Applied Research on Tunnel Lighting: Current Development in Japan

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Research on tunnel entrance lighting, which has been carried out in Japan during the past decade, is reviewed. Special emphasis is placed on research on a method to derive the so-called adaptation luminance of the observer's eyes for any complex luminance field. Such a method is essential for accurately determining the luminance to be provided in the threshold zone of the tunnel. The present method is based on fundamental research on the relationship between the adaptation luminance and the luminance to be provided in the tunnel to make possible perception of possible obstacles. As a representation of adaptation luminance, the equivalent luminance of the standard field is defined as a uniform luminance of the standard field for which the luminance difference threshold of the observer's eyes is equivalent to that for the complex luminance field. On the basis of research on the effect of the veiling luminance on the luminance difference thresholds (measuring the equivalent veiling luminance at the tunnel site by means of a glare lens and of the road surface to which the driver's fovea is assumed to be adapted) a method for deriving the equivalent luminance of the standard field for any complex luminance field has been developed. The method is briefly described.

In daytime and clear weather, open scenery is normally lit with intensive daylight at an average luminance of several thousand cd/m^2, depending on geographic features, season, weather, time, and so forth. The insides of tunnels, however, are not lit with daylight and the luminance in tunnels can only be provided by artificial lighting installations. The maximum attainable luminance level over the full length of the tunnel, due to technical and economic limitations associated with artificial lighting, is on the order of about 10 cd/m^2.

Such a big difference in the luminances of the open scenery and in the tunnel makes the brightness in the tunnel, seen by the driver approaching the tunnel, appear extremely dark and consequently the tunnel is seen as a black hole unless the exit of the tunnel can be seen (*1*). This means that, under such conditions, no one can perceive clearly anything about the inside of the tunnel because the luminance ahead is so low.

As is well known, to enjoy safe and comfortable driving, drivers need to be able to perceive clearly relevant visual information. They must be able to drive without fear that they are lacking this necessary visual information and be able to see a sufficient distance ahead. This distance will vary with driving speed, braking performance of the vehicle, and so forth. When the tunnel is seen as a black hole, the distance at which the driver is able to perceive relevant visual information is decreased as he approaches the tunnel and he may fear that he is driving without being able to see clearly what is ahead of him.

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To enable the driver approaching the entrance of a tunnel in daytime to perceive visual information in the dark tunnel ahead, without fear that he is lacking necessary visual information, a reinforced lighting section has to be provided in the first stretch of the tunnel so that the inside of the tunnel ahead is seen by the driver still on the access road with sufficient brightness. This reinforced section of tunnel lighting is called the threshold zone (*2*).

The luminance that is required to yield such a brightness in the threshold zone varies as a function of general level of the luminance structures of the driver's field of view to which his eyes are adapted. The luminance structures of the driver's field of view include a variety of componential luminances, such as the sky, the road surface, the dark tunnel, the tunnel portal and its adjacent structures, and the natural surroundings such as trees, grass, soil, and rocks.

The componential luminances vary with the daylight conditions depending on, among other things, the season, weather, time, and orientation of the access road and the tunnel portal and the consequent shadow cast over them. Their mutual apparent size in the driver's field of view, hence the luminance structure of the field of view, changes as his car approaches the tunnel entrance. Under such conditions, the luminance structures of the driver's field of view change in a complex way even though daylight conditions are stable and constant.

To derive an appropriate luminance level for the threshold zone on a scientific basis, therefore, the following relationships had to be experimentally clarified:

1. The relationship between the luminance to which the observer's eyes are adapted (the so-called adaptation luminance) and the luminance needed in the tunnel to make possible perception of visual information in the tunnel without fear and
2. The relationship between the adaptation luminance and the luminance structure of the field of view of the observer when the luminance structure is complex.

In these cases the adaptation luminance of an observer looking at a portion of a field of view is defined as the luminance of a uniform field to which the luminance difference threshold is just equivalent. As will be discussed later in this paper, this luminance is not the same as the luminance to which the fovea of the same observer is adapted under the same luminance structure conditions. This is because the fovea is adapted to the luminance that is projected onto the fovea and the veiling luminance caused by the scattering of lights from the surrounding field superimposed on it. For this reason, in this paper, to avoid possible confusion, the term "equivalent luminance of the standard field" (L1) will be used instead of the adaptation luminance.

In the initial stages of the investigations (around 1960), it was difficult to determine the equivalent luminance of standard field when the field of view had a complex luminance structure and was not uniform. To solve the problem, various investigators followed two different approaches in the laboratory.

One approach was based on the simple assumption, concerning the adaptation of the driver's eyes during approach, that the driver's eyes are adapted to the average luminance in his field of view, and experiments were conducted on the relationships between the luminance of a uniform field (L1) to which the observer's eyes are adapted and the luminance necessary to perceive objects (L2).

