Counterbeam Lighting, a Proven Alternative for the Lighting of the Entrance Zones of Road Tunnels

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The required lighting level in the entrance zone of road tunnels is determined by two main factors: (a) the perception of objects in the tunnel from outside and within a safe stopping distance, and (b) the prevention of the black-hole effect, which can lead to unexpected changes in driver behavior. Detailed analysis of the visual task of object perception shows that counterbeam lighting produces significantly enhanced object visibility because of the high contrast generated. This effect allows a much lower luminance level compared to symmetric lighting. In addition, the luminance yield on the road is much higher for R3-type road surfaces. Compared with conventional symmetric lighting, a substantial saving of energy can be achieved. The requirements for the luminaires and lighting design, the photometric values of counterbeam lighting attainable in practice, and the critical points associated with it are discussed in detail. The conclusions stemming from this discussion and the present experience with counterbeam lighting in Switzerland demonstrate that with this lighting system a high-quality alternative for tunnel entrance zone lighting is available.

The general aim of daytime lighting of tunnel entrances is to ensure adequate visual conditions for the driver to approach and enter the tunnel safely. For a quantitative discussion of this statement, the requisite conditions must be analyzed in detail.

The first requirement for safe driving is that the driver is able to perceive dangerous objects in the dark tunnel mouth from a sufficient viewing distance. This requirement leads to the generally accepted visual task for the driver to see an object with defined dimension and contrast from a safe stopping distance. The majority of research work on tunnel lighting done in the past refers to this visual task (*1*); the recommendations of CIE (*2*) and of many countries are based on it.

The second, but no less important, requirement for safe tunnel lighting is to prevent the so-called "black-hole" effect. If the lighting conditions in the dark tunnel mouth are insufficient, the driver feels insecure. This insecurity can lead to unexpected changes in driving behavior (e.g., decelerating, braking, and changing lanes), resulting in disturbed traffic flow with increased accident probability.

From the practical experience in tunnel lighting in recent decades, it is well known that, under normal circumstances, the black-hole effect can be avoided, if the tunnel lighting level is designed to fulfill the objective visual task of obstacle perception.

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The discussion of the quality characteristics of counterbeam lighting is based on aspects of obstacle perception. This task can be fulfilled with significantly lower lighting levels than with conventional lighting. The conditions for the prevention of the black-hole effect must, therefore, be carefully analyzed for counterbeam lighting.

FUNDAMENTALS OF THE VISUAL TASK

The visual situation of a driver approaching a tunnel portal is schematically shown in Figure 1. The tunnel mouth, the road surface, and the walls are illuminated with mean luminance L_e, the luminance of the entrance zone that is imaged on the fovea of the driver's eye. The original contrast C_{ob} of an object with a luminance L_{ob} is given by

$$C_{ob} = \frac{L_e - L_{ob}}{L_e} \tag{1}$$

With this definition of the contrast, the silhouette vision ($L_e > L_{ob}$) gives positive contrast values, the reversed silhouette vision ($L_e < L_{ob}$) negative ones.

The luminance levels in the access zone will superimpose additional luminances on the driver's fovea:

- The equivalent veiling luminance L_{seq} produced in the human eye lens by the bright surroundings of the tunnel mouth,
- Stray luminance L_{air} from the light scattering of the atmosphere, and
- Stray luminance L_{ws} from the windscreen.

The sum of these stray luminances ΣL_s will increase the adaptation level of the eye and reduce the contrast to the level C_{real}, given by

$$C_{real} = C_{ob} \cdot \frac{L_e}{L_e + (L_{seq} + L_{air} + L_{ws})} \tag{2}$$

For practical purposes, ΣL_s may be approximated by an easily measurable quantity, the luminance of the access zone L_{20}, the mean luminance in a 20-degree cone centered in the tunnel mouth. It has been shown that the correlation between L_{20} and the equivalent veiling luminance L_{seq} is rather good for many cases (*1*). The remaining luminances contributing to ΣL_s can also be expressed in terms of L_{20} (*3*). From these

