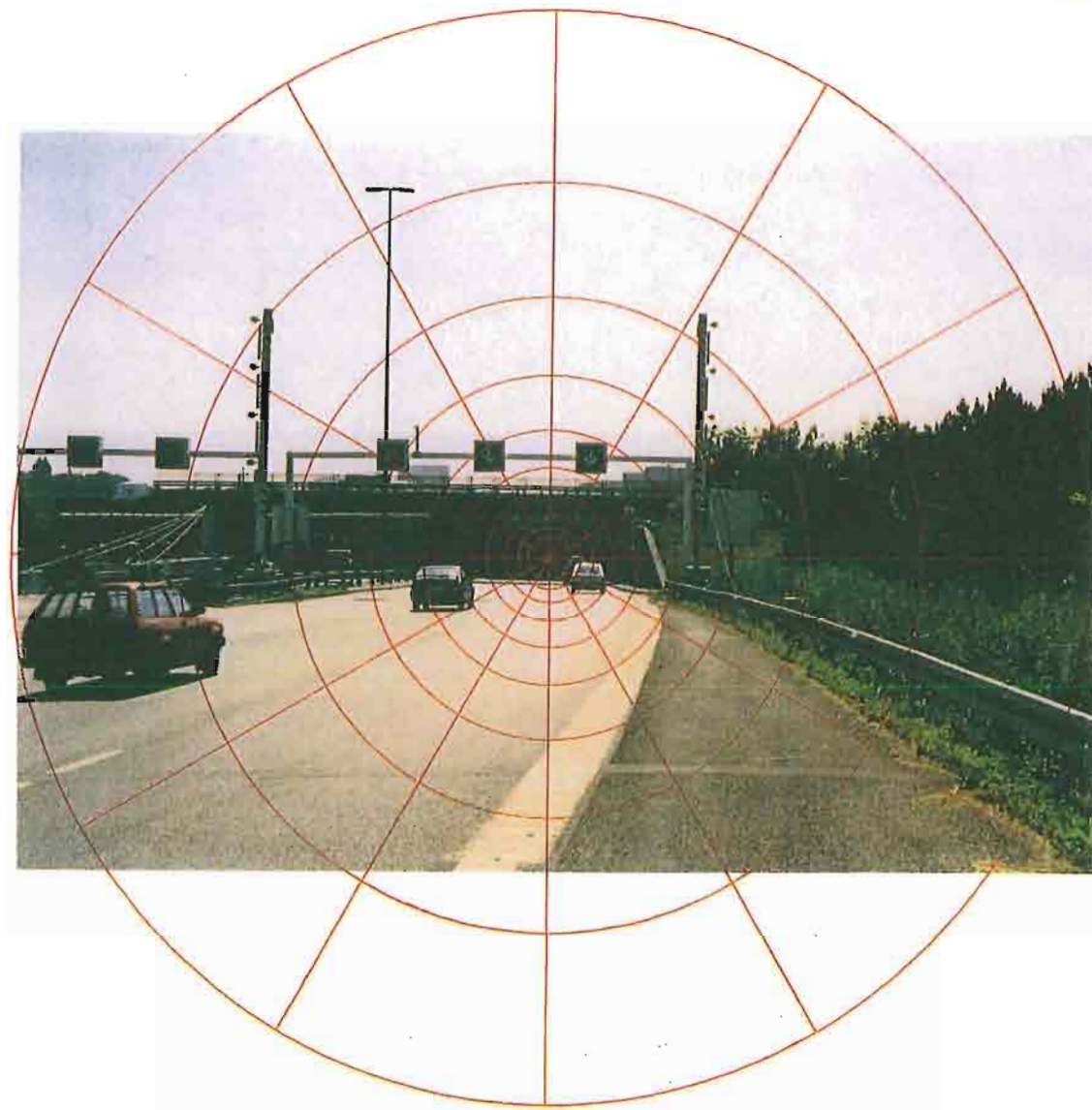




Road tunnel lighting

Common Nordic guidelines

Report No. 4: 1995

Committee 61: Bridges and tunnels, subcommittee tunnels

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Common nordic guidelines

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Foreword

NVF Committee 61, Bridges and Tunnels, has set up a Sub-Committee whose task is to prepare draft guidelines for the design, construction, operation and maintenance of traffic tunnels.

The Sub-Committee has previously prepared NVF report No. 6, "Ventilation af vejttunneler" ["Ventilation of road tunnels"] (1993), which, after minor revisions, will appear in English in 1995.