The second approach took into account the influence of the dark tunnel, at the center of the driver's field of view, on his adaptation. This was done by using an experimental setup in which a gradual change in the apparent size of the dark tunnel entrance in the driver's field of view during his approach was roughly the same as in "real life." Experiments were conducted on the relationships between the luminance of a uniform field (L1) (in the center of which the gradual change of the tunnel entrance is simulated) and the luminance necessary to perceive objects (L2).

The first approach was carried out, for example, by Schreuder (*2*). In his experiments, by choosing the small angular size for the simulated tunnel of only 1 degree × 1 degree (the actual tunnel with two lanes seen 100 m ahead has a size of about 2.5 × 5 degrees) and by employing the short duration of 0.1 sec for the presentation of the tunnel as well as the object to be observed, he tried to minimize as much as possible the effects on adaptation of the dark tunnel in a bright uniform field that represented the luminance of the open scenery seen by the driver in the access zone.

As a consequence, Schreuder determined the relationships between the luminance of the uniform field (L1) (with an angular size of about 20 × 20 degrees) and the luminance to be provided in the tunnel (L2) to make possible perception of the object.

Narisada and Yoshimura (*3*) have carried out experiments under similar experimental conditions. Their results were compared with those of Schreuder and it was found that the two groups of results agreed well with each other (*4*). When Schreuder applied his result, however, he simply assumed that the driver's eyes were adapted to the luminance of the road surface and that the adaptation was not altered until the driver got into the tunnel. Consequently, he required a very high luminance over the full length of the threshold zone irrespective of the braking distance, hence the driving speed, of the car that was being driven (*2*).

Nakamichi et al. (*5*) and Narisada (*1*), on the other hand, to simulate the effect of the tunnel in the driver's field of view on his adaptation, used a dynamic simulator in their experiments. On their dynamic simulator, a simulated tunnel mouth was gradually extended in the observer's field of view represented by a uniform field during the observation. The speed of the change in the apparent size of the simulated tunnel was roughly the same as that in the driver's perspective view under actual conditions when driving at about 80 km/hr.

Assuming that the driver started looking in the tunnel ahead at a distance of 150 m from the tunnel, Nakamichi et al. got a curve that shows the relationship between the time elapsed from the moment at which the driver started looking in the tunnel and the luminance to be provided in the tunnel to make possible perception of objects in the tunnel (L2) while keeping the luminance of the uniform screen constant. The assumption as to the distance at which the driver started looking in the tunnel was verified later by a series of experiments with an eye-mark recorder (*6*). By applying their results, Nakamichi et al. derived various luminance values to be provided in the threshold zone for different driving speeds (*5*).

The experimental results obtained by Schreuder (*2*) and Nakamichi et al. (*5*) were compared and the differences in their results were explained almost fully by the differences in experimental conditions (*6*). In the course of time, however, it was deemed necessary to develop a method to derive, objectively, the equivalent luminance of the standard field for any complex field of view. This is because the adaptation of drivers approaching tunnels and the change in adaptation during the approach are quite different depending on the structural and geometric construction of the tunnel access zone as well as the geographic features around the tunnel (even though the daylight conditions are stable and constant). The dynamic simulator Nakamichi et al. used could not simulate such a complex change in adaptation. If the adaptation cannot be dealt with in a scientific way, it is meaningless to discuss the precise differences in experimental results. Furthermore, changes in the daylight conditions, which alter extensively the luminance structures in the driver's field of view, have to be taken fully into consideration.

To overcome these problems and to enable lighting designers to determine the luminance in the access zone to which the luminance in the threshold zone has to be calculated, the following steps were taken:

1. Investigation to develop a method of deriving, objectively, the equivalent luminance of the standard field (to represent the adaptation luminance of an observer's eyes) for any complex luminance field;
2. Investigation to find the relationships between the equivalent luminance of the standard field and the luminance in the access zone [as defined in the International Commission on Illumination (CIE) Recommendations for Tunnel Lighting]; and
3. Survey of changes of the equivalent luminance of the standard field during approach at the access zones of various actual tunnels.

INVESTIGATION TO DEVELOP A METHOD FOR DERIVING THE EQUIVALENT LUMINANCE OF THE STANDARD FIELD

As shown by Holladay (*7*) and others (*8, 9*), the surrounding luminance in the field of view, due to the scattering in the observer's eyes of the light from it, causes an effect like the one that would be caused if a physical veiling were located between the object and the observer's eyes.

The luminance of the physical veiling that produces the same effect on the luminance difference threshold as that of the surrounding luminance is called the equivalent veiling luminance. Narisada and Yoshimura (*10*) conducted a series of investigations on the effects of surrounding luminance field (instead of point sources) on the luminance difference thresholds that confirmed Holladay's results. Holladay's results were obtained for point sources so that the effects of the surrounding field could be replaced by a veiling luminance in the central part of the observer's field of view.