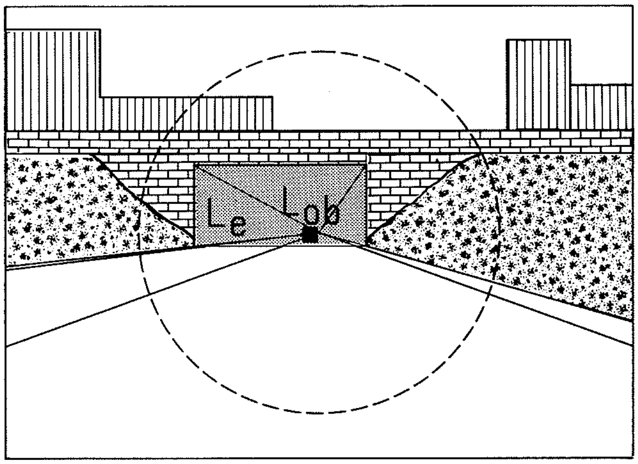

FIGURE 1 Schematic view of a tunnel entrance.

results, it follows that

$$L_{20} = m \cdot \sum L_s \tag{3}$$

where m is a proportionality factor. It is convenient to express the luminance in the entrance zone L_e as a function of the L_{20} luminance or, in other words, to consider the ratio

$$k = \frac{L_e}{L_{20}} \tag{4}$$

From the viewing direction of the driver, objects are seen close to the projection of a plane vertical to the longitudinal road axis. Therefore, object surface elements perpendicular and nearly perpendicular to this axis will contribute most to the total visible area of the object. From this, the luminance of the object L_{ob} can be evaluated approximately from the vertical illuminance E_v, measured perpendicular to the road axis:

$$L_{ob} = \frac{E_v \cdot \beta_{ob}}{\pi} \tag{5}$$

where β_{ob} is the mean luminance factor of the object surface. The object contrast C_{ob} is given from Equation 1 by

$$C_{ob} = 1 - \frac{E_v \cdot \beta_{ob}}{L_e \cdot \pi} = 1 - \frac{\beta_{ob}}{a \cdot \pi} \tag{6}$$

The ratio $a = L_e/E_v$ is the contrast quality coefficient that describes the contrast quality characteristics of the lighting system.

The connection between the required luminance of the entrance zone L_e and the luminance in the access zone (L_{20} or ΣL_s) can be evaluated with different methods (*1,4–6*). The method described in the following has been proposed by F. Sarteel (unpublished) and is based on the CIE analytic model for visual performance (*7*).

The visibility V of an object can be defined as the ratio between the real contrast C_{real} and the threshold contrast C_{th} for the same adaptation level of the eye:

$$V = \frac{|C_{real}|}{|C_{th}|} \tag{7}$$

The visibility can be expressed with help of the relative contrast sensitivity (RCS) function for the background luminance L_b (*7*):

$$\text{RCS}(L) = 100 \cdot \left[\left(\frac{1.675}{L_b} \right)^{0.4} + 1 \right]^{-2.5} \tag{8}$$

Substituting Equations 1–4 and 8 in Equation 7 yields

$$V = \frac{\left| a - \frac{\beta_{ob}}{\pi} \right|}{a \cdot \left(1 + \frac{m}{k} \right)} \cdot \frac{\left[\left(\frac{1.675}{L_{20} \cdot (m + k)} \right)^{0.4} + 1 \right]^{-2.5}}{C_{th}} \tag{9}$$

Equation 9 defines the functional dependence between the required luminance in the entrance zone expressed in k values and the other important quantities. Figure 2 shows the dependence of the k value on the access zone luminance L_{20}. For L_{20} values above about 500 cd/m², k varies slowly, indicating that the normal practice of keeping L_e proportional to L_{20} leads to correct lighting, if the luminance of the entrance zone L_e is kept constant for L_{20} values below about 500 cd/m².

Figure 3 shows the relation between the k value and the original object contrast C_{ob}. The required luminance in the entrance zone L_e depends strongly on the contrast value. Objects with contrast near the threshold value can only be perceived with unrealistically high lighting levels.

In order to demonstrate the influence of the lighting system on the required luminance in the entrance zone, the k value is shown in Figure 4 as a function of the contrast quality coefficient a. The choice of the value of the object luminance factor β_{ob} requires careful verification, because it has a strong nonlinear influence on the k factor. The value 0.5 used in the calculation of Figure 4 was deduced from investigations on

