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Investigating the Importance of Tunnel Lighting and its Role in Reducing Traffic Accidents

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Abstract:

Traffic safety is a major concern worldwide. Road accidents are the ninth leading cause of death in the world.

Tunnel accidents are less common than road accidents. However, the severity of the accidents is more severe. One of the key factors in preventing accidents in road tunnels is proper lighting system. Failure to pay attention to this issue causes the phenomenon of black hole when approaching the tunnel, visual mismatch inside the tunnel and the phenomenon of glowing hole when leaving the tunnel.

The creation of these factors has increased the risk potential at the entrance and exit of the tunnel up to 4 times the middle area of the tunnel. At the entrance to the tunnel, the reflection of sunlight from the surroundings and the lack of sufficient light usually cause some vision problems. It may lead to drivers' eyes not adapting to changing the brightness level at the tunnel entrance, thus increasing the risk of road accidents in this area.

The aim of this study was to evaluate the lighting safety in very long road tunnels based on the visual adaptation of drivers in the tunnels.

In this paper, first, generalities about tunnel safety are stated and using the CIE88-2004 standard, the required luminosity in the threshold, transition, interior and exit areas of the tunnel is designed. Finally, solutions are proposed to increase the safety of tunnels.

Keywords: Lighting safety, Tunnel lighting system, Reduction of black hole phenomenon, Brightness, Risk of road accidents.

Introduction

Tunnels are almost the only places where daylight is more important than night light. The reason for this is due to the nature of the human eye in which eye adaptation occurs. It takes time for the eye to adapt to the new environment. As a result, inside the tunnel, enough light must be provided during the day so that when the driver enters the tunnel, he can continue on his way without any visual problems.

Tunnel lighting is very important since it depends on the protection and health of people's lives. Designing the right lighting for a tunnel also requires special experience and expertise. Here I want to examine the key points of tunnel lighting design.

Why is it necessary to provide daylight for a tunnel?

1-1 An overview of the structure of the human eye: -

When a person enters a dark environment from a light environment, a certain time is needed to adapt to the light conditions of the new environment. The reason goes back to the structure of the eye as well as the stages of adaptation in the eye. We know that the human eye acts as a camera. The human retina is like a photographic film on analog cameras on which an image is formed. The pupil is like a controller that controls the amount of light entering the eye, and the lens, like the lens, helps to create a clear image of the object on the retina.

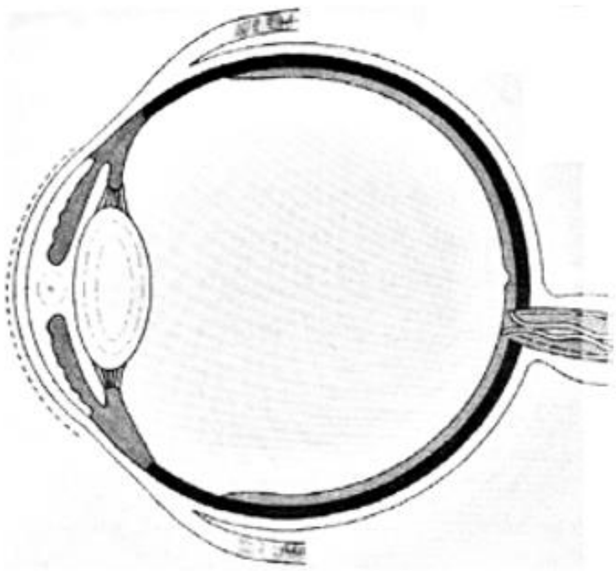

Figure (1) chemical image of the human eye.

At the surface of the retina, there are about 127 million vision cells.

These optic cells are actually sensors sensitive to light. When light reaches them, an electrical signal is sent to the brain via a neural network. There are two types of retinal cells: rod and cone. The number of rod cells is very large (about 120 million) and these cells are mainly active in very low light conditions (complete darkness at night). These cells have no sensitivity to color and only detect light intensity. There are approximately 7 million cone cells capable of color recognition but they do not activate in low light conditions. That is why we cannot recognize colors in very dark conditions.

1-2 matching operation in the eye

Vitamin A1 is used by both rod cells and cone cells. Vitamin A1 is converted to a substance called retinal and then combined with a protein called opsin to form a light-sensitive chemical called dopcin.

By irradiating light to the rods, part of rhodopsin is immediately converted to lumirhodopsin, which is a highly unstable substance. It remains in the retina for less than a second and then decomposes again into retinal and opsin.

As a result of this analysis, ions are released that transmit an electrical pulse to the brain through nerve fibers. The image of these developments is shown in the figure below.

When a person enters a light environment from a dark environment, the amount of rhodopsin in the bars is low because a small amount of rhodopsin is decomposed due to the low light energy in the dark environment. Upon entering the clear area, rhodopsin is degraded and vision function occurs.

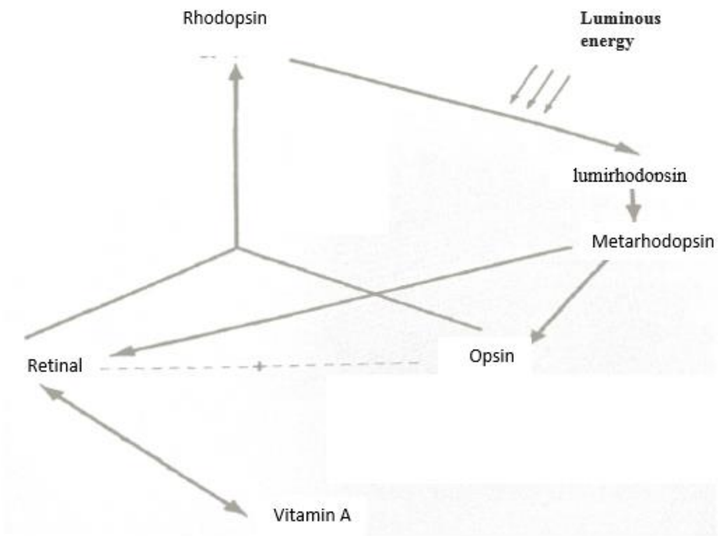

Figure (2) Cycles of chemical decomposition and composition in the eye.