The veiling luminance brings about two consequences:

1. A raise in the foveal adaptation level as a luminance superimposed on the foveal luminance (E1) and
2. An increase in the apparent luminance of the object and its background (E2).

As pointed out elsewhere (*11*, *12*), the foveal adaptation does not quickly follow the decrease in the luminance projected onto the fovea. The first effect therefore is rather stable in nature. The second effect, on the other hand, rapidly follows the variations in the luminance with which the veiling luminance was produced.

In the case of a driver approaching a tunnel entrance in daytime, the surrounding luminance field varies as he approaches the tunnel entrance. Consequently, the effect of the veiling caused by the surrounding field, which increases the apparent luminance of the field of view, varies accordingly. On the other hand, the foveal adaptation, established by the luminance projected directly from the foveal field and the equivalent veiling luminance superimposed on it, remains at a fairly constant level. This implies that the equivalent luminance of the standard field (L1), as defined previously, varies as the driver approaches the tunnel entrance, while his foveal adaptation remains fairly constant (*1*, *6*).

To arrive at a method for deriving the equivalent luminance of the standard field under such complex conditions, it is necessary to investigate, separately, the two effects of the surrounding field on the luminance difference threshold (*10*).

Experiments

In this subsection a portion of the investigation conducted by Narisada and Yoshimura (*10*) relevant to the present subject will be briefly outlined. In this part of the investigations, based on Holladay's finding that the effects of the surrounding field can be replaced by a veiling luminance in the central part of the field of view, the two effects of veiling luminance on the luminance difference threshold were investigated separately in two series of experiments. For further details of the experiments, reference is made to the original publication (*10*).

In the two series of experiments, in order to separate the two effects of veiling luminance, an observation scheme was constructed in the following way. In both series, the observer's fovea was preadapted to the luminance of the veiling through which the object was to be seen. In Series 1, the object was perceived through the veiling luminance to which the observer's fovea was adapted. Under such conditions, the luminance difference threshold of the observer—determined by the combined effects of the veiling luminance, which increased the foveal adaptation and the luminances of the object and its surrounding field—was investigated.

In Series 2, on the other hand, after sufficient preadaptation, at the instant when the object was presented the veiling luminance was extinguished. Under such conditions, the luminance difference threshold—determined by the single effect of the veiling luminance, which increased the foveal adaptation (while keeping the foveal adaptation at the same level as in Series 1)—was investigated.

The experiments were based on the assumptions that

1. The foveal adaptation remains constant, even though the luminance projected onto the fovea, including that of the veiling as stimuli, be extinguished for a short duration, for example, for 0.5 sec. A similar principle was applied by Schreuder (*2*, *13*).
2. The veiling luminance, with light scattering in the eyes as stimuli, disappears immediately after the luminance in the surrounding field, the cause of the veiling, is taken away.

Basic Construction of the Experimental Setup

Figure 1 shows the basic construction of the experimental setup, and Figure 2 is a schematic diagram of it. At the central axis of the experimental setup, a light box (LB-1) was placed as shown in Figures 1 and 2.

A diffuse panel (P1), shown in the lower part of Figure 2, was illuminated from behind by light box LB-1 in which a 30-watt incandescent lamp with an inner reflector was mounted. The luminance of the diffuse panel (P1) could be adjusted by means of a thyrister dimmer through which the incandescent lamp was fed.

In front of the diffuse panel (P1), a neutral gray filter (f1) was attached so that the luminance of P1 could also be varied step by step.

One of a series of transparent photographic films was located in front of the f1. On the films the object to be observed (Oj) was printed in a series of densities in a square shape with an angular size of 10 × 10 min.

Between the photographic film and f1, a high-speed mechanical shutter (S) was placed. The object (Oj) was visible against the background only when the mechanical shutter was opened. The luminance of the object (Lo), as well as that of the background (Lb), was practically zero when the mechanical

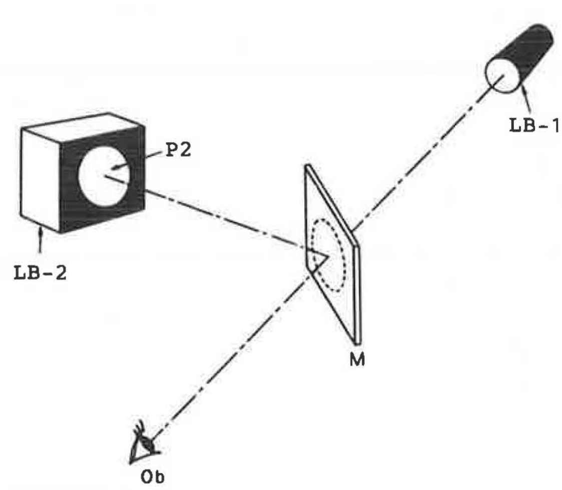


FIGURE 1 Basic construction of the experimental setup.

