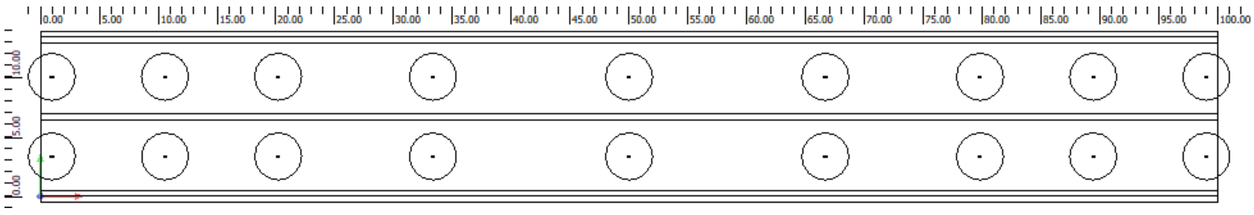
Properties	Ē	Emin	Emax	g1	g2
.	387 lx	175 lx	729 lx	0.45	0.24

c)

Fig. 3.11 - Curves of equal illumination of the tunnel during the day:

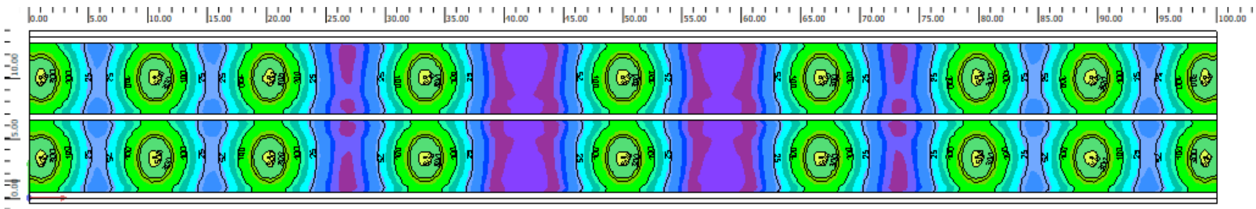
a) general view; b) isoluxes of the threshold zone; c) isoluxes of the inner zone

To illuminate the tunnel at night, we use a stepped method of dimming. Thus for maintenance of illumination of 50 lux we apply switching off of separate light devices. In our case from 82 luminaires we disconnect 64 lamps. Figure 3.12 shows the location of lighting devices that operate at night. Figure 3.13 shows the curves of light levels.



pcs.	Manufacturer	Article No.	Article name	P	Φ	Luminous efficacy
18	SYLVANIA	0039911	SYLFLOOD 1 Extensive + bulb HSI-TD 150W 4K	173.0 W	9959 lm	57.6 lm/W

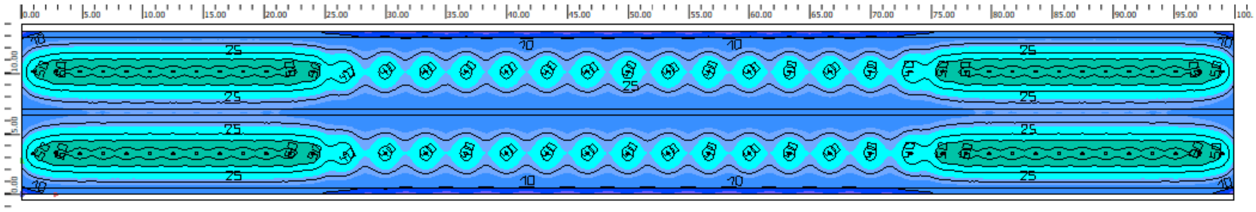
Fig. 3.12 - Placement of luminaires that work at night



Properties	Ē	E_{min}	E_{max}	g_1	g_2
.	107 lx	2.35 lx	559 lx	0.022	0.004

Fig. 3.13 - Curves of light levels at night

Figure 3.14 shows the curves of the levels of luminous of the road surface in the direction of the observer during the day with luminaires Havells Sylvania 0039911 SYLFLOOD1 HSI-TD 150W.