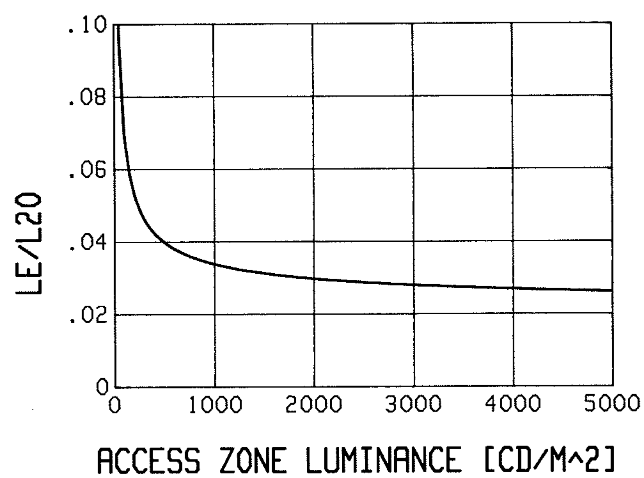

FIGURE 2 Ratio k of entrance zone luminance L_e to access zone luminance L_{20} as a function of the access zone luminance L_{20} (parameters: $m = 0.7$, $V = 1.1$, $C_{th} = 0.13$, $a = 0.6$, $\beta = 0.5$).

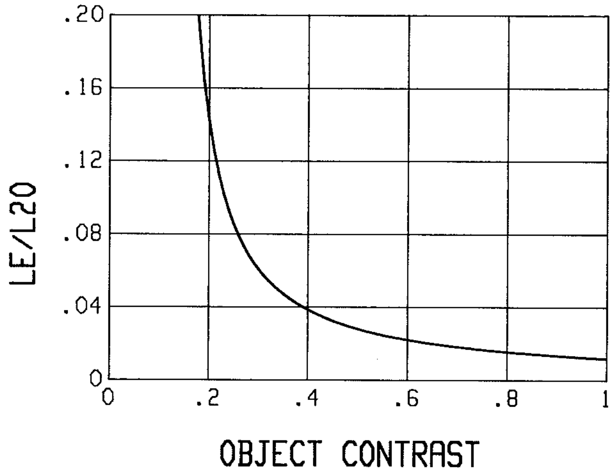

FIGURE 3 Ratio k of entrance zone luminance L_e to access zone luminance L_{20} as a function of the object contrast C_{ob} (parameters: $m = 0.7$, $V = 1.1$, $C_{th} = 0.13$, $L_{20} = 4{,}000$ cd/m^2).

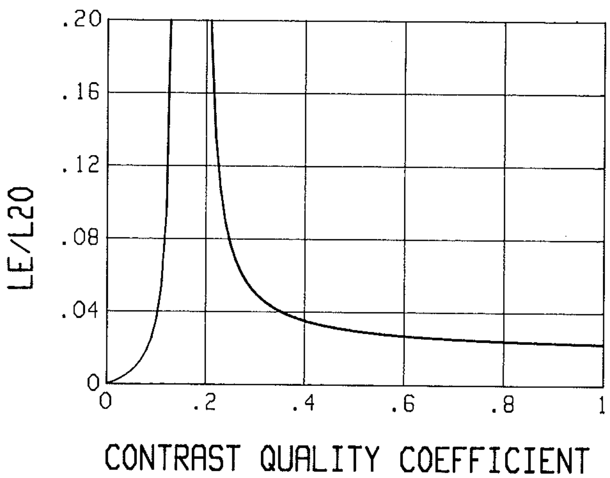

FIGURE 4 Ratio k of entrance zone luminance L_e to access zone luminance L_{20} as a function of the contrast quality coefficient a (parameters: $m = 0.7$, $V = 1.1$, $C_{th} = 0.13$, $\beta = 0.5$, $L_{20} = 4{,}000$ cd/m^2).

the statistical distribution of luminance factors of objects seen in the traffic (*8*) to be a realistic maximum value.

The curve in Figure 4 indicates three different ranges for the contrast quality coefficient a. For low values (between 0 and about 0.1), the required luminance of the entrance zone is low, with strong dependence on a. This range of a values can be realized with so-called "line-of-sight lighting." This type of lighting installation uses luminaires focusing the major part of the flux in the driving direction.

The range of a values higher than about 0.5 is the field of counterbeam lighting. The k values are rather low and the dependence on a is small. This fact is important, because the value of the contrast quality coefficient will vary in practice, depending on the reflection properties of the road surface because of weather and soiling.