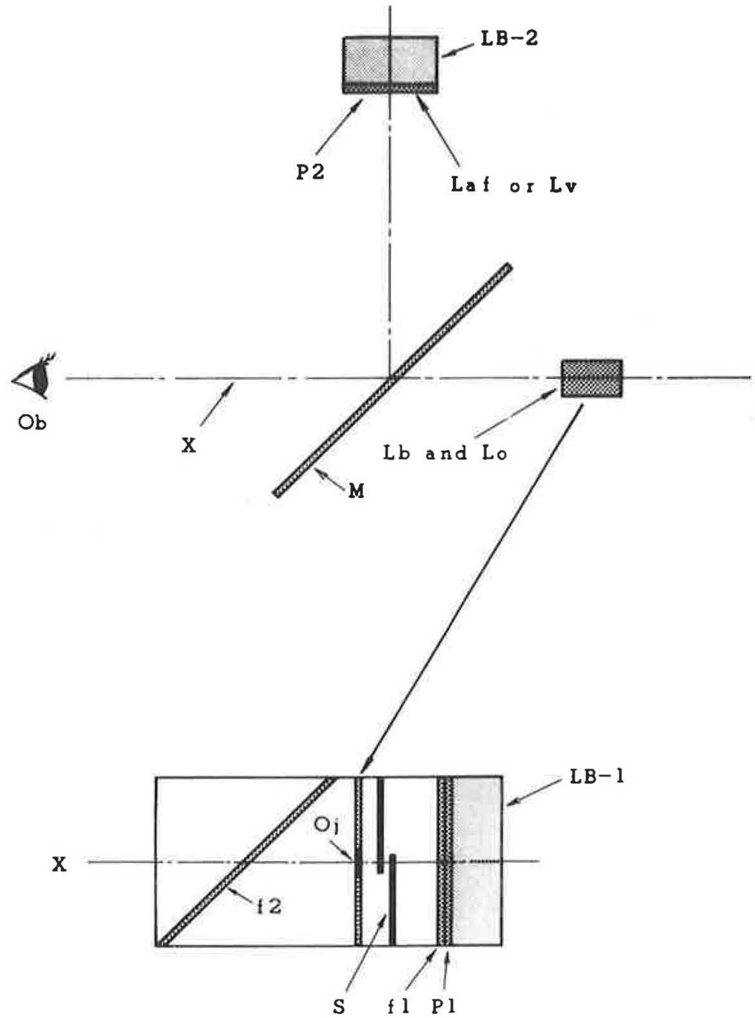


FIGURE 2 Schematic diagram of the experimental setup.

shutter was closed. The ratio between Lo and Lb was kept constant at 0.2. The circular background (Lb) had an angular diameter of 1.3 degrees.

To eliminate possible reflection from external light on the photographic film, another neutral gray filter (f2) was fixed at about 45 degrees to the optical axis X of the experimental setup.

On the optical axis X of the experimental setup, between light box LB-1 and the observer's eyes, a half mirror (M) was placed. The optical image of the circular area on light box LB-2, which was reflected on the half mirror, was superimposed on the luminance (Lo and Lb) produced by light box LB-1. The center of the two circles coincided with the optical axis X.

Light box LB-2 housed ten 15-watt white tubular fluorescent lamps fed through another thyrister dimmer. The diffuse panel (P2) was covered with a mask with a circular opening with an angular diameter of 3 degrees and was illuminated by light box LB-2 from behind with a uniform luminance (Laf or Lv).

The luminance of the diffuse panel of LB-2 was designated according to the role it played in the experiments. If the luminance played a role as the foveal luminance of the adaptation stimulus, the luminance was designated as Laf. If the luminance was used as the veiling luminance located between the object (Oj) and the eyes, the luminance was designated as Lv.

In the center of the circular area of Laf (or Lv), a small bright red spot was provided as a fixation point. Its luminance, generated by a small incandescent lamp with a red filter transmitted through an optical fiber, was kept low—almost at the perceptible level.

All of the relevant luminance values quoted were those measured at the position of the observer's eyes through the half mirror and various filters.

General Procedure

The observation procedure of the two series of observations was essentially the same. One male observer aged 28 with normal vision took part in the observations. The observer repeated the observations, experiencing one combination of the experimental condition 10 times at 10-sec intervals. Before each series of observations the observer stayed in a dark room for about 30 min to adapt his eyes to complete darkness.

After the adaptation to darkness, the observer moved to the experimental setup and was seated on a chair. His head was fixed on a dental impression plate located at a predetermined place in front of the experimental setup.