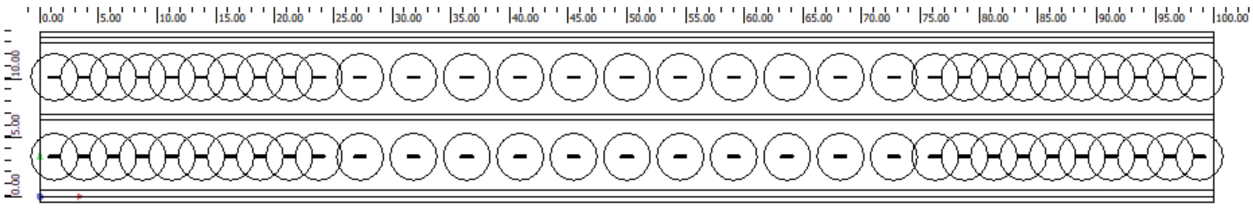


Properties	Ø	min	max	g1	g2
	30.1 cd/m²	6.74 cd/m²	63.2 cd/m²	0.22	0.11

Fig. 3.14 - Luminous levels of the road surface during the day

As you can see when using discharge lamps there is a significant value of the coefficient of inhomogeneity of lighting, especially at night, so to increase the uniformity of illumination, reduce operating costs, increase comfort, it is advisable to use LED lamps.

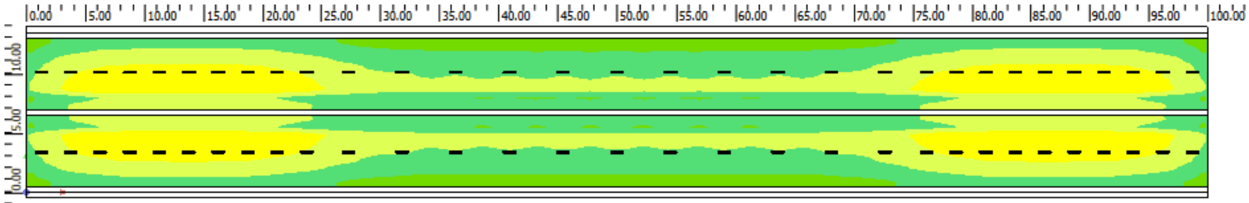
For the total daylight of the tunnel, we used 62 Schréder luminaires GL2 COMPACT 5 124 W, fixed in the center of the lane at a height of 4 m. Figure 3.15 shows the layout of these lighting fixtures, taking into account the normalized level of illumination of different areas of the tunnel.



pcs.	Manufacturer	Article No.	Article name	P	Φ	Luminous efficacy
62	SCHREDER		GL2 COMPACT 5 / 5121 / 80 LEDs 500mA NW 740 124W / / 336382	124.0 W	16846 lm	135.9 lm/W

