TUNNEL LIGHTING IN EUROPE (ABRIDGED)

by D. A. Schreuder, Institute for Road Safety Research SWOV

1. THE SPECIAL INTEREST OF TUNNEL LIGHTING

From a lighting point of view, tunnels present a case that deserves special attention. In no other field has a critical visual task (car driving) to be performed under conditions where luminances of extreme differences present themselves simultaneously or almost simultaneously within the field of view. Visibility is restricted by effects of induction and (partial and transitional) adaptation. The reason for this is, that it is economically impossible, even with present-day technology, to light a tunnel just as brightly as a sunlit open road. One has always to reckon with an extremely large discrepancy in luminances between the tunnel itself and the adjoining roads. From these considerations it will be clear where the main problems of tunnel lighting present themselves.

First, the car driver approaching the tunnel should be able to look into it, even while he is still in the open. Second, when he is close to or in the tunnel, adaptation of his visual system to the lower levels of lighting must be possible, and third, the interior of the tunnel should be lighted to a high standard, for by day only partial adaptation is to be expected. These are the most important problems of tunnel lighting and also the most difficult ones to solve. Typically, all three have to do with the day-time situation.

The principles outlined here, and laid down in the Recommendations of the CIE (1971) are beginning to be generally accepted throughout Europe - and incidentally, in several Latin-American and Asian countries as well. A further indication of this trend is provided by the many national Recommendations or Standards on Tunnel Lighting which show a similarity. It seems therefore justified to speak of a (European) "system" of tunnel lighting.

2. EXPERIMENTAL RESULTS

The European system of tunnel lighting is on the one hand based on scientific research and on the other hand on the function the tunnel itself as forming part of the road network. This implies as a principal aim of the tunnel and of its lighting a flow of traffic that is not inferior to the flow outside with respect to speed, safety and driver convenience. The underlying principles are described as the functional approach. (Schreuder 1970). An analysis of the problems prompted psychophysical measurements regarding the visual functions; fundamental measurements were followed by experiments in a laboratory, using scaled-down models of tunnels. The lighting design of a number of existing tunnels has been based on this research. Most of the research has been described by Schreuder (1964). See also Schreuder (1968).

When a motorist is driving on a normal open road, it may be assumed that the state of adaptation of his eyes will fluctuate around an average value. In the majority of cases, however, the open area may be represented with one value of the luminance which will be indicated by L_1. The particular average state of adaptation is assumed to be that resulting from continuous observation of L_1. It follows that it is essential to establish what quantitative value must be allotted to L_1. At day, the tunnel is darker than the surroundings; yet the state of adaptation will not change so long as much of these surroundings are well within the field of vision. Perception of the road within the section of the tunnel is hampered by the relatively bright surroundings - an effect known as induction, or as the "black-hole" effect.

In Fig. 1, the results of the research of Schreuder (1964) and Mader and Fuchs (1966) are given. Here L_1 represents the open road and L_2 the tunnel entrance. The minimum value of L_2 is given as a function of L_1. The value L_2 must be present in the beginning of the tunnel in order to be able to observe a critical object. The most important result of these investigations is that for a wide range of values of L_1, the relation L_2/L_1 is nearly contant and equals 0.1.

When the car-driver is quite close to the tunnel portal, the visual system begins to adapt itself. Adaptation is a very complex phenomenon, even when all the relevant levels of luminance are well within the photopic range. Experiments are described by Kabayama (1963), Mader and Fuchs (1966) and Schreuder (1964 and 1968). Some results are reproduced in Figure 2. Here, the minimum value of the luminance of a screen is plotted against the time on condition that during the transition the circumstances related to visibility do not drop below a specified level. It may be noted that the value of the starting luminance is of little importance for the relative course of the luminance. This implies that not only the avoidance of the black-hole effect, but also the decrease of luminance in the first section of the tunnel, needed to avoid difficulties from (lack of) adaptation, can be ensured by making the luminance in the first section of the tunnel directly proportional to L_1. This is a very important fact to note in regard to the practical lighting equipment of the tunnel.