In symmetric lighting systems, the contrast quality coefficient lies between about 0.1 and 0.2. For this range, the necessary luminance of the entrance zone must be high. The object contrast in this range is low and varies from positive (silhouette vision) to negative values. In order to get realistic k values, the luminance factors of objects must be limited to those giving a contrast higher than 20 percent (*1*). Objects with luminance factors generating contrasts lower than about 20 percent are invisible in symmetric lighting. To illustrate this fact, the dependence of the k values on the object luminance factor β_{ob} is shown in Figure 5. For $a = 0.12$ (typical for symmetric lighting on R3 road surfaces), objects with luminance factors between 0.35 and 0.45, which are frequent values in practice (*8*), are invisible.

The values of the other parameters of Equation 9 used in the above examples have been chosen arbitrarily, but in accordance with normal practice. However, the correct values for the threshold contrast C_{th}, the visibility V, and the factor m relating the access zone luminance L_{20} to the sum of stray luminances ΣL_s depend on assumptions made for practical conditions such as maximum driving speed, size of objects to perceive, air turbidity, influence of driver's age, and safety level. But the dependence of k on the critical parameter (the contrast quality coefficient a) remains qualitatively unaltered with different values of C_{th}, V, and m, because the relation between them and the k value is quasi-linear. For example, the choice of a higher visibility level leads to a higher value of k for the given lighting system.

QUALITY CHARACTERISTICS OF COUNTERBEAM LIGHTING SYSTEMS IN PRACTICE

Intensity Distribution of Counterbeam Luminaires

The luminous intensity distribution of counterbeam luminaires requires careful design. Because the main part of the luminous flux must be directed opposite to the driving direction, care must be taken to avoid glare. The intensity values

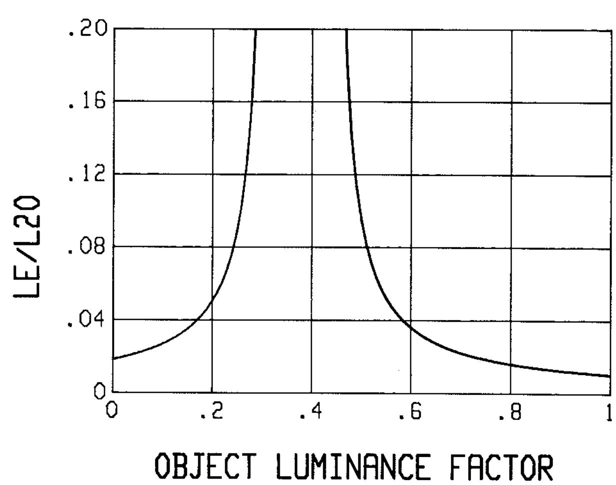

FIGURE 5 Ratio k of entrance zone luminance L_e to access zone luminance L_{20} as a function of the object luminance factor β (parameters: $m = 0.7$, $V = 1.1$, $C_{th} = 0.13$, $a = 0.12$, $L_{20} = 4{,}000$ cd/m^2).

for large gamma angles must be limited, with appropriate shielding to prevent high values of threshold increment.

In addition, the form of the distribution must be chosen carefully to obtain appropriate values of longitudinal uniformity. This result is easier to realize with symmetric distributions. The optimal distributions can only be attained with sophisticated reflector design and small light sources. The low-pressure sodium lamp with its large dimensions is not suitable for this application.

As the counterbeam luminaires commercially available in Switzerland demonstrate, the problems mentioned have been solved satisfactorily. These luminaires fulfill all the necessary requirements for a good-quality lighting system. Figure 6 shows the graph of a typical intensity distribution of a counterbeam luminaire in the C–0/180 plane.

Photometric Values of Real Tunnel Entrance Lighting

In the mountainous areas of Switzerland, tunnel entrances equipped with counterbeam lighting are typically designed for a maximum entrance zone luminance of about 100 cd/m^2. In accordance with Swiss recommendations, this value corresponds to a maximum access zone luminance L_{20} of about 4,000 cd/m^2. This value is rarely exceeded in such situations, with low- or no-sky percentage in the 20-degree field.

The typical photometric values of such an entrance zone lighting in a two-lane unidirectional motorway tunnel for the two reflection tables R1 (concrete) and R3 (asphalt concrete) corresponding to the usual road surfaces are presented in Table 1. For comparison with symmetric lighting systems, similar calculations with symmetric luminaires are also shown. The corresponding installation data are presented in Table 2. The values have been computed with a special computer program designed for tunnel lighting installations. The intensity distributions of the luminaires installed in these tunnels have been measured in the Federal Office of Metrology laboratory. The computed values are in good agreement with the field measurements made on several tunnel sites.