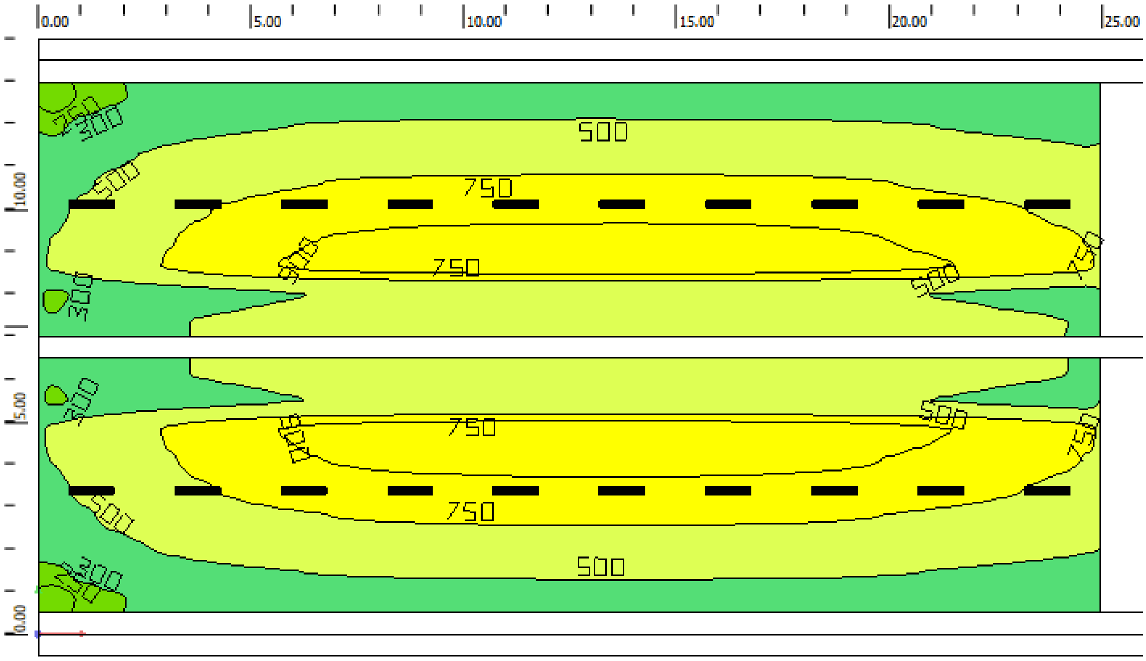
Fig. 3.15 - Layout of Schréder luminaries GL2 COMPACT 5 124 W

Figure 3.16 shows the curves of equal illumination of the tunnel in the general case and in individual zones.



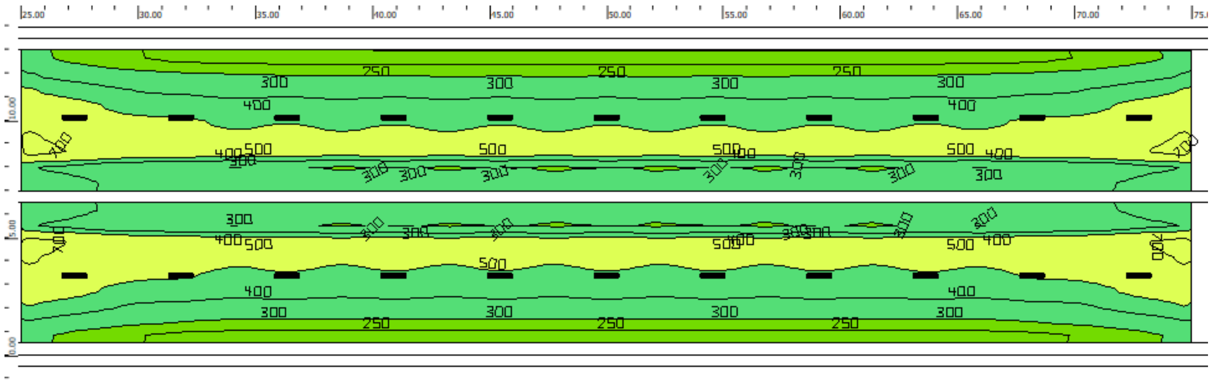
Properties	Ē	E_{min}	E_{max}	g_1	g_2
.	527 lx	222 lx	982 lx	0.42	0.23

a)



Properties	Ē	E_{min}	E_{max}	g_1	g_2
.	641 lx	222 lx	982 lx	0.35	0.23

b)

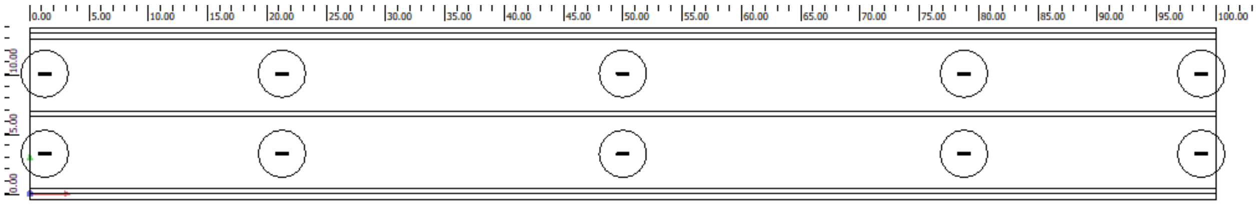


Properties	Ē	E_{min}	E_{max}	g_1	g_2
.	412 lx	231 lx	748 lx	0.56	0.31

c)