When a person enters a dark environment from a bright environment (a driver who enters the tunnel from a bright environment during the day) a large amount of energy enters the human eye in a bright environment, much of the rhodopsin in the rods is broken down. Therefore, a small amount of rhodopsin is present on the surface of the retina. It takes time for the eye to adjust to the new environment. This is called adaptation. The process of adapting to light is thirty times faster than adapting to darkness. The curve in Figure 3 shows the time required for the human eye to adapt to the intensity of ambient light.

As can be seen from the curve, as the intensity of the light increases, the time required for the eye to adapt decreases drastically.

Thus, when a driver who is in the driving mode during the day, when he enters the tunnel, at first, a large amount of radiance around him, followed by the radiance in his retina is greatly reduced and there may be obstacles in the tunnel.

Does not see and deal with it properly, so it is necessary to provide sufficient lighting inside the tunnel to provide the necessary opportunity for the driver's eye to adapt to the tunnel environment.

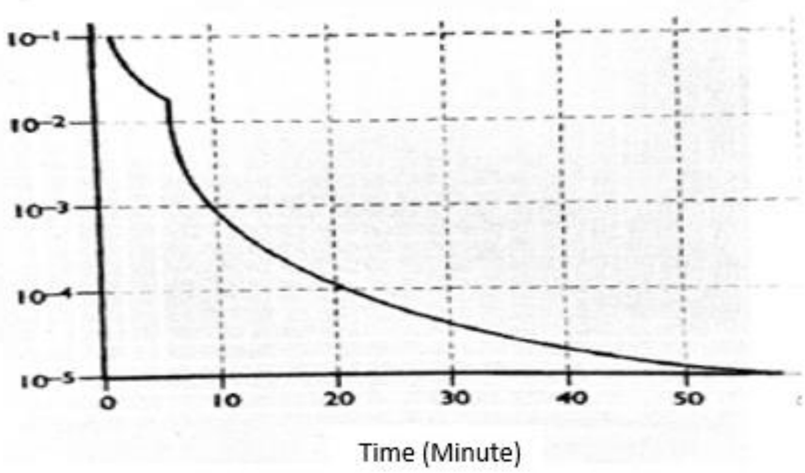

Figure (3) Eye matching time in terms of ambient light.

On the other hand, at the entrance of the tunnel, if not enough light is provided, the tunnel may look like a black hole for the driver, like the figure below, which looks completely dark inside the tunnel.

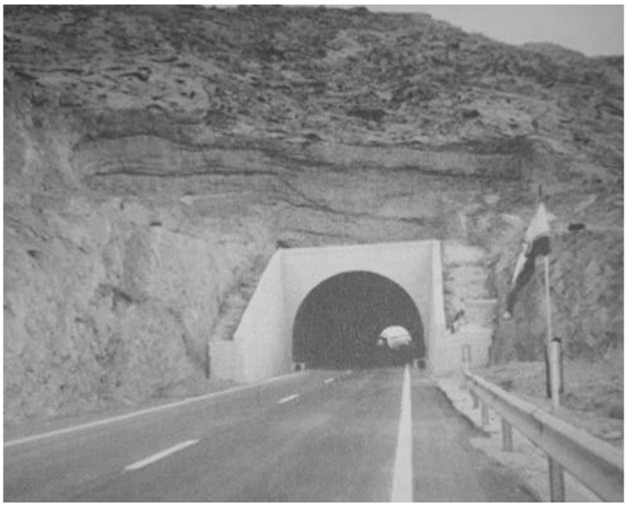

Figure (4) View of the tunnel entrance.

Background research

Recent research has shown that a high percentage of accidents occur 50 meters before entering the tunnel and the rate of accidents.

In this area, it is several times more than the middle of the tunnel (7). It is also shown that within 150 meters of entering the tunnel Drivers' attention is focused on the entrance to the tunnel, and almost all of them ignore the signs installed near the tunnel (8).

Studies have shown that the presence of sources and dazzling levels in the eyes of drivers cause detrimental effects on drivers' behavior Among other things, we can mention the reduction of vehicle speed and the inability to control the vehicle on the designated route (6). Another study has shown that the glare created in the eyes of drivers reduces the ability of drivers to see.

Pedestrians have been identified on the roads (7). Statistics published by the Norwegian Highway Authority show that 63.7% Tunnel accidents occur in the entrance area (13) when drivers enter the tunnel from the bright space to the dark space. They need a "stable compatibility distance" before detecting the internal condition of the tunnel. The coefficient of friction between the tire and the road (f), which depends on the speed of the vehicle and the road surface (dry or wet), is determined using the diagrams shown in Figure (6).

Research Methodology

In preparing this work, valid books and information of academic internet sites have been used, based on which the research method in this work is mainly library.

2- Different Zones in a tunnel:

Based on what has been said before, in order to provide suitable conditions for uniform lighting, it is necessary for the driver's eye to be adequately lit in the tunnel. Accordingly, according to Figure 5, the tunnels are divided into different areas, which will be explained in detail.

