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Research Article

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A Study on the Calculation of the Lighting Level with Simulation Programs in Tunnel Lighting

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Abstract In this study, the illumination level was determined with the help of a simulation program to be used in the calculations for tunnel illumination. Lighting levels on the road were calculated for the single hanger lighting fixture at 7m height in the tunnel. The places where the illumination level is low in the tunnel and the comfort of the view is good. Simulation program made easy and error-free calculations.

Keywords Lighting levels, tunnel lighting, road lighting

1. Introduction

According to data from TUIK (Turkish Statistical Institute), approximately 1% of the traffic road accidents in Turkey occur in tunnels. Although this rate seems very low, tunnel accidents result in deaths, especially accidents with fire as they occur in an enclosed space. As tunnels are enclosed, there is difficulty in evacuation and intervention. As a result, tunnel lighting is also important for both reducing the occurrence of and effects of traffic accidents [1].

2. Photometrıc Terms

2.1. Lumınance

A fluorescent lamp has a glow of 5000-15000 cd/m^2, a full moon has a glow of 2500 cd/m^2 and a road surface under 30 lux of lighting has a glow of 2 cd/m^2.Since the glitter concept involves a specific point of the surface and observation direction, it is necessary to identify these conditions when glitter is mentioned. The glow of ideal reflective surfaces can be calculated by benefiting from the illumination level [2]. When ρ is the reflection factor of the surface, the relation between glitter and illumination level is determined by Equation 1.

$$L = \rho \frac{E}{\pi} \tag{1}$$

The mean road level luminance (L_{th}) in any point of the threshold zone (it is the first extension at the tunnel entrance in Fig. 5) is called the threshold zone luminance [3-5].

The rate of the threshold zone and access zone luminances is $(k = L_{th}/L_{20})$, where (L_{th}) is the mean road surface luminance at the beginning of the threshold zone and (L_{20}) is the luminance distance equal to the stopping distance in front of the tunnel. The mean value of the road surface luminance at any point of the transition zone is called the transition luminance (L_{tr}). The value of the mean road surface luminance in the interior zone is called the interior zone luminance (L_{in}) [4-7].

2.2. Vısual Events for Tunnel Lıghtıng

Visual events in the tunnel are reaction of eyes to variable light events such as adaptation of the eyes, contrast sensitivity, acuity, uniformity, flicker, and glare. Events affecting eyesight, such as flicker, uniformity, and glare, affect the quality of the tunnel lighting [8].

2.2.1. Adaptatıon

Adaptation is the ability of the eyes to adapt to variable illumination levels. In tunnel lighting, the luminance levels should be ensured through the tunnel for the driver to sufficiently see inside the tunnel from a distance to allow for safe stopping.

2.2.2. Contrast Sensitivity of the Visual System

The general definition of contrast is as follows:

In the perceptual sense: the assessment of the difference in appearance of 2 or more parts of a field seen simultaneously or successively (hence: brightness contrast, lightness contrast, color contrast, simultaneous contrast, successive contrast, etc.)

In the physical sense: the quantity correlating to the perceived brightness contrast, usually defined by one of various formulas that involve the luminances of stimuli considered. For example, by the proportional variation in contrast near the luminance threshold, or by the ratio of luminances with much higher luminances.

2.2.3. Sensıtıvıty to Forms (Acuıty)

An object can be distinguished from various points depending on the sensitivity to forms or acuity of the eyes. If images of two points of an object are too close to each other, then eyes cannot distinguish between the two points. Sensitivity to form varies by vision, background luminance, contrast of the object, and observation time. 4.5 10^3 (l/rad) is typical for eyes [9]. Figure 1 shows variances in acuity depending on illumination. Accordingly, acuity reaches the highest value of approximately 500 lx and it remains stable up to 10.000 lx. After that, the acuity starts to decrease again because of glare [3-8, 10-14].