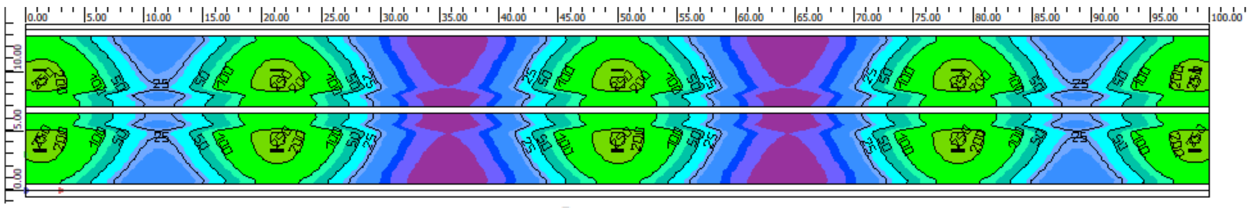
Fig. 3.16 - Curves of equal illumination of the tunnel during the day: a) general view; b) isoluxes of the threshold zone; c) isoluxes of the inner zone

To illuminate the tunnel at night, we use a stepped method of dimming. Thus for maintenance of illumination of 50 lux we apply switching off of separate light devices. In our case from 62 lamps we disconnect 52 lamps. Figure 3.17 shows the location of lighting devices that work at night. Figure 3.18 shows the curves of light levels.



pcs.	Manufacturer	Article No.	Article name	P	Φ	Luminous efficacy
10	SCHREDER		GL2 COMPACT 5 / 5121 / 80 LEDs 500mA NW 740 124W / / 336382	124.0 W	16846 lm	135.9 lm/W

Fig. 3.17 - Placement of luminaires that work at night

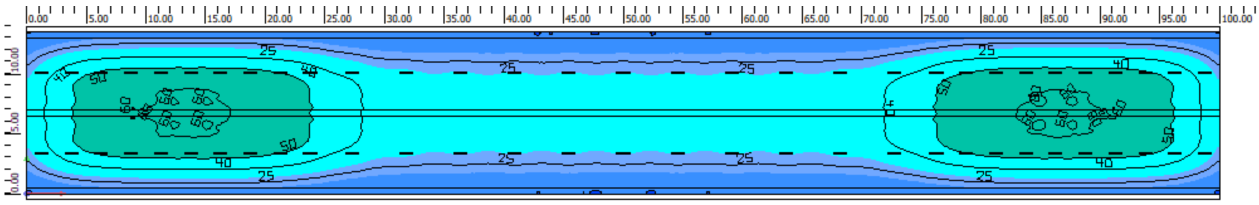


Properties	Ē	E_{min}	E_{max}	g_1	g_2
.	75.4 lx	3.15 lx	255 lx	0.042	0.012

Fig. 3.18 - Curves of light levels at night

As you can see from the above calculations, the use of LED lamps significantly increases the homogeneity of the normalized lighting both during the day and at night.

Figure 3.19 shows the curves of the luminous levels of the road surface during the day.



Properties	Ø	min	max	g1	g2
	35.3 cd/m²	9.68 cd/m²	61.2 cd/m²	0.27	0.16

Fig. 3.19 - Luminous levels of the road surface during the day

3.2 Adjusting the luminous flux of the lighting installation

The main methods of adjusting the luminous flux currently used:

- adjusting the luminous flux by changing the supply voltage,
- adjusting the luminous flux by changing the supply current,
- regulation of light flux by means of pulse-width modulation of supply voltage.

The prospect is to regulate the luminous flux using pulse-width modulation. A constant voltage with an adjustable pulse duration is applied to the LED. The voltage is determined so that the current amplitude of the LED is equal to the rated current. With this adjustment, the LED is in nominal mode during the passage of the pulse. The power frequency is selected depending on the inertia of the light source, so that the pulsations of the light flux were minimal.