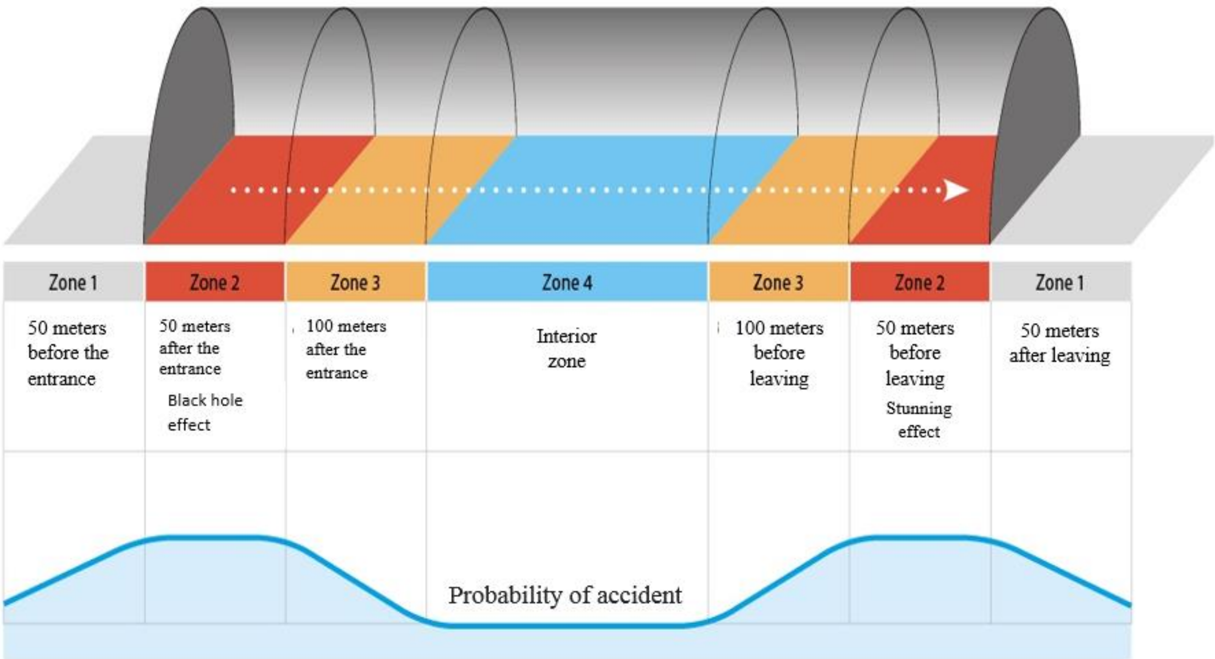

Figure (5) Picture of different areas of the tunnel.

2-1 access Zone:

The access zone is called a certain area before the entrance of the tunnel. The length of the access area is equal to the stopping distance, or the amount of distance that if a driver sees an obstacle in front of him, he has enough time to stop safely. Safe and safe stopping distance depends on various factors such as: permitted speed of the driver, mileage, friction coefficient, etc. And is calculated with the following relation:

$$\textit{Stopping}\ \text{Distance} = \text{U.t}_0 + \frac{U^2}{2.g(F \pm S)} \text{...........(1)}$$

In this regard:

U - is the maximum speed of passing vehicles. (m / sec)

t_0: - is equal to the reaction time of the driver, which is empirically considered to be one second.

g: - Earth's gravitational velocity of 9.81 m / sec^2.

F: - The coefficient of friction of the road surface is obtained from the curve of Figure (6). According to these curves, the coefficient of friction between the car tires and the road surface depends on the speed limit of passing vehicles as well as the usual environmental conditions (wet, dry).

S: - is the same road desire that is presented in percentage

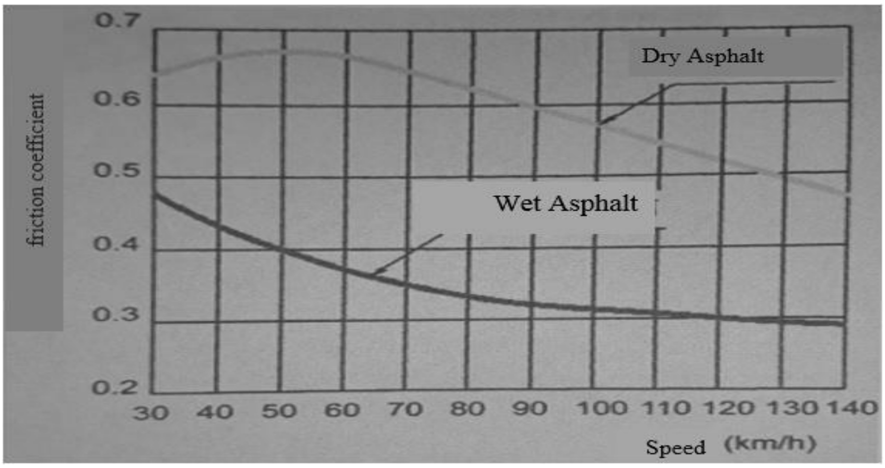

Figure (6) Curve for calculating the coefficient of road friction in terms of permitted speed of passing vehicles for roads located in the dry area (high curve) and wet area (low curve).

2-2 Threshold Zone:

The Threshold Zone is located at the entrance to the tunnel and is one of the most important areas. The length of the quiet area is equal to the length of the access area, which is divided into two equal parts.

In the first part of the quiet area, which is half the length of the access area, the intensity of the tunnel is at its highest and equal to the lth of Lth. In the second half of the calm zone, the amount of radiance decreases by up to 40% of the calm zone.

2-3 Transition Zone:

The Transition Zone is an area where the brightness of the tunnel gradually decreases. And the driver's eye gradually adapts to the environment. The length of this area is obtained from the curves.