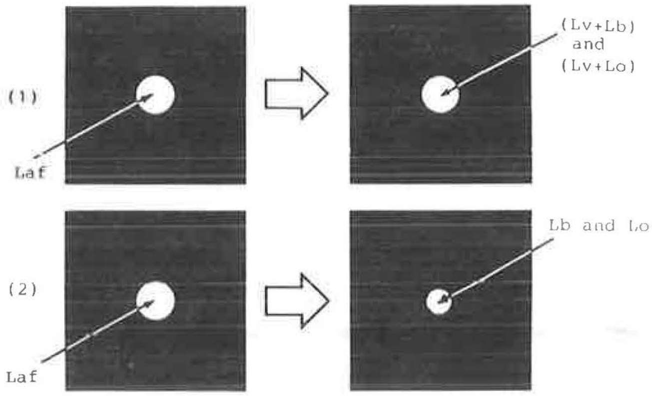


FIGURE 3 Luminance patterns in the observer's field of view during the period of preadaptation (*left*) and of observation (*right*).

In the experimental setup, two different patterns were provided, according to the experimental procedure, as shown in Figure 3. The number in the brackets attached on the left of Figure 3 indicates the series of experiments in which the patterns were observed.

In the experimental setup, the observer's eyes were preadapted to a given field luminance pattern, as shown in the left column of Figure 3, for about 5 min. The observer was asked to fix his visual attention on the fixation point, as previously mentioned, in the center of the foveal area so as to establish a stable visual adaptation to this luminance pattern.

After sufficient preadaptation, the object and its background were presented momentarily by opening the shutter for 0.125 sec. The luminance pattern at the moment when the object was presented is shown in the right column of Figure 3. To eliminate the effects of the background luminance (Lb) (against which the object was presented) on the foveal adaptation during the object presentation, the luminance of the background was chosen so that it was far lower than the adaptation luminance (about 1 percent) (*14*).

In Series 2 special care was taken to eliminate the backward masking effect (*15, 16*) and the forward masking effect (*15*) that possibly occur under such conditions.

The object was presented at one of two points against the background, either on the right or on the left of the background, in a random order not known to the observer. He was asked to state the point, to the right or the left, at which he could perceive the object presented. The luminance of the background as well as that of the object was varied by 0.1-log units.

On the basis of the responses that the observer made, the relationship between the background luminance (Lb) and the percentage of correct perceptions was constructed for each combination of experimental conditions. In the following discussion, the data are relevant to a probability of 50 percent correct perceptions.

Results and Discussion

As mentioned earlier, in these observations, the observer's fovea was preadapted to the veiling luminance located between the object and the observer's eyes as shown in Figure 3 on the left. In Series 1 the object was viewed through the veiling luminance. In Series 2 the object was seen directly after the veiling luminance was taken away, while the state of foveal adaptation remained the same as that of preadaptation. The results of Series 1 and 2 are shown in Figure 4 as curves 1 and 2, respectively.

It is obvious that the luminance difference threshold obtained in Series 1 was determined by combinations of the two effects (E1 + E2 where E1 = the first effect and E2 = the second effect) caused by the veiling luminance. The results of Series 2, shown as curve 2 in Figure 4, were determined entirely by the first effect (E1) of the veiling luminance, which increases foveal adaptation.

The difference in the luminance difference thresholds for the two curves in Figure 4 (i.e., E1 + E2 − E1 = E2) plotted as curve 3, therefore, gives the increase in the luminance difference threshold determined only by the second effect (E2), which was caused by the veiling luminance, and it increased the apparent luminance of the object and its background.

Two curves (Laf and Leq) in Figure 5 show an extrapolation of curves 2 and 3, respectively, in Figure 4 based on additional experiments (*17*). The figure can be used for practical design purposes.

The luminance difference threshold for a uniform field (a standard field) is obtained from these results by adding two luminance difference thresholds, one for the luminance that is projected onto the observer's fovea and the other for the equivalent veiling luminance caused by the surrounding part of the uniform field and superimposed on the field of view.

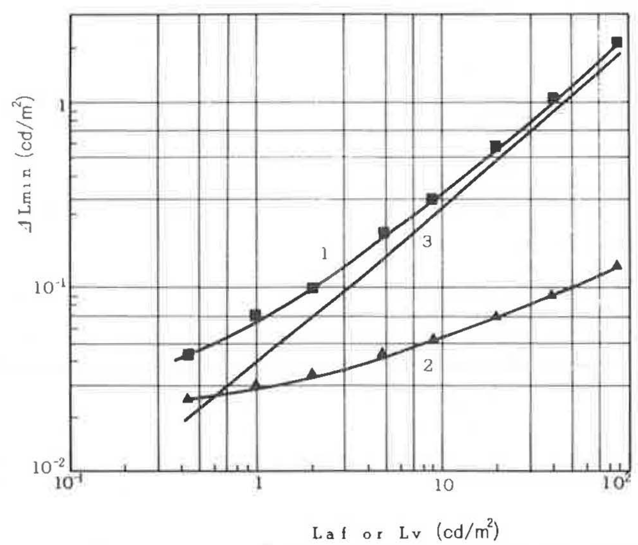


FIGURE 4 Luminance difference threshold as a function of the physical veiling luminance (Lv) located between the object and the observer's eye, or of the foveal luminance (Laf), where Lv = Laf. Curve 1 indicates the function when the object was seen through the physical veiling (Lv) located between the object and the observer's eye. Curve 2 indicates the function when the object was seen without the physical veiling. During the observation, the fovea of the observer's eye was adapted fully to the foveal luminance (Laf).