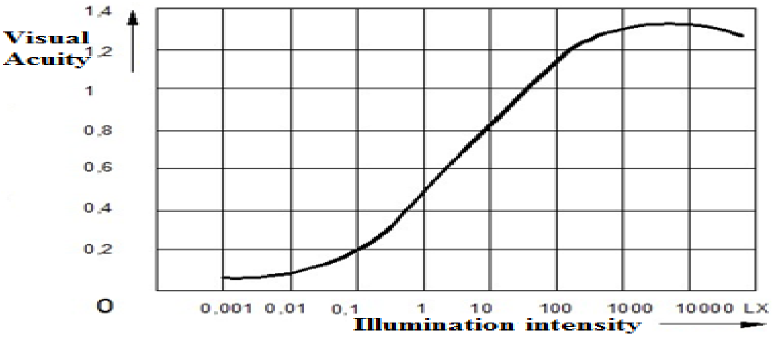


Figure 1: Variances in acuity by illumination [9]

2.2.4. Unıformıty

There should be an equal distribution of luminance in the tunnel (on the road surface and tunnel walls up to 2 m height) in order to provide a clear view for the driver. Two kinds of uniformity are considered important in tunnel lighting:

1) Mean (resultant) uniformity (Uo): When traffic is on the right side, it is the rate of minimum luminance (Lmin) to mean luminance of the road (Laverage), which is determined by an observer at ¼ distance of the road width on the right side of the road. The lower sections of the walls should be considered as well as road surface. Equation 2 presents the ratio suitable for the road surface and mean luminance uniformity of the walls up to 2 m from the ground according to CIE 88-1990-2004 (in clean tunnels) [4].

$$U_O = \frac{L_{\min}}{L_{average}} \geq 0.4 \qquad (2)$$

2) Longitudinal uniformity (U_l): According to an observer on the center line of road lane, it is the rate of minimum luminance applied through the center line to maximum luminance. Equation 3 presents the rate suitable for longitudinal uniformity through the road.

$$\frac{L_{\min}}{L_{\max}} > 0.6 \quad (3)$$

A standard related to the longitudinal uniformity can be ensured when the distance between luminaries are not three times more than the height of the light point. Since the height of luminaries is 4.5 m to 6 m in the tunnels, space between the luminaries should not exceed 13.5 m and 18 m depending on the height [4-14].

2.2.5. Flıcker Effect

Eyes cannot perceive some light stimulus that varies with time even though they perceive a difference in sudden changes of light and show reflex. The critical flicker frequency is high for large luminances; therefore, lighting at high illumination levels should be evaluated to ensure lighting without flicker as much as possible.

Disturbance levels formed by flickers on the driver depend on the period of which the effect continues and the number of flickers formed per second. Thus, distance between the luminaries determined to prevent flickers should be assigned according to the tunnel length and vehicle speed in the tunnel. Jantzen (1960) and Schreuder (1964) conducted research on the flicker effect according to the number of flickers per second and Waltbert (1977) studied the effect according to tunnel length. Jantzen found that the dangerous flicker frequency domain is 3.5 Hz to 15 Hz and the maximum disturbance is around 8.5 Hz. Compared to Jantzen, Schreuder performed studies at low road surface luminance (8 cd/m2) and at high resource luminance (9000 cd/m2) resulting in a dangerous flicker frequency domain of 2.5 Hz to 12.5 Hz and a maximum disturbance level of approximately 6.5 Hz. Thus, the disturbance level is maximum when the distance between the center points of the luminaries are between 2.5 Hz and 15 Hz and the flashing frequency is between 5 Hz and 120 Hz [15-17].

Walthert studied the flicker effect depending on tunnel length and demonstrated that the dangerous flicker frequency domain increases as the tunnel length increases. The tunnel length and variance of flickers depending on the vehicle speed by the distance between luminaries are shown in Figure 2. A driver would not be affected by a flicker event depending on the proportion of the highest luminance value to the lowest luminance or the flicker frequency [14]. Figure 3 presents the flicker frequency and limit values allowed by (Lmaks/Lmin) [15-17].