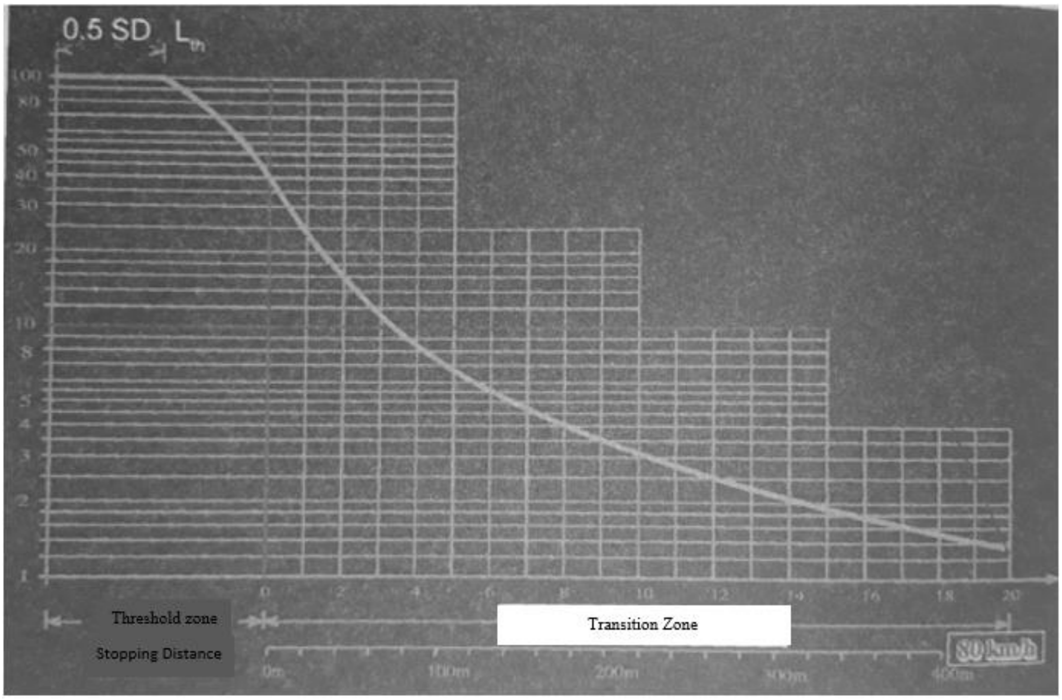

Figure (7) The total length of the quiet area at the entrance to the tunnel is equal to the length of the stopping distance.

2-4 Interior Zone:

In the Interior Zone, the driver's eye is completely accustomed to the tunnel and the amount of light in the interior will be constant.

2-5 Exit Zone:

In some tunnels, if the position of the tunnel is such that at the exit, the driver may be exposed to direct sunlight, or in tunnels where the volume of traffic is large (such as Salang) and this possibility There is a car that is behind a large car, when it suddenly encounters a lot of light coming out of the tunnel, the exit zone is considered. To prepare the driver to face a lot of light after the tunnel. In most tunnels, there is no need to consider the exit area because, as mentioned, the human eye usually adapts to the environment at high speed. The length of the exit area is equal to the stop area.

3. Calm area radiance:

The maximum amount of light is provided in a tunnel in the quiet area and its amount is equal to the lithe brightness. The luminosity of the calm zone depends on the luminosity of the driver's field of vision from outside the tunnel. If the location of the tunnel and its surroundings is such that the brightness of the driver's field of vision is high, the brightness of the quiet area should also be high. Therefore, before calculating the luminosity of the calm zone, the luminosity of the driver's field of vision must be calculated before entering the tunnel called L20.

According to the standard for calculating the luminosity of L20, we are at a safe stop distance from the entrance of the tunnel and from a height of 1.5 meters (equivalent to the approximate height of the eye written on the back of the tunnel) assume a cone with an angle of 20 degrees to the tunnel (Figure The apex of the cone in the driver's eye and its base is a circle that encloses the tunnel). As a result, the value of L20 can be obtained by the following equation:

$$L_{20} = \alpha . L_{sky} + \beta . L_{road} + \theta . L_{sorounding} + \varepsilon ._{LThreshold} \qquad (2)$$

In this equation:

$\varepsilon, \theta, \beta, \alpha$ They are equal to the ratio of the area of the sky, the road, the area around the tunnel, and the part of the quiet area at the entrance of the tunnel that is in the driver's field of view (at the base of the cone), respectively.

Different values at different levels based on the standard are given in **Table (1).**

Driving side	L sky	L Road	L sorounding			
			Rock	Building	snow	Vegetation
North	8000	3000	3000	8000	1500	2000

Eastern -Western	12000	4000	2000	6000		2000
South	16000	5000	1000	4000		2000

It is also possible to obtain the value of Lth after calculating L20 based on the following equation:

$$L_{th} = K.L_{20} \quad (3)$$

Table (2). Proposed value for K in CIE 88- 2004

Permitted speed of passing vehicles (Km/h)	Coefficient (K)
Less than or equal to 60	0.05
80	0.06
120	0.1