The Sub-Committee consists of permanent members, supplemented by specialists to give the reports a high technical standard.

For the present report on tunnel lighting the Sub-Committee had the following composition:

Akademiing. Jens Vejlby Thomsen, Road Directorate, Denmark.
Director Jens Gudum, Hansen & Henneberg, Denmark.
Dipl.ing. Olli Niskanen, Highway Authority, Finland.
Overing. Erik Norstrøm, Road Directorate, Norway.
Overing. Jan Eirik Henning, Road Directorate, Norway.
Civ.ing. Bernt Freiholtz, Highway Authority, Sweden.
Civ.ing. Peter Aalto, Highway Authority, Sweden.
Civ.ing. Bengt Brännvall, Highway Authority, Sweden.

The report gives an account of the objectives and functional requirements for lighting installations and other factors that influence visibility in tunnels for road traffic without cyclists and pedestrians.

The Sub-Committee hopes that the guidelines will be used in the design, renovation and maintenance of lighting installations.

As the guidelines are not a Nordic standard, departures from them can be expected in practice, and their use does not necessarily involve a common standard for lighting installations in road tunnels in the Nordic countries.

The original text of the report is in Danish.

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0 **Resumé**

The report deals with lighting in road tunnels for motorized traffic without cyclists and pedestrians.

The report first describes the primary aim of the lighting - to ensure traffic safety by illuminating all important objects during the entire passage.

The technical requirements for the lighting, by day and by night, with the associated definitions of zones and zone luminances, are then given.

The tunnel is divided into a threshold zone, a number of transition zones, an inner zone and an exit zone.

For each zone, requirements are set up for the carriageway luminance as a function of the adaptation luminance in the open, the speed and the traffic intensity. In addition, requirements are proposed for the luminance of the tunnel walls and the limitation of glare and flicker effects of the installation.

On the basis of the technical requirements, the dimensioning, stepping and control of the lighting installation are dealt with.

An account is also given of the form of the installation, including the components to be supplied with emergency power, and other matters affecting visibility in the tunnel.

Finally, the use of daylight screens at the tunnel entrance to facilitate the transition from daylight to the tunnel lighting level is treated.

The report concludes with a section on maintenance and three examples of calculations of the adaptation luminance in the stopping distance from the tunnel entrance.

1 Objectives and functional requirements

The objective of lighting in road tunnels is to ensure that traffic can enter, pass through and leave the tunnel, by day or by night, with the same level of safety as on the adjacent roads. To achieve this it is necessary for the carriageway to be clearly visible throughout the length of the tunnel, and that the carriageway and tunnel walls give a clear picture of the road.

It is also important that the road markings (road stripes) are clearly visible, i.e. there must be sufficient contrast between the painted markings and the road surfacing.

Finally, it is important that objects on the carriageway are visible at a sufficient distance, i.e. there must be adequate contrast between the object and the carriageway and/or tunnel walls.

To achieve these objectives, the lighting must meet the following requirements:

- The lighting shall give the carriageway an adequate luminance level, and the luminance shall be uniformly distributed over the carriageway, in wet as well as dry conditions.
- The angle of incidence of the light relative to the line of sight shall be such as to give high visibility to the road markings, in wet as well as dry conditions.
- The lower part of the tunnel wall must receive an adequate level of luminance.
- The lighting must not give rise to glare.
- The lighting must not produce flicker.

2 The function of the tunnel lighting

The most important function of the tunnel lighting is to illuminate the tunnel sufficiently to enable the drivers to see all that needs to be seen during the entire passage of the tunnel.

Visibility and lighting are most critical during the day, because the eye, accustomed to daylight, cannot immediately adapt to the relative darkness of the tunnel.

Because it takes time for the eye to adapt, it is necessary for the light intensity to decline from daylight to the lower level in the tunnel over a certain distance.

How long this distance should be, and what levels of illumination are needed while traversing it, depend on the speed and the light intensity in the open at the tunnel entrance.

3 Definition of zones and luminances

To describe the necessary lighting in the tunnel sections, a number of zones, each with a specific lighting requirement, have been defined as shown schematically in Figure 1.

Furthermore, values for the braking distance are determined on the basis of the regulations for road geometry that apply in the country in question.