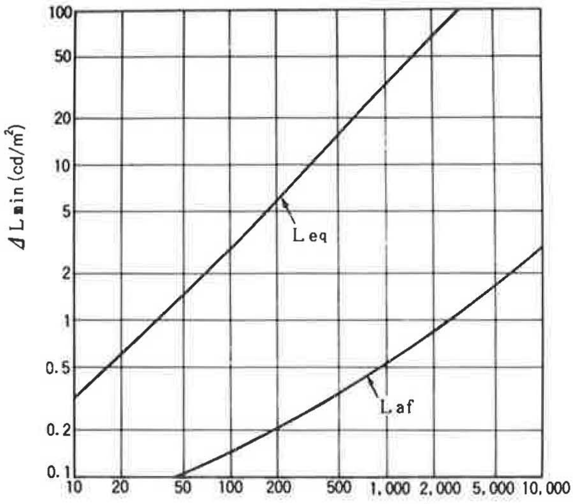


FIGURE 5 Extrapolation of curves 2 and 3 in Figure 4, based on the additional experiments, to a range of horizontal axis (Laf or Leq) of 10,000 cd/m^2 for design purposes.

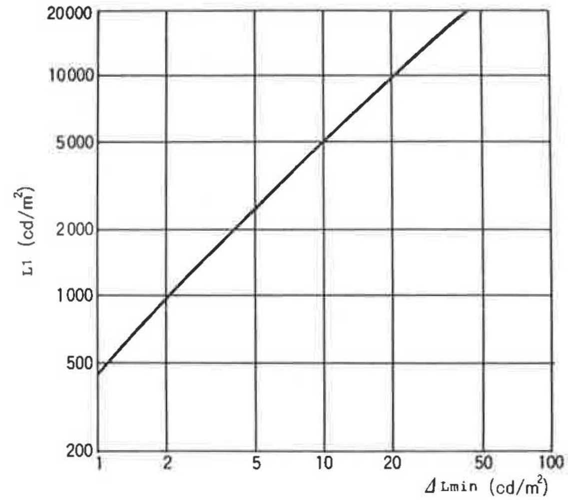


FIGURE 6 Relationship between the equivalent luminance of the standard field (L1) and the luminance difference thresholds Δ Lmin.

The luminance to which the observer's fovea is adapted is the sum of the luminance of the uniform field and the equivalent veiling luminance [calculated by Moon and Spencer's formula (*18*)] caused by the surrounding part of the uniform field. The equivalent veiling luminance for the uniform field therefore differs with the angular size of the uniform field.

Figure 6 shows the luminance difference threshold for a uniform field with an angular size of 20 degrees × 20 degrees thus obtained. [The experimental conditions were different from those of the experiments by Schreuder (*2*) on which the CIE Recommendations for Tunnel Lighting (*19*) were based. The aim of the experiments, however, was to mediate the complex luminance field conditions and the uniform conditions and consequently the differences were cancelled.]

METHOD FOR DERIVING THE EQUIVALENT LUMINANCE OF THE STANDARD FIELD

Based on the experimental results, the equivalent luminance of the standard field (L1) for any complex luminance field can be derived in the following manner (*20*):

1. Measure the equivalent veiling luminance (Leq) for the complex luminance field by means of a luminance meter equipped with a Fry-Pritchard-Blackwell type of glare lens (*21*);
2. Read off, from curve 3 in Figure 4, the value of the luminance difference threshold that corresponds with the value of Leq [Δ Lmin(Leq)];
3. Measure the luminance in the central field (Laf), which is projected onto the observer's fovea (in what follows, the luminance of the road surface in the access zone was taken as Laf);
4. Find, from curve 2 in Figure 4, a value for the luminance difference threshold that corresponds with the value of Laf [Δ Lmin(Laf)];
5. Calculate the sum of the two luminance difference thresholds Δ Lmin = [Δ Lmin(Leq) + Δ Lmin(Laf)];
6. Find, from Figure 6, the value of the equivalent luminance of the standard field (L1) that corresponds with the sum of the luminance difference thresholds Δ Lmin = [Δ Lmin(Leq) + Δ Lmin(Laf)].