From the values in Table 1, the following conclusions can be drawn:

- Road surfaces with asphalt concrete of R3 type are better suited for counterbeam lighting. The higher specular factor leads to an increased luminance yield and therefore to a better contrast quality factor.
- Compared with symmetric lighting, the counterbeam lighting gives about 40 percent higher luminance yield for R3 surfaces. This higher luminance is important with regard to energy savings.
- The value of the vertical illuminance E_v originates to a large extent from the indirect contributions from the walls and the road surface. This fact should be taken into account in computations for the design of counterbeam lighting installations. Otherwise, unrealistically high values for the contrast quality coefficient are calculated.
- The attainable contrast quality coefficient is normally sufficiently above the critical limit value of 0.5. Care has to be taken in tunnels with R1 surface and high interreflection from the walls and the ceiling. Thus, the wall luminance should not be higher than the recommended values.
- The glare restrictions of the CIE recommendations with a threshold increment lower than 15 percent can easily be fulfilled.
- The uniformity values in the entrance zone with small luminaire distances are well within the limits of the recommendations. Care has to be taken at the end of the transition zone with luminaire distances of about 10 to 15 m. If the recommended values could not be attained, the problem can be solved by the use of smaller lamp wattages in the same luminaire and smaller luminaire distances.

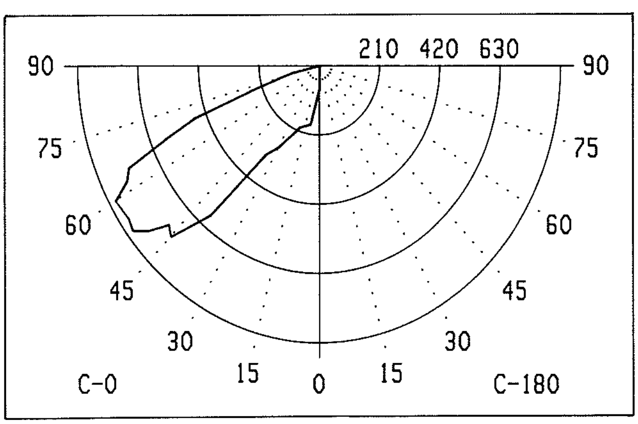

FIGURE 6 Luminous intensity distribution of a counterbeam luminaire in the C–0/180 plane.

In summary, it has been demonstrated that a high-quality lighting installation can be produced with appropriate and well-designed counterbeam luminaires.

CRITICAL POINTS CONCERNING COUNTERBEAM LIGHTING

Counterbeam lighting is relatively new, especially in countries other than Switzerland, and it has been used on only a few sites to date. In our country, the first tunnel lighting with this system was installed about 15 years ago and today there are about 40 tunnels with counterbeam lighting, providing several years of practical experience. So, in discussions with specialists from other countries, a number of questions and doubts arise that must be cleared up. In the following, the most important of these are now discussed in detail.

Influence of Daylight in the Portal Zone

The daylight penetrating into the first few meters of the entrance zone produces a high amount of vertical illuminance that destroys the contrast properties of the counterbeam system. For a quantitative evaluation of this effect, the vertical illuminance produced by daylight in a typical tunnel entrance was measured at a high daylight level and the object visibility was calculated using Equation 9 in relation to the distance from the tunnel mouth. The viewing conditions are expressed by the ranges of luminance factors for which objects are invisible because of insufficient contrast for the given ratio k. From the curves in Figure 7, the overall probability of seeing an object in a counterbeam system is better than in a symmetric