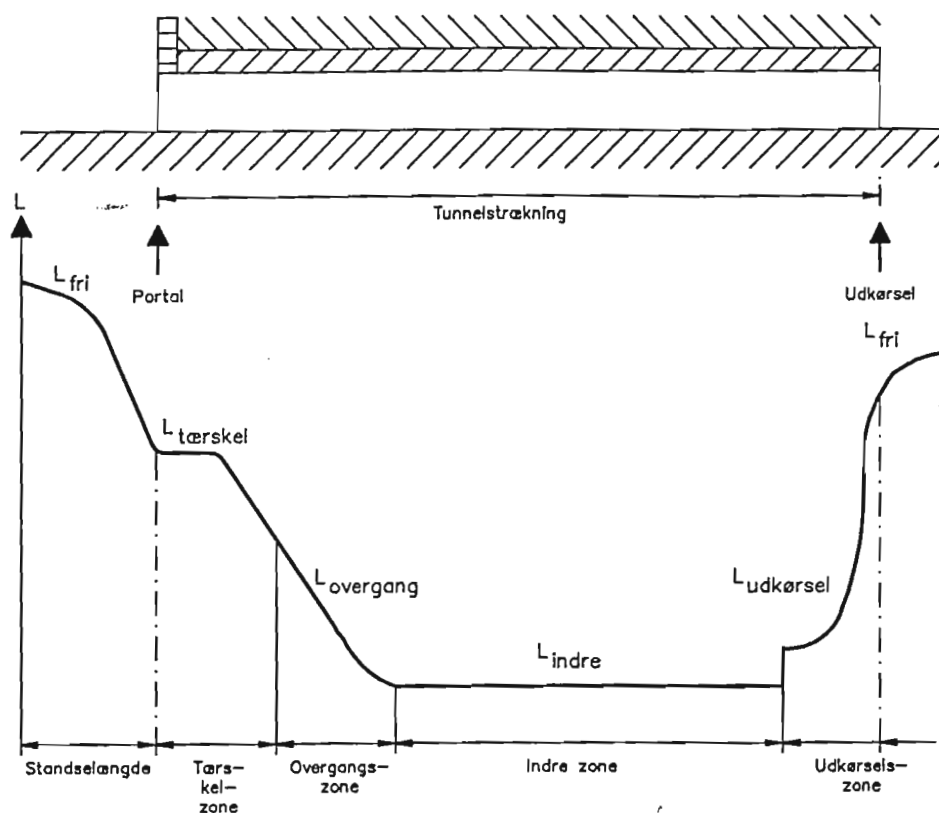


Figure 1

3.1 Adaptation luminance (L_A)

The adaptation luminance is the luminance to which our sight is accustomed in the open at a stopping distance from the tunnel entrance.

3.2 Threshold zone and threshold zone luminance (L_T)

The threshold zone is the section of the tunnel that is visible before one drives into the tunnel; its length is equal to the stopping distance.

The threshold zone luminance is the necessary carriageway luminance in the tunnel if one is to be able to see a stopping length ahead when approaching the tunnel entrance.

3.3 Transition zone and transition zone luminance (L_o)

The transition zone follows the threshold zone, and is the section in which the luminance declines to the level in the inner zone. The transition zone luminance is the carriageway luminance necessary to be able to see a stopping length ahead from any point in the threshold zone and the transition zone.

3.4 Inner zone and inner zone luminance (L_i)

The inner zone lies between the transition zone and the exit zone. The inner zone luminance is the carriageway luminance necessary for an acceptable level of traffic safety in the tunnel by day.

3.5 Exit zone and exit zone luminance (L_{UD})

The exit zone is the last part of the tunnel, in which the eye begins to adjust to the outdoor lighting level.

The exit zone luminance is the carriageway luminance necessary to prevent an excessive contrast between the luminance in the tunnel and the luminance in the open.

4 Requirements for zone lengths and zone luminances by day (maintained values)

4.1 Adaptation luminance L_A

To determine the required luminance in the threshold zone of the tunnel, it is necessary to determine the adaptation luminance.

In the braking distance up to the tunnel entrance, the adaptation of the eye is primarily determined by the size of the tunnel opening in the visual field and the luminance of the surfaces (especially the carriageway) which are near the line of sight; it is determined to a lesser degree by the tunnel surroundings and any skylight above the tunnel.

At high speeds with long stopping distance the tunnel opening fills a smaller part of the visual field than at low speeds and short stopping distance. With a free horizon above the tunnel opening, the sky appears closer to the line of sight than with buildings or trees around the tunnel entrance.