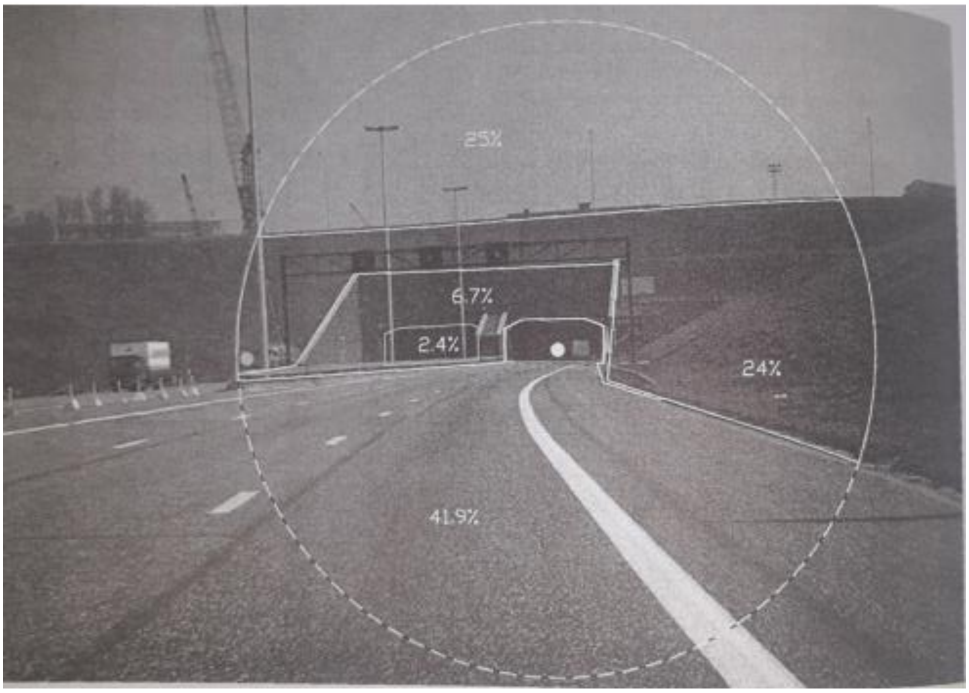

Figure (8) an example of an L20 cone base.

Inner radiance:

The standards specify the amount of light in the interior. First, it should be determined based on Table (3) whether the tunnel traffic is light or heavy, then with the help of Tables (4) and (5) the amount of radiance in the inner area of the tunnel is determined.

Table (3) Classification of tunnels in terms of traffic volume according to CIE 88 standard.

Traffic volume	Number of passing cars per rush hour and traffic per hour per line	
	Move to one side	Move on both sides
Heavy Traffic	1500 <	400 <
Light Traffic	500 >	100 >

Table (4) Recommended value for luminosity in the inner area of long tunnels.

Safe stopping distance	Traffic Type (long Tunnels)	
	Light traffic	Heavy traffic
160 meter	6	10
60 meter	3	6

According to the standard, if the driver drives in the interior for more than 30 seconds, the tunnel can be considered as very long tunnels.

And considering that during this period, the driver's eye is completely accustomed to the environmental conditions, in order to cough up energy consumption, it is possible to reduce the amount of radiance in the second part of the inner area after 30 seconds from the cross to the inner area.

Table (5) Recommended value for luminosity in the second part of the inner zone of very long tunnels

Safe stopping distance	Traffic Type (long Tunnels) and The amount of luminosity	
	Light Traffic	Heavy Traffic
160 meter	2.5	4.5
60 meter	1	2

4. Transition area luminosity:

In the passage area of the eye, the driver gradually adapts to the lighting conditions inside the tunnel. The luminosity at the beginning of the transition zone (starting at the end of the calm zone) is 0.4 Lth luminosity. And at the end of the inner zone, the amount of luminosity reaches twice the luminosity of the inner zone of the tunnel. The calculation of the luminosity changes in the transition zone and the length of the transition zone is obtained by the following formula:

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

In this equation:

t-: - Time to enter the transition zone in seconds.

L_{th}- The amount of radiance in the calm area, the amount of which is considered 100%.

The curved image of the above equation is shown in Figure (11). The vertical axis is based on the percentage of luminosity of the quiet region and the horizontal axis is the indicator of time in seconds.