An example of how to derive the equivalent luminance of the standard field at the access zone of a tunnel is presented next.

1. With a luminance meter equipped with the glare lens, a luminance value for Leq of 250 cd/m^2 is obtained at the access zone of a tunnel.
2. From the curve (Leq) in Figure 5, a value for Δ Lmin (Leq) of 7.2 cd/m^2 that corresponds with the value for Leq of 250 cd/m^2 is read off.
3. With a normal luminance meter with a small aperture, say 3 degrees, a value (Laf) of 3850 cd/m^2 for the luminance of the road surface to which the driver's eyes approaching the tunnel entrance are assumed to be adapted is measured.
4. From the curve (Laf) in Figure 5, a value for Δ Lmin(Laf) of 1.4 cd/m^2, which corresponds with the value for Laf of 3850 cd/m^2, is read off.
5. By calculation, a value of 8.6 cd/m^2 for the Δ Lmin as the sum of Δ Lmin (Leq) for Leq of 7.2 cd/m^2 and Δ Lmin (Laf) for Laf of 1.4 cd/m^2 can be obtained.
6. Finally, from Figure 6, a value for the equivalent luminance of the standard field (L1) of 4300 cd/m^2 that corresponds with the Δ Lmin can be derived for this particular entrance to the tunnel.

From the two curves in Figure 5 and the curve in Figure 6, Figure 7 was constructed (*20*). From Figure 7 it became obvious that Laf had only a minor effect on the equivalent luminance of the standard field (L1) at higher values for Leq. The dots in the figure were obtained by measurements at actual motorway tunnels, to be described later, and give a general picture of the range of Leq and Laf under practical conditions.

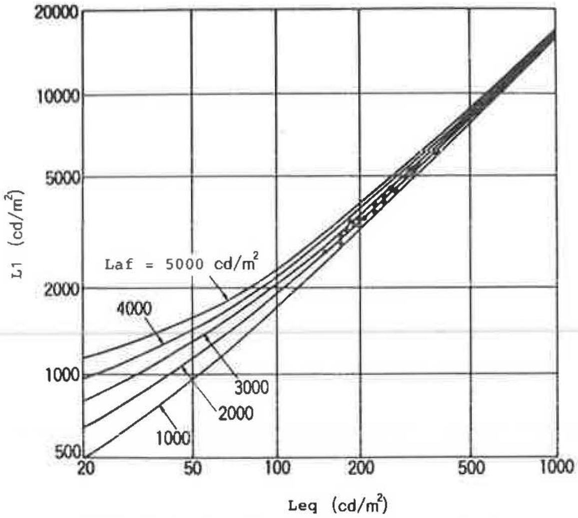
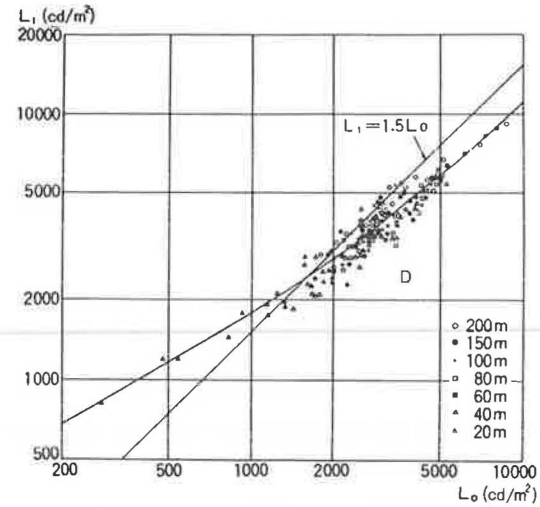


FIGURE 7 Relationship between the equivalent veiling luminance (Leq) and the equivalent luminance of the standard field (L1) (angular size of 20 degrees × 20 degrees) with the foveal adaptation luminance (Laf) as parameter. The dots in the figure are taken from measurements at the entrances to 22 actual tunnels.



Lo; Luminance in the access zone (2×10°)
L₁; Equivalent luminance of the standard field
D ; Distance from the tunnel entrance

FIGURE 8 Comparison of the average luminance in the measuring field of 2 × 10 degrees measured at the access zone of actual tunnels (Lo) and the equivalent luminance of the standard field (L1).

MEASUREMENTS AT THE ACCESS ZONE OF 22 MOTORWAY TUNNELS

To investigate the relationship between the values of the equivalent luminance of the standard field (L1) and the luminance in the access zone (Lo) as described in the CIE Recommendations for Tunnel Lighting (*19*), the values that are needed to derive the relevant luminances of the equivalent luminance of the standard field (L1) and the luminance (Lo) were measured simultaneously at the access zone of 22 entrances of actual motorway tunnels and were compared (*20*).