The adaptation luminance thus depends both on speed and the tunnel surroundings, so that high speed and a free horizon give the highest adaptation luminance, and low speed and high buildings the lowest adaptation luminance.

There are three methods for determining the adaptation luminance L_A .

Method 1:

L_A is determined on the basis of empirical correlations with speed and surroundings.

A set of empirical levels for the adaptation luminance is given in Table 1, in which the surroundings are divided into 3 categories and speeds into 2 intervals.

Table 1. Empirical adaptation luminance L_A in cd/m^2 with different surroundings and at different speeds

Speed	50-80 km/h	80-110 km/h
Surroundings		
Free horizon	$\leq 5000 \text{ cd/m}^2$	$\leq 6000 \text{ cd/m}^2$
Low buildings, bushes	$\leq 4000 \text{ cd/m}^2$	$\leq 5000 \text{ cd/m}^2$
High buildings, trees	$\leq 3000 \text{ cd/m}^2$	$\leq 4000 \text{ cd/m}^2$

The method is rapid but approximate, and does not take factors specific to the tunnel entrance into account.

Method 2:

The adaptation luminance is determined as the mean luminance L_{20} in a 20° wide circular field around the line of sight when one is at the braking distance from the tunnel entrance.

The method requires a perspective drawing or photo of the tunnel entrance and its surroundings, and a measurement or calculation of the areas and luminances of the various surfaces.

In CIE 88, 1990 (1), it is suggested that a choice be made between three stopping lengths (60, 100 and 160 m), corresponding to three speeds (60-70, 90 and 110 km/h respectively).

It is further proposed that the surroundings be divided into sky, road and other areas, and that L_{20} be calculated as:

$$L_{20} = \gamma * L_G + \rho * L_R + \varepsilon * L_E$$

where γ is the area of sky as a % of the visual field

ρ is the carriageway area as a % of the visual field

ε is the remaining area as a % of the visual field

L_G is the luminance of the sky

L_R is the carriageway luminance

L_E is the luminance of the surroundings

The following are approximate magnitudes of various luminances, which differ slightly from the estimated values for the Nordic countries given in Sect. 13:

Sky	8-16	kcd/m ²
Carriageway	3-5	kcd/m ²
Rocks	1-3	kcd/m ²
Buildings	4-8	kcd/m ²
Fields	2	kcd/m ²

The method takes the characteristics of the specific tunnel into account, but if a result better than that obtainable by method 1 is to be achieved, the luminances of the various areas in the visual field must be chosen correctly. However, the method involves making the systematic error of giving equal weights to all surfaces in the visual field, regardless of their position relative to the line of sight.

Method 3:

The adaptation luminance is determined by giving the luminances of the various surfaces weights depending on their position in the visual field, as in calculating the veiling luminance.

The method is based on the assumption that the sensitivity of the retina is affected by the surroundings in the same way that the eye is affected by glare, where the equivalent veiling luminance is a measure of the glare effect.

The calculation of the veiling luminance for determining the threshold zone luminance is given in an appendix to CIE-88-90, and the method has been further developed and tested in a number of Norwegian tunnels, as described in EFI report TR3728(2).

It is proposed to go a step further and omit the calculation of the veiling luminance; instead, the luminances in the visual field are weighted in the same way as in the calculation of the veiling luminance.

The method requires, as in Method 2, a perspective drawing or photograph of the tunnel approach and surroundings, together with a determination of the luminances of the various surfaces.

With the help of a polar diagram (Figure 2) the visual field is divided into surfaces that contribute with the same weight, and the mean luminance L_{FL} of each surface evaluated. The adaptation luminance L_A is then determined by calculating the mean value of the calculated surface luminances.

$$L_A = (1/n) \sum_{1}^n L_{FL}$$

The method has not yet been used in practice, but it should give a better result than Method 2, and can be recommended if a more accurate value of L_A than that obtainable from Method 1 is desired.

4.2 Threshold zone and threshold zone luminance L_T

The necessary luminance in the threshold zone L_T , besides being the adaptation luminance in the stopping distance from the tunnel entrance, is dependent on the adjustment of the eye when approaching the tunnel entrance. The higher the speed, the less time the eye has to adjust from the luminance in the open to the luminance of the tunnel entrance and its surroundings.

This means that the necessary luminance in the threshold zone depends on the speed, and must be a higher percentage of the adaptation luminance when the speed is high than when it is low.