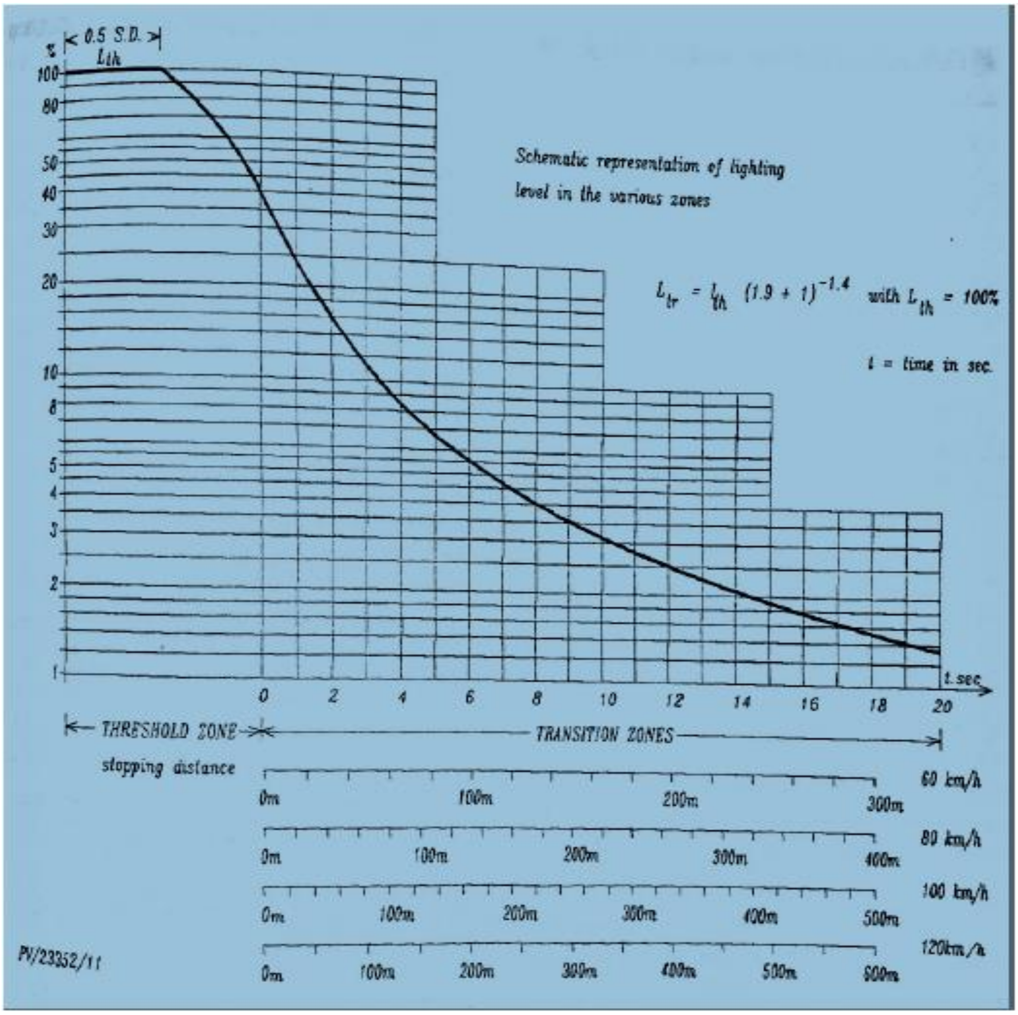

Figure (9) Curve of luminosity changes in the transition zone over time relative to the luminosity percentage of the relaxation zone.

Then, considering the numerical value of the luminosity of the calm region, when the luminosity of the tunnel reaches twice the value of the inner region, we obtain it from Equation 4 or with the help of the above curve. If we get the exact amount of time by solving Equation 4-5, then we multiply it by the default allowable speed of problem solving to get the length of the transition area. If we refer to the curve instead of solving the equation, we extend the point where the luminosity is twice the luminosity of the inner region to the end of the curve to strike one of the four lines drawn below the curve. These four lines give the length of the transition area based on different speeds.

5. Output brightness:

As mentioned, the exit area does not need to be considered in all tunnels, but if the volume of large traffic is large or the direction of the tunnel is such that it is directly in front of the sunrise, then the exit area is considered.

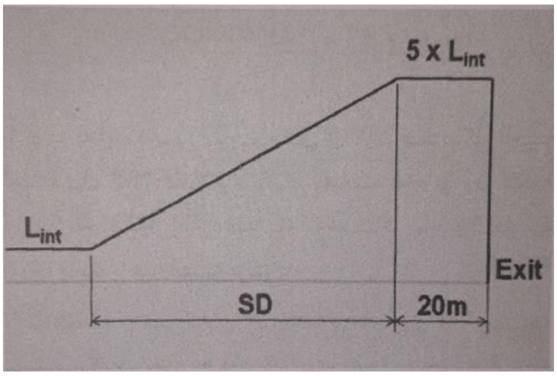

Figure (10) Syntax of luminosity changes in the output area

According to the figure above, the length of the output area will be equal to the length of the stop thread (for the exit of the tunnel) plus 20 meters. The amount of luminosity at the end 20 meters of the tunnel is equal to 5 times the luminosity in the inner area The end of the inner area increases up to 5 times the brightness of the inner area.

Also, using the light flux, we can consider the amount of light in different areas of the tunnel according to the following figure:

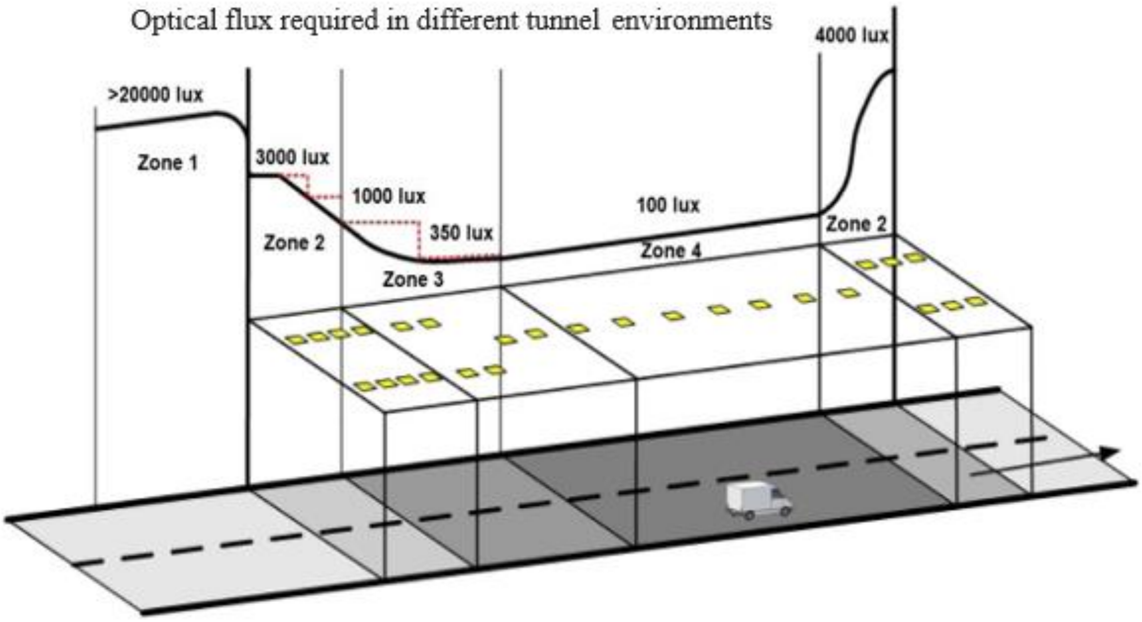

Figure (11) optical flux required in different tunnel environments.