In order to reduce the fluctuations of the light flux at low values of the fill factor, you need to choose a higher frequency.

Luminous flux control is performed by changing the duration of the power pulse at a constant power frequency. The pulse amplitude is determined by the rated supply voltage of semiconductor power supplies.

$$\eta = \frac{t_{im}}{T},$$

where η - fill factor;

t_{im} - pulse duration;

T - the period of impulses.

We accept the fill factor 1.

$$\frac{\Phi_{day}}{\Phi_{night}} = \frac{\eta_{day}}{\eta_{night}},$$

where Φ_{day} - light flux during the day;

Φ_{night} - light flux at night.

From the above formula determine the fill factor at night:

$$\eta_{night} = \frac{168460 \cdot 1}{1044452} = 0{,}16.$$

To regulate the luminous flux of luminaires with a sodium lamp, we use the method of stepwise dimming, because other control methods can not provide the required level of illumination at night.

3.3 Comparison of energy efficiency of the developed lighting installations

To compare the energy efficiency of the proposed general lighting systems, the power consumption of each of the installations in different operating modes that was calculated. The results of the calculations are given in table 3.1.

Table 3.1 - Parameters of lighting installations for the tunnel

№	Type of lighting	Type of lighting device	Power of lighting installation, W	Average illumination, lux	
				Threshold zones	Inner zone
1	Day mode	Havells Sylvania 0039826 SYLVEO2 SHP-TS 250W	11928	642	357
		Havells Sylvania 0039911 SYLFLOOD1 HSI-TD 150W	14186	629	387
		Schréder GL2 COMPACT 5 124 W	7688	641	412
2	Night mode (Step adjustment)	Havells Sylvania 0039826 SYLVEO2 SHP-TS 250W	3408	145	
		Havells Sylvania 0039911 SYLFLOOD1 HSI-TD 150W	3114	107	
		Schréder GL2 COMPACT 5 124 W	1240	75,4	

As observed from the calculations, when using an LED lighting installation during the day, the energy consumption is 1.55 times less than for an installation with a sodium lamp power 250 W and 1.85 times less than for an installation with a metal halide lamp power 150 W, and with stepwise regulation of the light flux - 2.75 times less than an installation with a sodium lamp power 250 W and 2,51 times less for an installation with a metal halide lamp power 150 W. In addition, table 3.2 presents a comparison of the performance of the proposed lighting luminaires.

In the Table 3.2 given main characteristics of developed lighting installations.

Table 3.2. - Characteristics of lighting installations

Features	Schréder GL2 COMPACT 5 124 W	Havells Sylvania 0039826 SYLVEO2 SHP-TS 250W	Havells Sylvania 0039911 SYLFLOOD1 HSI-TD 150W
Efficiency, %	> 98	65	65
Service life of a light source, h.	100000	55000	9000
Protection level	IP66	IP65	IP65
Operating temperature range during operation	–30 upto + 50 C^{o}	–30 upto + 40 C^{o}	–30 upto + 40 C^{o}
Weight, kg	11.5	10.9	5.8
Access to operating mode	less than 1 second	15 minutes	15 minutes
Resistance to mains voltage fluctuations	120-277 V	220-240 V	220-240 V
Operational expenses	missing	medium	medium
Network overload	-	at startup	at startup
Calorification	low	high	high
Flicker	is absent	is present	is present
Remote lighting	possible	impossible	impossible

Features	Schréder GL2 COMPACT 5 124 W	Havells Sylvania 0039826 SYLVEO2 SHP-TS 250W	Havells Sylvania 0039911 SYLFLOOD1 HSI-TD 150W
control			
Starting current, A	-	3.1-4.5	1.8-2.9
Current consumption, A	0.7-1.1	3.1	1.8
Special conditions for disposal of light sources	no	necessary	necessary
Vibration resistance of luminaires during operation	great	small	small
Stability of street lighting systems at low temperatures	high	low	low

3.4 Conclusions to section 3

1. The general lighting of the motorway tunnel was designed with the use of lighting devices Havells Sylvania 0039826 SYLVEO2 SHP-TS 250W, Havells Sylvania 0039911 SYLFLOOD1 HSI-TD 150W, Schréder GL2 COMPACT 5 124 W taking into account the normalized level of illumination in different areas of the tunnel.
2. The possibility of stepwise and smooth regulation of tunnel illumination at night is considered. The expediency of application of step control of

illumination at use of high pressure discharge lamps and possibility of smooth and step control of illumination at use of LED is substantiated.