TABLE 1 PHOTOMETRIC VALUE OF TUNNEL LIGHTING INSTALLATIONS

Luminaires			CBS		SYM	
R-Table			R1	R3	R1	R3
Direct contributions from luminaires						
Road luminance	L_e	(cd/m²)	99.9	123	97.8	85.9
Horizontal illuminance	E_h	(lx)	953	953	1190	1190
Vertical illuminance	E_v	(lx)	14.6	14.6	555	555
Indirect contributions from the walls						
Road luminance	L_e	(cd/m²)	5.15	2.97	9.63	5.59
Horizontal illuminance	E_h	(lx)	59.0	59.0	109	109
Vertical illuminance	E_v	(lx)	42.1	42.1	78.5	78.5
Indirect contribution from the road surface						
Vertical illuminance	E_v	(lx)	105	45.0	135	107
Total						
Road luminance	L_e	(cd/m²)	105	126	107	91.5
Left wall luminance	L_{wl}	(cd/m²)	86.5	86.5	95.4	95.4
Right wall luminance	L_{wr}	(cd/m²)	87.5	87.5	96.3	96.3
Horizontal illuminance	E_h	(lx)	1010	1010	1300	1300
Vertical illuminance	E_v	(lx)	162	102	768	740
Contrast quality coeff	$a=L_e/E_v$		.648	1.23	.139	.123
Min. contrast qual. coeff	a_{min}		.563	.895	.119	.105
Overall uniformity	U_o		.766	.614	.834	.718
Threshold increment	TI	(%)	5.00	4.14	2.26	2.95
Longitudinal uniformity	$U_l(1)$		.968	.949	.993	.975
Longitudinal uniformity	$U_l(2)$		.968	.988	.991	.985

SYM: symmetrical luminaires, CBS: counterbeam luminaires.

one. The zone of luminance factors for invisible objects is situated in a range in which they are less frequent in practice.

Object Visibility

It has often been mentioned in discussions that the assumptions about the luminance of objects described earlier are not consistent with the appearance of real objects seen in traffic. In the derivation of the fundamental formulas, it was stated that from the viewing direction of the driver, the projection of the surface of a complex object was seen. Therefore, surface parts that are nearly perpendicular to the road and the driving direction contribute most to the visible area. For these surface parts, the assumptions made in Equation 5 are accurate. So, the contrast of the visible area of most real objects found on the road will not deviate strongly from the contrast of a vertical flat object.

As a proof, measurements of the contrast distribution of the visible area of different objects were performed in a tunnel entrance with counterbeam lighting. The objects were cylinders, spheres, and cones, painted with two different matt paints with luminance factors of 0.2 and 0.5, respectively. The measurement results are presented in Table 3 and the corresponding photograph of the setup in Figure 8. As an example of an object with complex surface and reflection characteristics, a photograph of a body lying on the road is shown in Figure 9.

A second point to discuss is the visibility of objects such as fallen cargo and small cars behind a truck, shadowing a part of the road behind it. First, the perception of objects in flowing traffic is a dynamic process. Fallen cargo would be in the shadow of the truck for only a few 10ths of a second. When the shadow of the truck has passed it, the object is revealed again on the bright road. Small cars behind a truck become dangerous only if their speed decreases relative to other traffic. In this case, they leave the shadowed region behind the truck and become normally visible. In addition, cars and motorcycles with very different materials and surface tilt angles are

TABLE 2 INPUT DATA FOR THE CALCULATION

	Row:	1	2
Suspension height of luminaires	(m)	6.00	6.00
R- coordinate in the row	(m)	1.83	5.63
S- coordinate	(m)	60.00	60.00
Distance of luminaires	(m)	3.00	3.00
Luminous flux of lamps	(klm)	50.00	50.00
Maintenance factor		0.70	0.70
Angular position of luminaires:			
Angle to traffic direction	(°)	0.0	0.0
Angle to road plane in the C-90 plane	(°)	0.0	0.0
Angle to road plane in the C-0 plane	(°)	0.0	0.0
Road geometry: The road contains 2 lanes of 3.75 m width, numbered from left to right. The overall width of the road is 7.50 m.			
Reflection properties: Road surface: R-table R1 q_o = .10 R-table R3 q_o = .08 Wall surface: R-table R1 q_o = .15 luminance factor β = .45 Interreflection factor k_{ir} = 1.30			
Coordinates of tunnel walls: R - coordinate left: -1.00 m, right: 8.50 m Height of calculation field left: 5.00 m, right: 5.00 m			

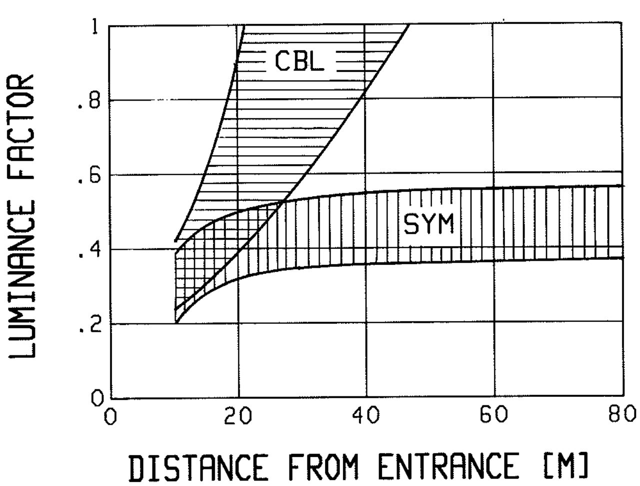

FIGURE 7 Zone of invisible objects defined by the range of their luminance factors as a function of the distance from entrance: Curve 1, symmetric lighting, $k = 0.1$, $a = 0.12$; Curve 2, counterbeam lighting, $k = 0.025$, $a = 0.8$.