6. Other lighting parameters:

A: Lighting the walls

Due to the fact that most of the driver's field of vision in tunnels are walls, according to the standard, the average brightness of tunnel walls up to 2 meters from the road floor is at least 60% of the road surface brightness in each area.

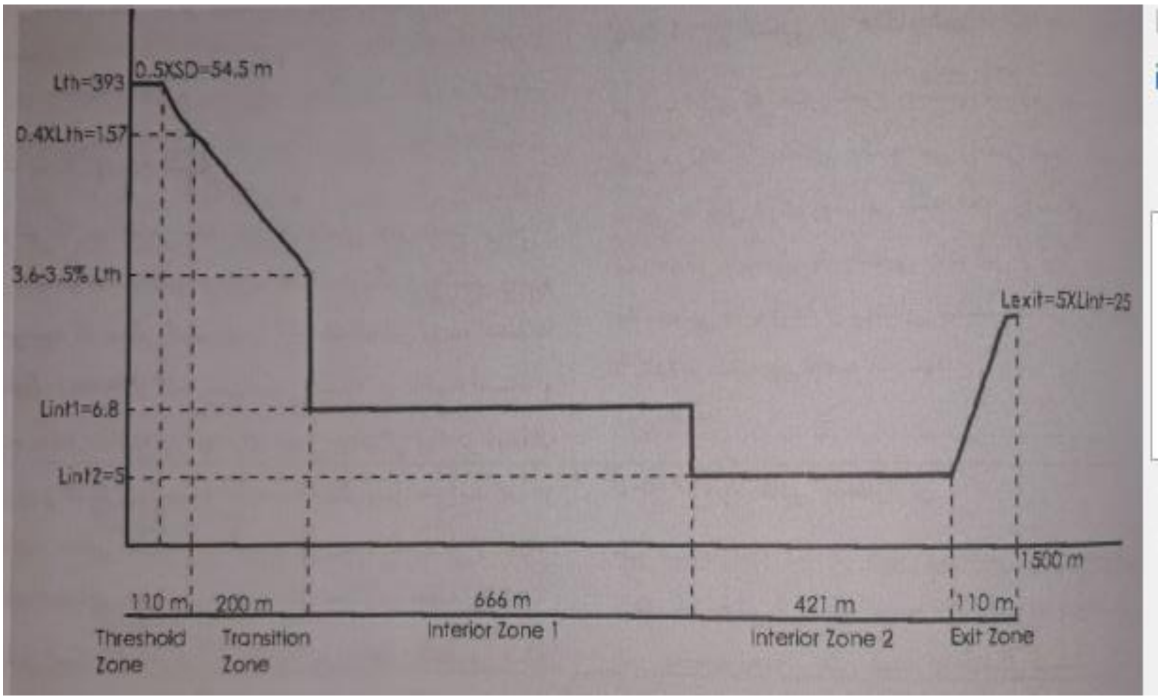

Figure (12) Different areas and their luminosity values in tunnel sections

B: uniformity coefficients

In the case of overall uniformity coefficients for road surfaces as well as walls up to 2 m high, it should be at least 40%.

A: Limit glare

The criterion for limiting glare in the tunnel is the maximum allowable value of 15%.

D: Flickr phenomenon

When the lights are installed on the roof of the tunnel at regular intervals, the driver encounters dark and bright spots while crossing regularly, which may bother him. This phenomenon is called flicker. In the quiet area and the transition area, the distance between the lights to provide brightness is high and at the entrance is very small. Increasingly, this phenomenon may occur. According to the standard, if the frequency of seeing bright spots in the human eye is less than 2.5 Hz and more than 13 Hz, the effect of Flickr is negligible and is not considered

If the frequency is in the range of 4 to 11 Hz and lasts more than 20 seconds, it may cause visual annoyance to the driver. Figure 5-13 shows the allowable installation distance based on the allowable tunnel speed.

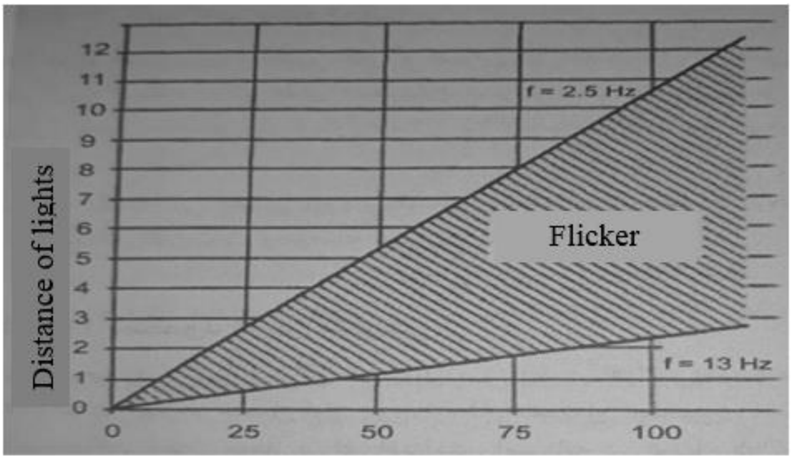

Figure (13) Obtaining the appropriate distance to install the lights in the interior to avoid the flicker phenomenon at different speeds

7. Lighting at night

There is no need to change the lighting levels in the tunnel at night. And the whole tunnel can be lit with uniform brightness. If the road connected to the tunnel is bright, the amount of tunnel lighting should be at least equal to the light of the road before the tunnel at night.