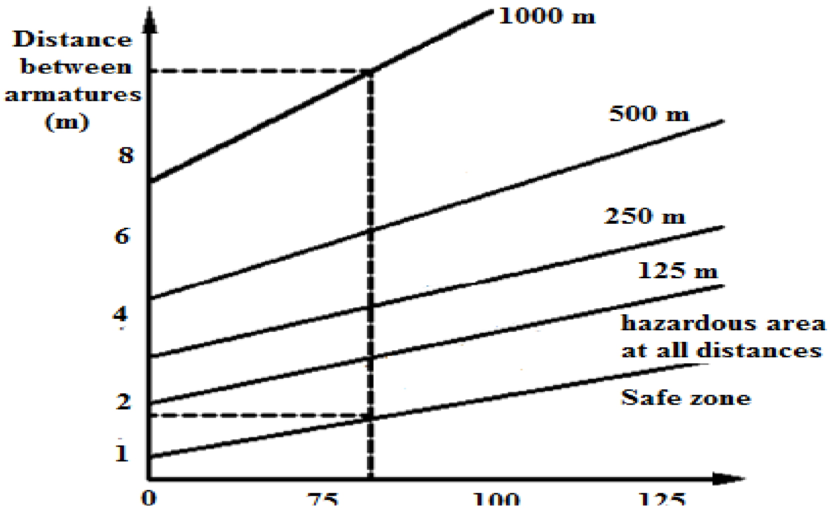


Figure 2: Tunnel length and variance of flickers depending on vehicle speed by distance between luminaries [14].

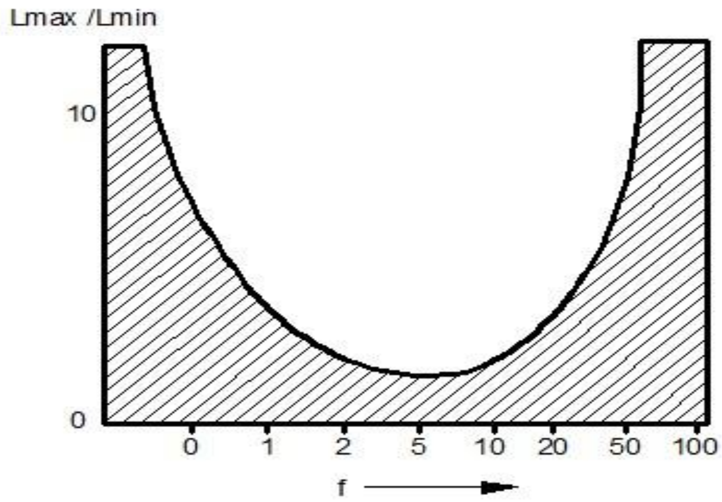


Figure 3: Flicker frequency and limit values allowed by (Lmaks/Lmin) [16-18].

2.2.6. Glare

Glare means that healthy eyes cannot temporarily see surrounding objects because of external effects. Glare formed by luminaries and their reflections should be limited in the tunnel.

2.2.6.1. Glare Restrıctıon

Since glare decreases vision, its limitation is important. In tunnel illumination according to CIE-31, only physiological (disability) glare should be considered. The threshold increment (TI), TI should be less than 10% in M2-type road lighting of the whole region and levels in the tunnel, except the exit zone during daylight [18, 19]. The T_I value can be calculated with Equations 5 and 6,

$$TI = 65 L_V / L_r^{0.8} \quad (for\ Lr \le 5\ cd/m^2) \quad (4)$$

$$TI = 95 L_V / L_r^{1.05} \quad (for\ Lr > 5\ cd/m^2) \quad (5)$$

Where:

L_r : Average glow of the pavement and walls from the ground.

L_v : Covering glow formed by illumination armatures within sight, from horizontal up to 20 degrees [18].

2.2.7. Vısual Dıscrımınatıon

Human visualization can perceive electromagnetic propagation only at wavelengths between 380 nm (ultraviolet, actually UV are λ<380 nm) and 780 nm (infrared, idem) as light. While human eyes perceive based on the difference between daylight/darkness when the lighting level is low, they perceive according to colors when the daylight level is high. Eyes have difficulty focusing when the iris is open (low daylight level) in environments illuminated by white light [2, 19].

3. Crıtıcal Object

It is essential to supply luminance levels sufficient to detect the presence of the smallest object from a distance it is possible to stop safely, which may pose danger in the tunnel for a moving observer under tunnel lighting. For this reason, the smallest object that may pose a danger must be determined. In literature, a “critical object” is defined as an object that has 20% contrast with its background and 20 x 20 cm dimensions. Such an object can be seen at 75% possibility under observation for 0.1 seconds from 100 m out [3,5,7-9,19].