3. Based on a comparative analysis of the parameters of the proposed installations, it was found that when using an LED lighting installation during the day, the energy consumption is 1.55 times less than for an installation with a sodium lamp power 250 W and 1.85 times less than for an installation with a metal halide lamp power 150 W, and with stepwise regulation of the light flux - 2.75 times less than an installation with a sodium lamp power 250 W and 2,51 times less for an installation with a metal halide lamp power 150 W.

4 LABOR OCCUPATIONAL SAFETY AND SECURITY IN EMERGENCY SITUATIONS

4.1 Safety requirements for the installation of lighting fixtures

Work in which the worker is above 1 and up to 5 m from the surface of the ground, floor or bedding is considered work at height. Works at a height of more than 5 m is climbing.

Persons who have passed medical examination and instruction on labor protection are allowed to work at height. The works can be performed from additional ladders up to 5 m long, with suburbs, telescopic and other lifts, which have a perimeter of the fence at least 1 m high and solid bedding.

Repair and maintenance of electrical installations using ladders must be performed by two workers, one of whom must be on the floor. It is forbidden to use metal ladders, as well as work with boxes, stools and other random, not intended for this purpose.

Installation and removal of lighting fixtures, panels and devices weighing more than 10 kg are performed by two people or one person, but with the help of mechanical devices.

It is dangerous to clean lighting fixtures and electric lamps from dirt and dust when the switch is switched on, ie live, with wet or damp cloths.

It is necessary to clean at the disconnected switch with a dry cloth, standing on a support which does not conduct an electric current.

4.2 The effect of electric current on humans. First aid for electric injuries

Electric current is a directed movement of electric charges inside a conductive substance (inside metals, liquid conductors).

Electric current, passing through the human body, causes the conversion of electrical energy into other types of energy, causing thermal, electrolytic and biological effects.

Thermal action is that the current passing through the human body heats it, like any conductor through which it passes. Thus, passing through the organs of the human body, an electric current can cause their burns, charring of tissues and the whole body.

The electrolytic action is that the electric current has the property of splitting acidic, alkaline and other conductive liquid solutions into constituent parts. Passing through the human body, which consists of 70% water (protoplasm of cells, blood), it has a similar electrolytic effect, breaking down protoplasm and blood. As a result, cells lose the ability to exist and metabolize normally.

The biological effect of electric current is that during its passage there is irritation and excitation of living tissues of the body and disruption of internal biological processes. As a result, there may be involuntary movements of limbs, head and other organs; the rhythm of the heartbeat may change (fibrillation occurs, uncontrolled vibration of the heart); lung function is disturbed.

The mechanical action of an electric current can lead to tissue rupture due to the electrodynamic effect, as well as the instantaneous explosive formation of vapor from tissue fluid and blood; to dislocations, fractures. The action of electric current can lead to both injuries and death.

The effect of electric current on the human body is classified by degrees of complexity:

1) electric injuries are burns, electrical signs (specific tissue damage); metallization of leather (part of molten metal); electrophthalmia (inflammation of the outer shells of the eyes under the action of ultraviolet rays of the electric arc); mechanical injuries (tearing of the skin, dislocations, fractures caused by involuntary muscle contraction);

2) electric shock. There are 4 degrees of electric shock:

Grade 1 is convulsive muscle contraction without loss of consciousness;

Grade 2 is convulsive muscle contraction with loss of consciousness, but with preservation of respiration and heart rate;

Grade 3 is loss of consciousness, respiratory or cardiac disorders;

Grade 4 is clinical death.