objects with so-called "self-sustaining contrast." At least one part of them would produce sufficient contrast to be seen.

Black-Hole Effect

The influence of the black-hole effect may be more important for traffic safety than the visibility of small objects. From accident statistics, it is well known that collisions with objects lying on the road are rare. For that reason, the prevention of the black-hole effect is especially important for counterbeam lighting, for which the necessary luminance for object perception is significantly lower than in symmetrical lighting systems.

First, the visual impression of a tunnel entrance is not only a function of road luminance. The driver's overall sense of security also depends on the design of the portal and the surroundings, the visibility of the borders of the road, visual attention control, and other factors. A well-designed tunnel portal will contribute a lot to the prevention of the black-hole effect.

On the other hand, the influence of the luminance level on the black-hole effect should not be neglected. Practical experience with Swiss counterbeam tunnel lighting shows that the majority of the drivers normally notice no black-hole effect, provided that the luminance level is in accordance with the recommended value of $k = 2.5$ percent and the entrance zone is well designed. Accident statistics (*9,10*) confirm this. The accident rate in tunnels illuminated in accordance with the recommendations is lower than on the open road.

The experience with the black-hole effect in Switzerland differs strongly from the results of an investigation carried out in the United States (*11*). In this study, the threshold for the black-hole effect was found with significantly higher lighting levels. This divergence cannot be explained at present and the visual conditions for the prevention of the black-hole effect should be investigated in further detail. The variations in driving practice in different countries may be one of the reasons for the discrepancies observed.

TABLE 3 CONTRAST DISTRIBUTION ON THE VISIBLE AREA OF DIFFERENT OBJECTS IN COUNTERBEAM LIGHTING

	ß = 0.22	ß = 0.50
Cylinder with horizontal axis	.76 .78 .76 .89 .89 .89 .93 .93 .93 .94 .94 .94 .98 .98 .98	.51 .46 .44 .79 .78 .77 .84 .84 .84 .88 .88 .88 .94 .94 .94
Cylinder with vertical axis	.88 .92 .91 .89 .93 .90 .89 .93 .91	.80 .84 .82 .81 .85 .83 .82 .86 .83
Sphere	.81 .86 .89 .87 .91 .92 .91 .93 .94 .93 .95	.54 .70 .78 .71 .81 .84 .82 .86 .87 .86 .90
Cone	.91	.81

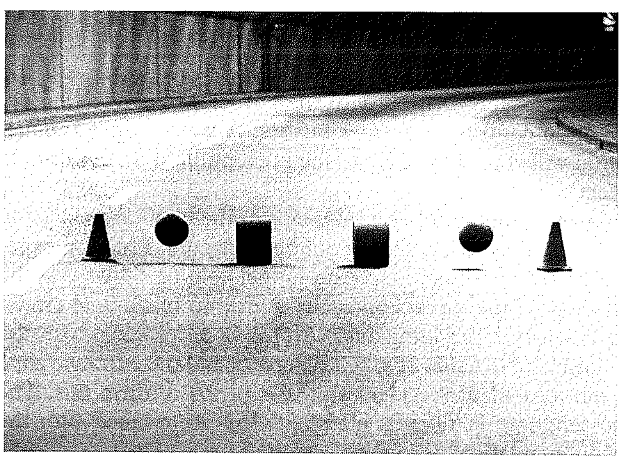

FIGURE 8 Photograph showing the contrast of different objects in counterbeam lighting.