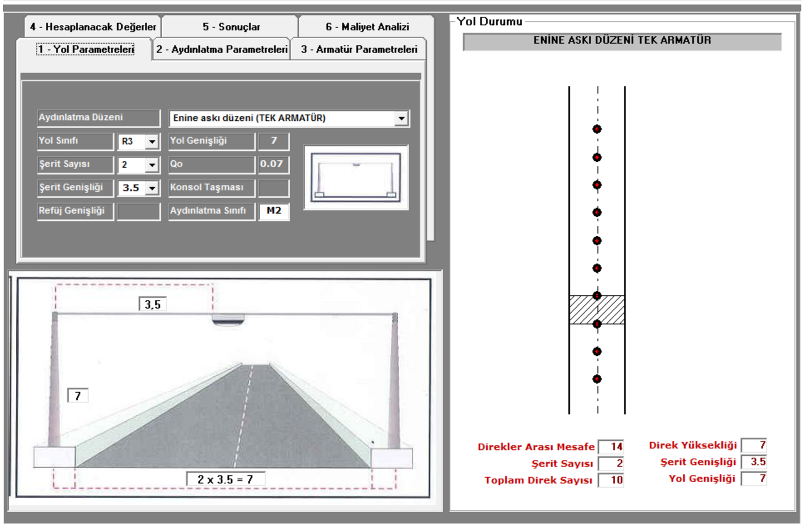
4. Light Sources

High-pressure sodium vapor (HPS) lamps are preferred under conditions of higher luminance level, including under water tunnels, as HPS lamps have higher light flux and smaller dimensions than low-pressure lamps. As a result, less luminaries and area are required for lighting. Lighting efficiency (in terms of electricity consumption) of a similar lighting system increases up to 90% with HPS lamps compared to fluorescent lamps based on results obtained from various tunnels with different structures that are open to vehicular traffic. The luminance efficiency is defined as the luminance level from the power required for the tunnel (for 1 m^2). Table 1 illustrates the tunnel road and lighting parameters [19-22].

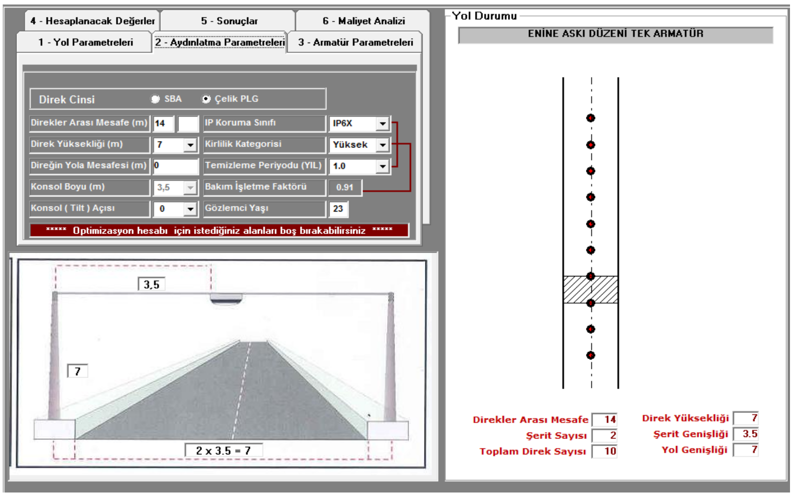
Table 1: Tunnel road and lighting parameters

Tunnel road parameters		**Tunnel lighting parameters**	
Double armature, transverse arrangement		Armature height	7 m
Road class	R3	Fence distance	0 m
Number of lanes	2	Console angle	0
Strip width	3.5 m	IP protection	IP65
Road width	7 m	Pollution category	High (IP6X)
Q_o	0.07	Annual clear period	1
Road lighting class	M2	Distance between armatures	15 m (70 W)