The length of the threshold zone must be equal to the stopping length and is thus determined by the speed.

Table 2 gives the length of the threshold zone and the ratio of the threshold zone luminance L_T to the adaptation luminance L_A at various speeds.

Table 2. The threshold zone length and the ratio k between the threshold zone luminance and the adaptation luminance, at various speeds

Speed	Threshold zone length	$k = L_T/L_A$
50 km/h	40 m	0.04
60 km/h	50 m	0.05
70 km/h	65 m	0.05
80 km/h	80 m	0.06
90 km/h	100 m	0.06
100 km/h	120 m	0.07
110 km/h	150 m	0.07

As Table 2 shows, the threshold zone luminance should normally be from 4% to 7% of the adaptation luminance.

With low traffic flows, the tabulated values can be reduced by approx. 50%, especially at speeds near the lower end of the range.

The threshold zone luminance L_T shall be present in the first half of the zone; in the second half it can decline uniformly to 40% at the end of the zone, cf. Figure 5.

4.3 Inner zone luminance L_i

The necessary inner zone luminance by day is chiefly dependent on the speed and intensity of the traffic.

Table 3. Luminance level in the inner zone as function of speed and traffic intensity

Carriageway mean luminance in cd/m ²		Traffic intensity		
		Low	Medium	High
Speed km/h	50-70	1	2	3
	70-90	2	4	6
	90-110	4	8	12

The luminances adopted in practice vary from country to country.

The lighting level should be increased under difficult visibility or traffic conditions, e.g. dark walls, approach and exit lanes in the tunnel, etc.

In long tunnels, where the drive-through time exceeds 2-3 minutes, the inner zone luminance by day can be reduced to the nighttime level, as shown in Table 7.

4.4 Transition zone length S_0 and luminance L_0

The transition zone is necessary to enable the eye to adjust to the lower lighting level in the tunnel. The length of the transition zone is currently determined by using the equation given below. This equation appears to be in need of revision, as it gives zone lengths that are considered excessive.

The transition zone length S_0 is at present determined by the speed (V) in km/h, the threshold zone luminance (L_T) and the inner zone luminance (L_I). It is given by:

$$S_0 = \frac{V}{3.6} \cdot \left(\frac{L_T}{L_I} \right)^{-0.71} - 1.9 \text{ (m)}$$

The luminance L_0 at any point in the transition zone can be determined from the following expression:

$$L_0 = L_T \cdot \left(1.9 + 3.6 \cdot \frac{S}{V} \right)^{-1.4}$$

where L_T is the threshold zone luminance in cd/m²

S is the distance from the start of the transition zone in m

V is the speed in km/h

L_0 as a function of the distance d , determined by the speed, can be read off from Graph 1.

The carriageway luminance in the transition zone can be reduced in steps, provided that the luminance at any point is above the L_0 curve and the ratio between the luminance of one step and the next does not exceed 3 (in special cases 5).

4.5 Exit zone length and luminance

The exit zone is the last part of the tunnel, in which the eye begins to adjust to the higher outdoor level. The carriageway and tunnel walls in the exit zone can thus seem dark. This effect can be compensated for by increasing the luminance in the last 60 metres to 5 times the luminance in the inner zone.

Whether this additional luminance is necessary for safety is debatable; it should therefore be considered optional.

5 Other technical requirements (maintained values)

5.1 Distribution of carriageway luminance by day

The distribution of luminance on the carriageway by day shall meet the uniformity requirements for the highest illumination class in the Nordic road lighting regulations, as given in Table 6.

Table 6. Uniformity of the luminance by day

Speed V km/h	Uniformity $L_{\min}/L_{\text{mean}}$		Longitudinal uniformity $L_{\min}/L_{\max}$
	dry	wet	dry
$V \leq 80$	0,4	0,15	0,35
$V > 80$			0,6

5.2 The entire tunnel zone by night

The lighting by night shall meet the requirements for the relevant illumination class in the Common Nordic guidelines for road lighting, as given in Table 7.

Table 7. Luminance and uniformity by night

Surround-ings	Speed km/h	Luminance cd/m ² L _{mean}	Uniformity		Longit. uniformity L _{min} /L _{max} dry		
			L _{min} / L _{mid} dry	L _{min} / L _{mid} wet			
Lighted	V ≤ 80	2	0,4	0,15	0,35		
	V > 80				0,6		
Unlighted	V ≤ 80	1					0,35
	V > 80						0,6

5.3 The luminance of the tunnel walls

As the visibility of the tunnel walls helps the drivers to keep to the traffic lane, and as the walls at the tunnel entrance occupy the greater part of the visual field, it is important that they have a certain luminance.