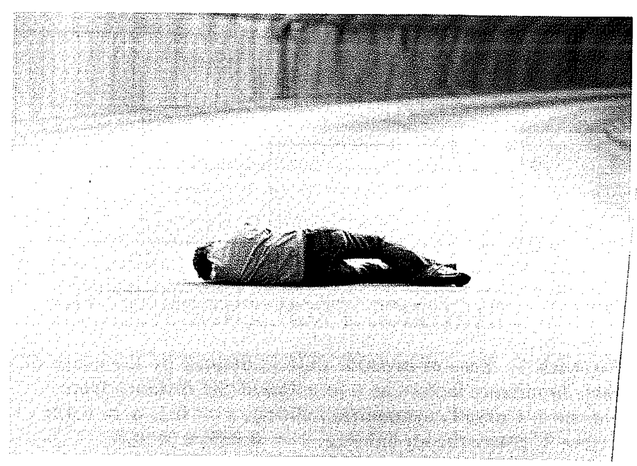

FIGURE 9 Photograph showing a body lying in counterbeam lighting as an example of an object with complex surface structure.

Uniformity of Luminance on Wet Road Surface

If the road surface is wet, the image of the luminaire rows reflected on the road is noticeably brighter in counterbeam lighting systems. However, the road surface is more often moist than totally wet. On a moist surface, the reflected image is not as distinct as on a totally wet one. On the other hand, the mean luminance of a moist road surface is also significantly higher for counterbeam lighting. As is well known in practice, the poor uniformity can be well compensated by the higher luminance level.

Visibility of Road Markings

If the road markings are retroreflective, their visibility may be poor and not only in counterbeam lighting. Observations in the interior zones of tunnels with fluorescent tube luminaires indicate that the retroreflective road markings are only clearly visible if the cars dipped-beam headlights are on.

In the case of regular white-paint road markings, their visibility is much better in counterbeam systems. The specular factor of the painted road surface is higher than that of the unpainted road, which leads to a higher luminance yield for the marking and, therefore, to a better negative contrast.

Counterbeam Lighting in Tunnels with Two-Directional Traffic

In tunnels with two-directional traffic, the entrance zone for one direction will be the exit zone for the other direction. For a driver reaching the exit zone, the counterbeam lighting will appear as line-of-sight lighting, a system also with enhanced contrast quality. The luminance yield of this lighting is about 50 percent lower than with counterbeam lighting. The required luminance in the exit zone must be at the same level as the interior zone. Therefore the luminance of the exit zone designed for the entrance zone level in the other direction is sufficient in any case.

Calculation of Photometric Values

The calculation of the photometric values of tunnel lighting installations can be accomplished, in principle, with the same methods and tools as for street lighting (*12*). The main difference is that in tunnel lighting computations the indirect contributions from the walls, the road surface, and possibly the ceiling have to be borne in mind. In case of counterbeam lighting, the resulting vertical illuminance is an especially important parameter because the contrast quality is composed mainly of the indirect contributions as the figures in Table 1 indicate.

The computation of the indirect contributions can only be performed with some assumptions about the spatial distribution of the light reflected back from the walls and the road surface. The choice of diffuse reflection characteristics can lead to differences between computation and measurements that are larger than the commonly stated uncertainty of 10 to 15 percent. This can be corrected by the introduction of an overall interreflection factor k_{ir}, as has been done in the calculations for the figures presented in Table 1.

CONCLUSIONS

Analysis of the visual task of the driver clearly shows that there is a fundamental difference in object visibility between counterbeam and conventional symmetric lighting. In symmetric lighting, a whole class of objects on the road may become invisible if their luminance factors generate contrasts below about 20 percent. On the other hand, counterbeam lighting produces sufficient contrast for nearly all real objects likely to be found on the road. Beyond that, counterbeam lighting provides safe object perception with a luminance level at the entrance zone significantly lower than with symmetric lighting.

The reduction of the ratio between the luminance at the entrance zone and the luminance at the access zone that is allowed for counterbeam lighting depends on the estimation of the black-hole effect. The new CIE recommendations (*2*) will apply a rather conservative practice, with recommended reductions compared with symmetric lighting of 17 to 30 percent. The experience from lighting practice in Switzerland shows that a reduction of 50 percent can be allowed without any impact on traffic safety.

The use of counterbeam lighting for the entrance and transition zone of road tunnels leads to a substantial reduction of energy consumption. With an assumed reduction of the k value of 50 percent and the increased luminance yield of about 30 percent, the power consumption of a counterbeam lighting installation will be about one-third that of a conventional symmetric system.

The current state-of-the-art in luminaire construction and lighting design guarantees a sufficiently high quality of counterbeam lighting installations. The majority of critical points concerning this type of lighting has been discussed and the associated problems solved.

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