From Figure 2 it follows, that we are fairly free in our choice of the lighting level in the interior of the tunnel, provided adequate adaptation is ensured. If a low level is selected for the tunnel interior, a longer time for adaptation must be provided. The "Transition zone" should be long. The luminance of long tunnels should be well above the level generally accepted for nighttime street lighting, because even partial adaptation to such a level takes several minutes. Thus, it is generally accepted, albeit without specific research, that the value should be 5-10 cd/m^2 *) in very long mountain tunnels and some 10-20 cd/m^2 in heavy trafficked tunnels of medium length.

3. INTERNATIONAL RECOMMENDATIONS

A draft for International Recommendations on Tunnel Lighting has been published by CIE (1971). These Recommendations are based on the consideration quoted above. Recommendations issued by the CIE are generally not applied directly but from the basis for National Codes and Recommendations. The Codes in operation or in preparation in the Netherlands, Germany, France and Switzerland are similar to the Draft of the CIE.

A number of the most important points from the Draft Recommendations of the CIE are quoted here:

a. "In order to avoid the black-hole effect, the luminance in the threshold zone should be at least 1/10 of the luminance in the access zone.(.....)"

b. "The length of the threshold zone being the stretch where the 1 to 10 ratio is realised is related to the speed and should take care of the safe stopping sight distance. It should be e.g. 200 m for speeds up to 100 km/h. The actual length of the threshold zone can be shorter, depending on the shape and construction of the tunnel entrance.(.....)"

c. "The Luminance of the background against which details in the transition zone have to be observed must decrease according to the curve given in Figure 3. (i.e. Fig. 2 of this paper).(.....)"

d. "In day-time the luminance in the interior of long tunnels must be at least 10 cd/m^2 and preferably 15 to 20 cd/m^2.(.....)"

e. "Supplementary lighting at the exit is generally not necessary, except in special local circumstances where, for example, direct sunlight can enter against the traffic.(.....)"

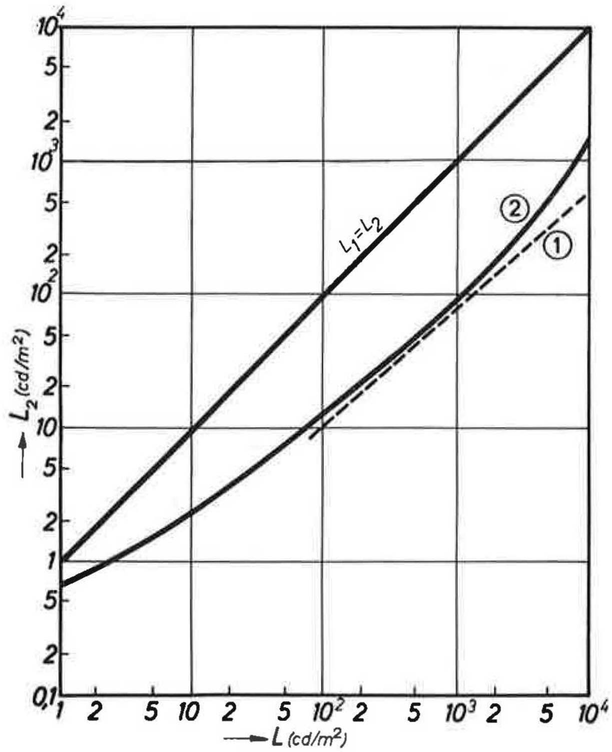
f. "In very long tunnels of many kilometers in length, which convey little traffic - such as mountain tunnels - a lower luminance level for the interior can be tolerated, provided the length of the entrance zone is accordingly adapted. For all tunnels, however, the luminance must not be lower than 5 cd/m^2.(.....)"

g. "In tunnels that are too long to stay unlit, but are shorter than 20 to 80 m (depending on the circumstances) a lighting system consisting of one single transverse bright strip can sometimes be applied. The lighting in this strip can either be daylight falling through a slot in the ceiling, or artificail lighting. The luminance must be related to the daylight level outside. The value of 800 cd/m^2 must be provided in full daylight. The strip must be about half-way the tunnel and be several meters wide.(.....)"