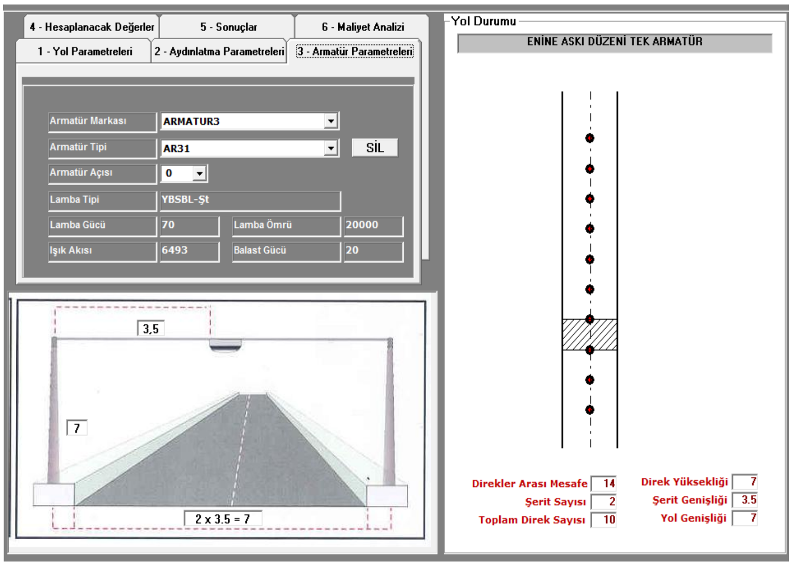
Acceptablelighting level values that do not disturb the vision comfort into the tunnel were calculated in the simulation performed with the values in the table. According to CIE-88:2004 on 3.5 m wide road with true lanes. Figure 4 illustrates the simulation program and data entered for a 70 W HPS lamp.



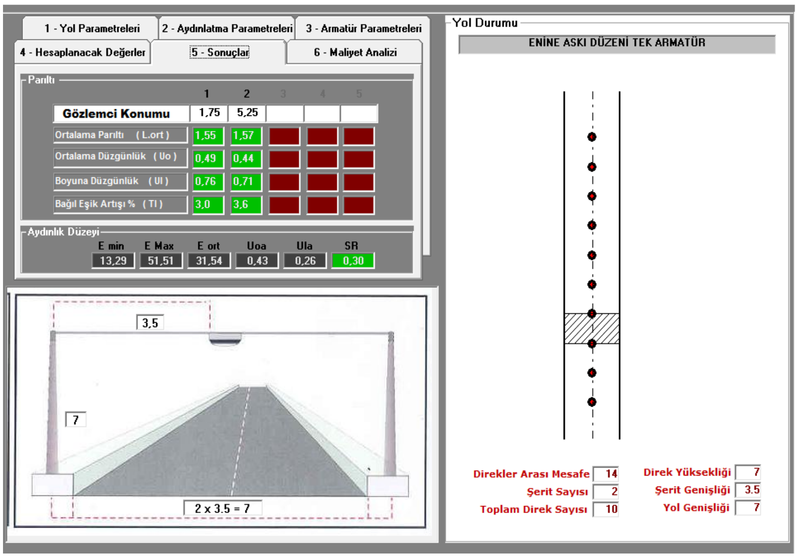
a) Road parameters



b) Lighting parameters



c) Luminary parameters



d) Results

Figure 4: Simulation program: a) road parameters, b) lighting parameters, c) luminary parameters, and d) results

5.4. Luminance Values

Table 2 presents the lighting level for under 70 W HPS lamps in the tunnel according to simulation results.

Table 2: Lighting level for under 70 W HPS lamps

Emin=13,29 Lx Emax=51,51 Lx Eort=31,54 Lx Uoa=0,43 Ula=0,26 SR=0,30

	0,700	**2,100**	**3,500**	**4,900**	**6,300**	**7,700**	**9,100**	**10,500**	**11,900**	**13,300**
0,583	24,644	18,015	20,713	16,409	13,293	13,294	16,411	20,716	18,019	24,649
1,750	35,020	28,082	31,521	25,167	18,559	18,559	25,169	31,523	28,086	35,025
2,917	42,913	44,680	43,650	34,100	25,909	25,909	34,102	43,653	44,684	42,919
4,083	48,940	45,567	51,511	39,999	31,799	31,800	40,001	51,514	45,571	48,946
5,250	41,983	37,809	43,671	32,471	27,192	27,193	32,473	43,674	37,814	41,989

6,417	29,082	25,857	28,112	21,556	17,807	17,808	21,558	28,116	25,861	29,088

4. Results

It has been determined at which points low the light level of the illuminated road and tunnel. This finding is useful to show that vehicle drivers are more likely to cause accidents. It also shows which aspects of lighting design are incomplete or defective.

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