It is worth remembering that one of the features of the danger of electric current is that the live parts of the equipment are often stationary, do not have a high temperature, visible radiation. Therefore, human analyzers do not record the danger that actually exists.

The consequences of electric shock depend on many factors: body resistance, duration of current flow, current path, type and frequency of current, voltage.

From the point of view of safety there are three degrees of influence of current:

a) the maximum perceptible current is the minimum current that causes sensory, contact irritation of the corresponding skin analyzers. The magnitude of the alternating current is 0.5-1.5 mA, DC - 5-7 mA. As we can see, the constant significant limiting current is an order of magnitude greater than the alternating current;

b) maximum current (non-release) is the minimum current that causes convulsive muscle contraction. The magnitude of the alternating current is 6-10 mA; constant is 50-80 mA. Again, there is a pattern that the limiting direct current is an order of magnitude greater than alternating current, ie the nervous system is more sensitive to alternating current;

c) maximum fibrillation current is the current at which fibrillation of the heart begins. The magnitude of the alternating fibrillation current is 80-100 mA; constant is 300 mA. Based on this, safety rules state that an electric current of 0.1 A (100 mA) is lethal. The current is not divided into direct or alternating. For women, these current limits are 1.5 times lower.

The main resistance of the human body is the upper horny skin - the epidermis. Its thickness varies from 0.05 to 0.2 mm. When the epidermis is removed, the body's resistance does not exceed 1000 ohms, with dry and rough skin - up to 100,000 ohms. Thus, the resistance of the human body ranges from 1000 to 100000 ohms and depends on many reasons: skin condition, contact density, contact area, skin moisture, time and current, current frequency, condition and mood. In the investigation of accidents and calculations, the resistance of the human body equal to 1000 ohms is taken.

The path of current through the human body is also important. The most dangerous - through the heart and lung muscles, as well as through the brain. The amount of current flowing through the body through the human heart depends on the path of its passage.

The current passes through the body not only by the shortest path, but by the path of least resistance, which is different in different tissues (bone, muscle, fat). The most dangerous way is the right hand - legs, and also the head (temporal part) - any parts of a body. But this does not mean that other ways are not dangerous.

The action of electric current is influenced by the type and frequency of current. It is established that alternating current with a frequency of 50 Hz is more dangerous than direct current. The same effect is caused by a larger value of direct current than alternating current.

Saving the life of a person affected by an electric shock in many cases depends on the speed and correctness of the actions of caregivers. First of all, it is necessary to release the victim from the electric current as soon as possible. If it is not possible to disconnect the electrical equipment from the mains, the victim must be immediately disconnected from the live parts without touching the victim.

Measures of pre-medical care after the release of the victim from the current depend on his condition. Assistance should be provided immediately, if possible - at the scene, while calling for medical help. If the victim has not fainted, it is necessary to provide him with some rest, not allowing him to move until the doctor arrives. If the victim breathes infrequently and convulsively, but the pulse is heard, it is necessary to give him artificial respiration immediately. In case of respiratory arrest, dilation of the pupils and bruising of the skin, artificial respiration and indirect heart massage should be performed.

It is worth noting that it is necessary to provide assistance before the arrival of the doctor, as repeatedly artificial respiration and heart massage brought the victims back to life.

4.3 Influence of electromagnetic fields on the human body

Electromagnetic fields of radio frequency installations in excess of the normative values of their components can cause occupational diseases. Due to the action of electromagnetic fields on the human body there are functional changes in the central nervous system. At the same time the increased fatigue, a headache is observed. The primary manifestation of the action of an electromagnetic wave is heating, which leads to damage to tissues and organs.

Ultra-high frequency fields affect the eyes, causing cataracts. Repeated exposure to low-intensity radiation leads to persistent functional changes in the central nervous system. The degree of biological influence of electromagnetic fields on the human body depends on the frequency of oscillations, intensity and intensity of the field, the duration of its impact. Due to prolonged stay in the area of electromagnetic fields there is premature fatigue, drowsiness or sleep disturbances, often headaches, nervous system disorders. Systematic irradiation causes persistent neuropsychiatric diseases, changes in blood pressure, slowing of the pulse, hypotension or hypertension, hair loss, brittle nails, reduced accuracy of work movements, heart pain, accompanied by arrhythmia.