The tunnel walls should therefore be light in colour and illuminated up to at least 2 metres above the carriageway, so that their mean luminance is at least equal to that of the carriageway. The wall luminance should also be distributed along the tunnel as uniformly as possible.

5.4 Glare

The disability glare from the lighting must be limited in such a way that the Threshold Increment (TI) does not exceed 15%.

The value of TI is calculated from the following expressions:

$$TI = 60 \cdot L_v / L_{\text{mean}}^{0.8} \text{ if } L_{\text{mean}} \leq 5 \text{ cd/m}^2$$

$$TI = 95 \cdot L_v / L_{\text{mean}}^{1.05} \text{ if } L_{\text{mean}} > 5 \text{ cd/m}^2$$

where L_{mean} is the mean luminance of the carriageway and L_v is the veiling luminance from all luminaires in the visual field within 20° above the horizontal.

5.5 Flicker frequency

To avoid unpleasant flicker from the lamps, the distance between them should be such that the frequency with which a vehicle passes them lies outside the range 2.5 - 15 Hz. The distance between lamps at various speeds should lie outside the intervals given in Table 8.

Table 8. Intervals within which the distance between lamps gives rise to flicker

Speed	Flicker interval
50 km/h	0.9 m - 5.6 m
60 km/h	1.1 m - 6.7 m
70 km/h	1.3 m - 7.8 m
80 km/h	1.5 m - 8.9 m
90 km/h	1.7 m - 10 m
100 km/h	1.9 m - 11 m
110 km/h	2 m - 12 m

Flicker avoidance is particularly important in long tunnels; a certain amount of flicker is acceptable in the threshold and transition zones, and in tunnels with a drive-through time of less than 2 minutes.

6 Dimensioning and stepping of the lighting installations

The lighting installations are dimensioned on the basis of the requirements for the operational levels in the various zones.

In the threshold and transition zones, and possibly also in the exit zone, a high level that can be regulated according to the intensity of daylight outside the tunnel is required; in the inner zone, a low level that can be regulated from day-level to night-level is all that is needed.

The lighting installation must therefore be capable of operating at several emission levels or steps, consisting of the basic step - the minimum lighting level throughout the tunnel in daytime - and a number of additional steps, that constitute the supplementary lighting in the entry zones and possibly the exit zone. The basic step is reduced at night to the nighttime level either by dimming all the luminaires or switching off some of them.

The supplementary steps in the threshold and transition zones, and possibly in the exit zone, are coupled in as the intensity of daylight increases, so that the required level of illumination in these zones relative to daylight is maintained (the k values in Table 2).

The number of supplementary steps should be determined by balancing the saving of electricity via a rapid uncoupling of part of the illumination against the cost of adding steps to the installation.

The number of supplementary steps is usually 3 to 5.

With reversible operation in 2-duct tunnels, it should be possible to establish a threshold and transition zone illumination in the exit zone sufficient to permit vehicles to enter the tunnel at the max. permissible speed.

7 Control of the illumination levels

The necessary lighting in the threshold and transition zones is determined by the adaptation luminance.

The adaptation luminance can in principle be determined by measuring the veiling luminance at the stopping distance from the tunnel entrance, from the observation point of the driver. Equipment for measuring the veiling luminance is available, but is not normally used in connection with tunnel lighting.

The equipment normally used measures the luminance L_{20} in a 20° field, and is likewise set up at the stopping distance from the tunnel entrance and at the driver's point of observation.

As the carriageway is frequently the part of the visual field that has the greatest influence on the adaptation luminance, the lighting level can also be controlled by the horizontal lighting level on the carriageway. This can be measured by a horizontally oriented photo-cell, screened in the same way as the surroundings screen the carriageway from the sky. This method has the advantage of enabling the equipment to be placed at a distance from the traffic, so that the cell is protected and accessible for cleaning and inspection.

When the measured value rises above or falls below one of the values at which a step is to be coupled in or uncoupled, a control signal shall be given. To prevent coupling in and uncoupling resulting from short-period changes in the illumination, e.g. from drifting clouds, the coupling/uncoupling should be effected with a delay that should be adjustable.