As may be seen from the above quotations, the Recommendations stress the three important points indicated earlier. A great number of other points, of which several are also quoted, complete the Recommendations.

One question, however, is not fully clear at this moment. The problem is, that it is not possible under all circumstances to indicate what exactly has to be taken as the relevant value of the luminance in the open (L_1). This value is of the utmost importance for the practical lighting design of the tunnel, because the absolute values of the luminance both in the threshold zone, and in the transition zone are directly proportional to the value of L_1. Thus, with L_1 = 8000 cd/m^2 the threshold zone should have at least 800 cd/m^2, but when L_1 is only 5000 cd/m^2, for the threshold zone 500 cd/m^2 will do. When artificial light is applied, the power to be installed is, quite naturally, in turn directly proportional to the luminance to

*) Footnote. 1 cd/m^2 (candela per square meter) equals 0.29 fL.



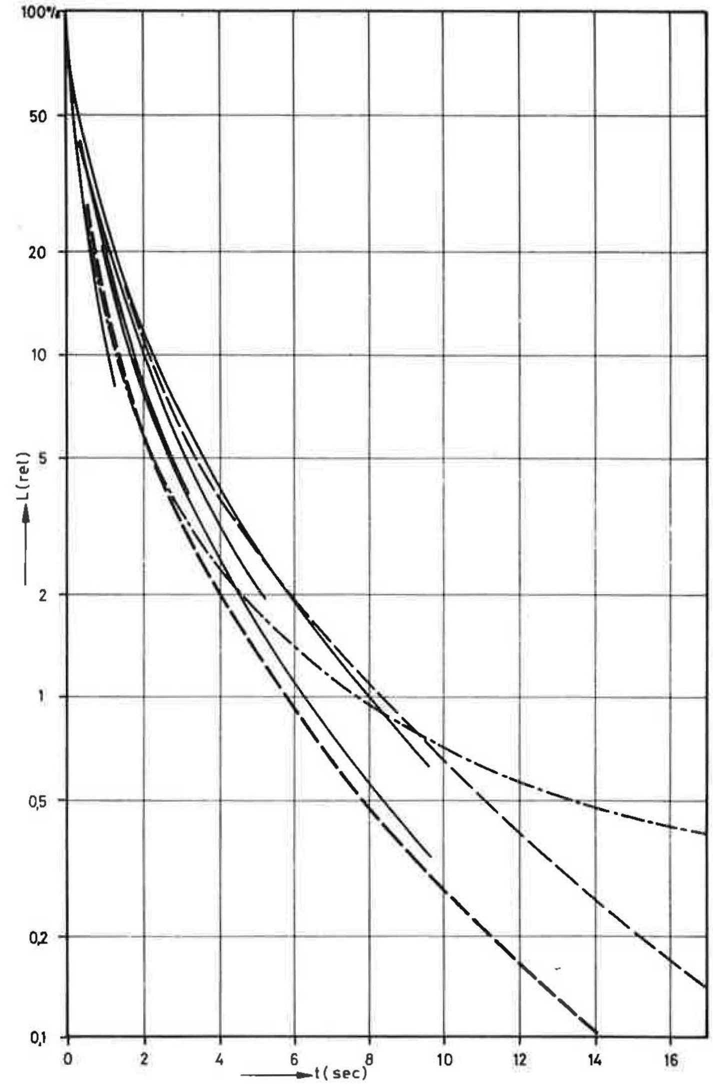


Figure 1. ① after Mader and Fuchs (1966), formula 2; ② after Schrueder (1964), Figure 3.

Figure 2. ——— after Kabayama (1963), table 3; L_o : 100...1600 cd/m^2;
— — — after Schreuder (1964), table 24; L_o : 8000 cd/m^2 (50% and 75% of observations);
·—·— after Mader and Fuchs (1966), formula 3 (with K = Ba/7, m = -1.5) L_o : 80...6000 cd/m^2.

Both figures are from Schreuder (1968). Details of the experiments are given in the original publications.

be yieled. Now, a first rough estimation of L_1 can be made by applying the basic formula $L = (\rho/\pi)\, E$.