If the road connected to the tunnel is not bright, at least brightness 1 Candela per square meter is recommended.

8. Emergency lighting

According to the standard, if you have problems with the main power supply of the tunnel, part of the lights should be turned on by an uninterruptible power supply in such a way as to provide at least 2 to 1 lux of light intensity to allow people to leave. In addition, according to CIE 193, which is related to emergency lighting of tunnels, lights must be installed in the walls of the tunnel as shown below.

Accordingly, the lights indicating the output path should:

Be installed at a maximum distance of 10 meters from each other.

Their minimum installation height should be 1 meter

Their maximum light intensity is 40 candelas in the direction of the driver's vision.

Work permanently or be on standby

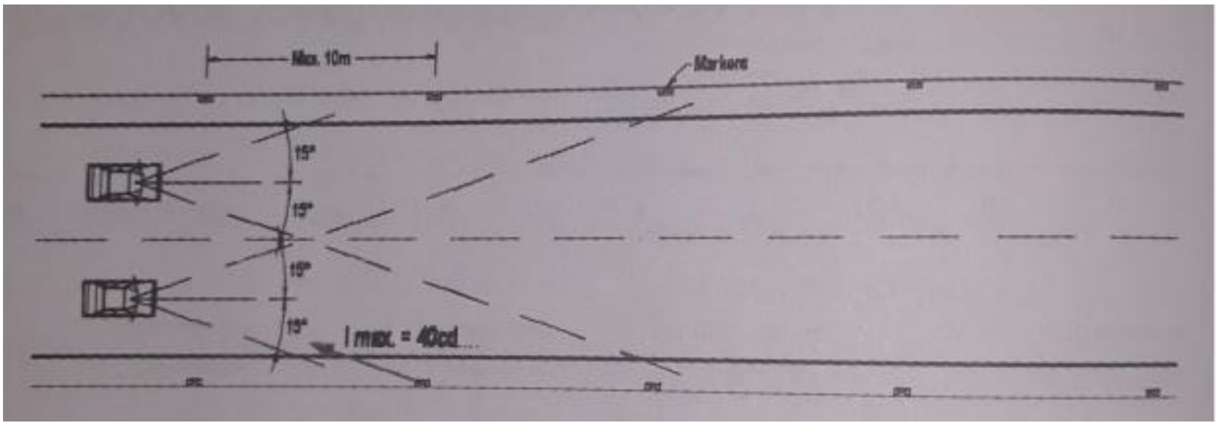

Figure (14) the proposed standard configuration for the installation of emergency lights

9. Maintenance coefficient

The lights that are installed in the tunnel work under special conditions and must be in accordance with the technical and photometric specifications. Since the inside of the tunnel is very polluted and on the other hand, due to the compounds obtained from car exhaust gases and air humidity, corrosive acidic substances are placed on the lights, which causes damage to the lights. The degree of protection of tunnel lights is at least IP65. Also, the light flow of the groups is reduced. It is recommended to replace the lamps before the end of their useful life.

The following maintenance coefficients are recommended for different tunnels:

Maintenance factor 0.35 If the lights are not cleaned regularly and the lights are not of good quality.

Maintenance factor 0.5 If cleaning the lights and replacing the lamps is normal and the quality of the lights is normal.

Maintenance coefficient 0.7 If the lights are cleaned and the lamps are replaced at regular intervals and the quality of the lights is good.

10. Lights and lighting equipment

Since it is difficult to operate, maintain and maintain in tunnels, the best option for providing lighting is to use sodium lamps, which have a longer lifespan and are more effective. They are high. Yellow light does not feel good for the driver and white light is preferred. LED lamps can be used for this purpose. Due to the high brightness at the entrance of the tunnel, it is now more economical to use sodium lamps and it is better to use LED lamps only in the interior.

11. Install the lights

The installation of lights depends on the form and shape of the tunnel, as well as the location of mechanical installations, lighting equipment. Installing lights in the direction of the central axis of the tunnel is more effective, but it is difficult to maintain because both lanes must be closed. Installing lights on the wall reduces the efficiency of the whole system because the light is reflected less than the road surface. Installing lights at the corner of the wall and ceiling and irradiating light at an angle can be a middle ground.

Conclusion

Tunnels play an important role in Afghanistan's transportation network, especially in the northern regions and its crowded cities.
The threshold of a tunnel should correspond to the level of eye adaptation of drivers. For drivers approaching a tunnel,
The contrast of tunnel barriers is reduced due to the brilliant distribution of the tunnel environment in their field of view, and thus their ability to see
Obstacles in the tunnel are reduced, resulting in the formation of black holes. The black hole phenomenon leads to uncertainty

Drivers make decisions when approaching a tunnel. The severity of injuries caused by accidents at the entrance to the tunnel is greater than. It is what happens on highways. At the entrance to the tunnel, the reflection of sunlight from the surroundings and the lack of sufficient light are usually some Causes vision problems.

The lighting of the tunnels is related to the safety of people, so it is extremely important. In tunnel lighting, the luminance parameter is currently used instead of the light intensity. In the lighting of roads and tunnels, lighting is the goal, not objects. Reliability and long service life of equipment in lighting is very important. The lighting of the tunnels creates security and tranquility, and if the lamps are used properly, without spending a lot of money, it will cause many changes in the beauty of the environment and security.

It is suggested that in future studies, with corrective measures such as planting trees and shrubs, painting the structures around the tunnel with colors with low reflection coefficient and installing asymmetric lights at the entrance of the tunnels can effectively reduce the contrast perception of obstacles and thus increase The risk of road accidents was prevented at the entrance of these tunnels.

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