Under the influence of electromagnetic fields is the absorption of field energy by body tissues. In this case, ion dispersion, dipole and resonant absorption occur in the irradiated tissues.

In alternating electromagnetic fields, the electrical properties of living cells depend on frequency. As the frequency increases, they acquire the properties of conductors. The energy of electromagnetic radiation is converted into heat. The degree of heating of the tissues of the human body depends on the intensity, frequency of the field and the intensity of irradiation. Heating is especially dangerous for organs with low thermoregulation, which have a small number of blood vessels or insufficient blood circulation (brain, stomach, lens of the eye, intestines, gallbladder, ovaries). Electromagnetic radiation with a wavelength of 1-20 cm adversely affects the eyes, causing cataracts and vision loss. Under the influence of a magnetic field with a frequency of 50 Hz there is a feeling of flicker.

The non-thermal effect of the electromagnetic field concerns the structure and appearance of tissues and organs of the human body (burns, deaths, hemorrhages, changes in the structure of blood cells, vascular changes, malnutrition of tissues and organs).

Under the influence of ultrahigh-frequency radiation there is an orientation effect. In this case, the solid suspended particles contained in adipose tissue, solutions of erythrocytes, milk, blood and lymph are collected in annular chains. There is a skin disease, the manifestation of which is the appearance of successive blisters filled with turbid fluid.

In addition to biological action, the electric field causes discharges between humans and metal objects that have a different potential than humans. If a person is isolated from the ground, the body is exposed to a potential that can reach several kilovolts.

When a person isolated from the ground touches a grounded metal object or when a person in contact with the ground touches a metal object isolated from the ground, a discharge current passes through the human body into the ground, which can cause pain. The discharge current irritates the nerve endings of the skin and causes reflex, convulsive muscle contraction. With a potential difference of about 15 kV, a discharge current of several tens of amperes passes through a person for 0.05…0.5 μs, causing short-term shocks. Such discharges are especially dangerous when performing work at height. When touching large objects, the current flowing through the person can reach life-threatening values.

CONCLUSION

1. Based on the analysis of the international standards of lighting of motor transport tunnels the generalization of the basic directions of increase of economy, safety and comfort of lighting is carried out. The normative indicators of illumination and brightness in different zones of the tunnel depending on its parameters and characteristics of road traffic taking into account features of light adaptation of a human eye are systematized.
2. Different types of lighting of motor tunnels depending on the purpose of lighting, location of lighting fixtures, direction and intensity of road traffic are analyzed.
3. Based on the analysis of lighting and electrical parameters of light sources, the expediency of their use for different types of tunnel lighting is substantiated.
4. The characteristics of luminaires with discharge lamps of high pressure and LED are compared.
5. Methods of light regulation in tunnels are analyzed, their advantages and disadvantages are established, recommendations on use for different types of lighting installations are given.
6. The general lighting of the motorway tunnel was designed with the use of lighting devices Havells Sylvania 0039826 SYLVEO2 SHP-TS 250W, Havells Sylvania 0039911 SYLFLOOD1 HSI-TD 150W, Schréder GL2 COMPACT 5 124 W taking into account the normalized level of illumination in different areas of the tunnel.
7. The possibility of stepwise and smooth regulation of tunnel illumination at night is considered. The expediency of application of step control of

illumination at use of high pressure discharge lamps and possibility of smooth and step control of illumination at use of LED is substantiated.

8. Based on a comparative analysis of the parameters of the proposed installations, it was found that when using an LED lighting installation during the day, the energy consumption is 1.55 times less than for an installation with a sodium lamp power 250 W and 1.85 times less than for an installation with a metal halide lamp power 150 W, and with stepwise regulation of the light flux - 2.75 times less than an installation with a sodium lamp power 250 W and 2,51 times less for an installation with a metal halide lamp power 150 W.
9. Measures for labor occupational and security in emergency situations have been developed.

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