The horizontal illumination E may easily reach 100,000 lux. (10,000 fc). The reflectance can generally be kept below 0.25. This leads to a first approximation of L_1 = 8000 cd/m^2 for diffuse illumination and diffuse reflection. The applicability of this rule of thumb is restricted. Particularly in mountainous regions, the background near the tunnel portal will generally be formed by dark woods or rock formations. Here, a lower value of L_1 seems to be justified, just as within urban areas where high buildings may predominate. Both, by the way, situations where tunnels are quite likely to be found. A more general rule for the predermination of L_1 (to be applied in the lighting design) is under consideration.

In principle, this rule includes the weighted average of a number of luminance readings, made at a specified time of the day and of the year at various distances from the tunnel portal. (See CIE (1971)).

4. THE PRACTICE OF TUNNEL LIGHTING IN EUROPE

Not only several national Codes, but also many tunnels in operation or under consideration follow the lines put down in the draft of the Recommendations of the CIE. This, of course, is no coincidence; the Recommendations reflect to a large extent the present-day lighting practice. The lines of thought will be indicated here. Examples of existing tunnel lighting schemes are described in the literature (Schreuder 1964, 1967). Three important groups of tunnels will be discussed: the very long moutain tunnels, the tunnels for heavy traffic of intermediate length, and the long urban underpasses.

a. The very long mountain tunnels

Most of the European long mountain tunnels pass through the main chain of the Alps. Generally, the traffic is light, compared with low-land standards. Furthermore, the sinuous approach roads and the toll-booths and customs controls prohibit high driving speeds when entering the tunnel. This results in a similar type of installation in most of these tunnels. Generally the length is 5 to 10 km, they have one two-lane passage for two-way traffic; overtaking is forbidden, maximum and sometimes minimum speeds are imposed, the cross-section is more or less semi-circular, the lighting consists of one longitudinal line of fluorescent tubes in the center of the ceiling, the luminance level is some 5 cd/m^2 or less, and the lighting provisions at the entrance are not very elaborate. Their main interest may be found, therefore, more in the field of traffic engineering or construction rather than in the lighting itself.

b. Tunnels with very heavy traffic and of intermediate length

From a lighting point of view, these tunnels are the most interesting. Freeways prohibit interruptions of the flow of vehicular traffic; this implies of course that all intersections must be off-grade. Where waterways with seagoing vessels have to be crossed, bridges have to be high, and tunnels are often more economical. Airport runways have to be tunneled under for obvious reasons. Typically, they are between 500 m and 2,000 m long, they consist of at least two one-way passages for high-speed traffic only, speed restrictions are high or even absent (which is normal in Continental Europe for all rural roads). Often they are submerged or built in open pits, favouring a rectangular cross-section. Approach roads are generally (nearly) straight, toll booths are either absent or at a large distance from the entrance. This results in high speeds for entering the tunnel. The entrance zone (threshold zone plus transition zone) is generally provided with daylight screens. Urban and rural tunnels are of very similar design. Their lighting consists of one or more uninterrupted rows of fittings with fluorescent tubes, which are dimmed at night. The daytime level is often around 10 cd/m^2. Generally speaking, the lighting installation is quite elaborate and often of a very high quality.

c. Long urban underpasses

Until recently, long urban underpasses of length of say 100 to 300 m. generally were very poorly lighted. The reason for this, presumably, is that high speeds are not possible in the normal overcrowded city streets anyway, and that a really good lighting installation is very expensive in relation to the total costs of the tunnel. As the construction of urban freeways is beginning to be normal in Europe, the lighting of a great number of tunnels in these roads becomes critical. High-level installations are often provided, in view of the fact that a lighting of some 1000 lux hardly makes any sense at all. Thus, one may find an increasing number of tunnels (or underpasses) in urban areas where the lighting can provide up to 5000 lux. Generally daylight screening is not applied. As for lamps, the main interest is with high-wattage, high efficiency units, such as high-pressure mercury or low-pressure sodium lamps: efficiency is rated higher than aesthetics. Naturally the great majority of long urban underpasses are lighted according to current standards - or rather, lack of appropriate standards. An increasing number, however, is being equipped according to the International Recommendations.

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