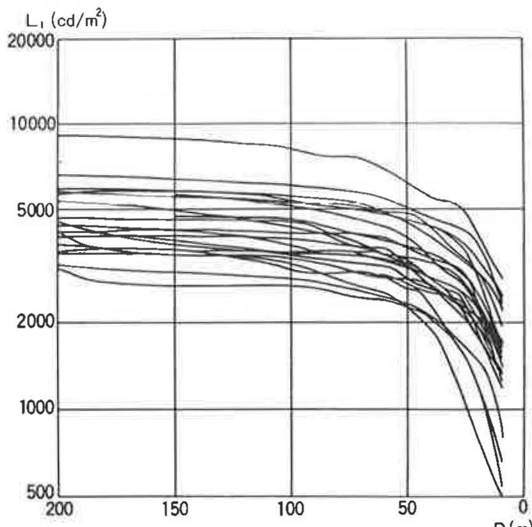
On a car, which was equipped with various measuring devices, variations in the following three luminance values were continuously and simultaneously measured and recorded during the approach to the tunnels. The following measurements were taken between 10:00 a.m. and 2:00 p.m. under actual traffic conditions and various weather conditions (horizontal luminance in the open field was higher than 5×10^4 lx) in September and October 1978:

- The luminance of the road surface about 100 m ahead, as the representation of Laf, with a circular measuring field of 2 × 1.5 degrees;
- Leq, measured by means of the glare lens; and
- Lo with a circular measuring field of 2 × 10 degrees.

Depending on the method used to obtain L1, mentioned already, a great number of combinations for L1 and Lo were recorded from the results of the measurements. To correct for the influence of the front window of the vehicle (a van) that had a transmission factor of 70 percent on the measuring results, all the luminance values were increased by a factor of 1.43. In Figure 8 a portion of the data thus obtained for various distances from the tunnel entrance between 200 and 20 m is plotted.

From the figure it is evident that Lo increased by a factor of 1.5 accurately represents L1 (for a standard field with an angular size of 20 × 20 degrees as employed by Schreuder) with a safety margin of about 10 percent in the higher range of L1. [Van Bommel obtained similar results in his experiments concerning subaqueous road tunnels (*22*).] It has already been pointed out that the measurement of Lo during construction ensures sufficient accuracy for lighting design (*23*).

In Figure 9 the variations of L1 during the approaches to 22 entrances of motorway tunnels thus obtained are shown. Even



L₁; Equivalent luminance of the standard field
D ; Distance from the tunnel entrance

FIGURE 9 Variation of the equivalent luminance of the standard field (L1) with the distance (D) from the tunnel entrance at which L1 was measured.

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Daytime Conspicuity of Road Traffic Control Devices

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In this paper is presented a summary of the results of work carried out in Australia by the Australian Road Research Board (ARRB) and Melbourne University under ARRB sponsorship. The concept of conspicuity and how it forms part of the process of transferring information to the road user is addressed. The means by which conspicuity has been measured are described together with their strengths and limitations. An experimental program that has advanced the understanding of conspicuity and its usefulness is summarized. The major findings of the experiments are discussed in terms of their practical implications for enhancing the daytime conspicuity of road traffic control devices. The review concludes that the important variables that determine the daytime conspicuity of traffic control devices are the complexity of the background, the size of the object, and its contrast with the immediate surroundings. It was also suggested that there are two distinct components of background complexity, clutter and distraction.

The concept of conspicuity, how it can be measured, and the means by which the conspicuity of traffic control devices can be enhanced are addressed. The purpose of this paper is to present a summary of the results of work carried out in Australia by the Australian Road Research Board (ARRB) and at Melbourne University under ARRB sponsorship during the last 10 years and to draw some practical implications from the experimental studies.

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CONCEPT OF CONSPICUITY

The purpose of a traffic sign is to transfer information from the traffic engineer to the driver. In the road environment there is an enormous influx of visual information with which the driver has to contend. It is essential that priorities be allocated to this information so that the driver directs his attention to only those facets that are necessary for his purpose and safety.

The perceptual system must therefore perform a filtering action by which the majority of the visual information is shed and the important and necessary information is attended to and used. What information the driver considers important, and so pays attention to, depends on the message of the sign and its relevance to him at the time. Thus some degree of preattentive processing of all information must occur so that the important information is not discarded but progresses to the stage of consciously being used.

If the information that the traffic engineer wishes to convey to the driver is not visually prominent, legible, and comprehensible at this preattentive level of processing, its importance cannot be evaluated and it will not warrant attention. Conspicuity, then, is the attribute of an object within a visual context that ensures that its presence is noticed at the preattentive level of processing.

Engel *(1)* distinguishes between "sensory conspicuity" and "cognitive conspicuity." Sensory conspicuity is taken as the degree of visual prominence afforded a sign by its crude sensory features (brightness, color, size, legibility), which will ensure that its message content is available at the preattentive level of processing. The cognitive conspicuity of a sign arises