Coupling in could for example be delayed by 5 minutes, and uncoupling by 10 minutes.

It should be made possible to adjust the level at which a given step is coupled in or uncoupled without changing the coupling levels of any of the other steps.

As the adaptation luminances at the two tunnel entrances are often different, it should be made possible to control the lighting levels at the entrances independently.

8 The form of the lighting installations

The luminaires can be mounted either on the walls or the ceiling, and should normally be as high as possible above the carriageway.

The most effective and suitable light sources are fluorescent tubes and high-pressure sodium lamps with clear cylindrical bulbs. Low-pressure sodium lamps can be used, but are less suitable because of their low colourrendering.

Fluorescent tubes can be dimmed to under 10% of their maximum light output; high-pressure sodium lamps can be dimmed to approx. 50% of the maximum.

For the basic lighting level, both low-wattage high-pressure sodium lamps and fluorescent tubes are suitable. For the supplementary steps, high-pressure sodium lamps of higher wattage are suitable.

If fluorescent tubes are used for the basic level, the best optical effect and the maximum uniformity of carriageway luminance is obtained by placing the luminaires in a continuous line along the tunnel, and dimming them at night.

If high-pressure sodium lamps are used, the series of point-lights must meet the requirements for uniformity of carriageway luminance as well as give the lowest 2 metres of tunnel wall as uniform a luminance as possible.

Normally the luminaires will be set up in groups, and the distance between groups will exceed the critical interval for flicker given in Table 8.

In each group, the luminaires needed to give the required illumination level are coupled in. The nighttime level can sometimes be established by dimming all the luminaires to a level below the basic (daytime) step.

The illumination should normally be distributed symmetrically in a vertical plane across the tunnel.

A continuous line of luminaires can have maximum light intensity across the carriageway; a series of point-sources should have maximum intensity diagonally forwards and backwards to the carriageway areas midway between the luminaires.

Luminaires placed at the walls shall illuminate the lowest 2 metres of the opposite wall as well as the carriageway. Luminaires placed in the ceiling can illuminate both walls, but if they are placed close to the walls and the light-source is a series of points, the luminaires should illuminate the opposite wall.

Placing the luminaires at the ceiling vertically above the edge of the carriageway, or on the walls, has the following advantages:

1. The lighting gives the best contrast between the road markings and the road surface.
2. Light reflection by a wet road surface is kept to a minimum, giving a better uniformity of carriageway luminance in wet conditions.
3. The luminaires do not produce reflections in the bonnet of one's own car or in the rear window of the car ahead.

4. The luminaires can be serviced easily without interrupting the traffic.

Counterbeam lighting

Counterbeam lighting is a special form of lighting in the threshold and transition zones, and is described in CIE 88, 1990.

It consists of a beam in the direction opposite to that of the drivers' vision; the aim is to illuminate vertical surfaces as little as possible, to give the maximum contrast with the carriageway surface.

As the carriageway has some reflectivity even when dry, one obtains a given carriageway luminance with a lower light emission, and it is claimed that the increased contrast reduces the required level of carriageway luminance. This gives lower installed power and operational costs, and has resulted in widespread use of counterbeam lighting.

However, counterbeam lighting has a number of disadvantages that may outweigh the above-mentioned advantages. The three most important are:

- Counterbeam lighting reduces the contrast between road markings and the road surface.
- When the road surface is humid or wet, it reflects the luminaires and the uniformity of the carriageway luminance is low.
- Sizeable objects, seen against the much darker background of the carriageway further into the tunnel, have a lower visibility than with normal lighting.

9 Other matters

The following points should be taken into account as they have an important influence on visibility and the form of the lighting installations:

- The road stretch in front of the tunnel entrance should be straight over a length at least equal to the stopping distance.
- The road surface outside the tunnel should be dark over a stretch at least equal to the stopping distance, with a mean luminance coefficient of approx. $0.06 \text{ cd} / \text{m}^2 / \text{lx}$.
- The largest possible surface around the tunnel opening should be vertical (so that snow cannot accumulate on it), and as dark as possible.
- Where possible, dark trees (such as spruce or pine) should be planted near the tunnel opening.
- For economic reasons, the road surface inside the tunnel should be as light as possible when a good contrast with the road markings is to be achieved at the same time.
- The road markings should be light and as retro-reflective as possible, as the effect of the light from the tunnel entrance is hereby utilized to increase the contrast between markings and road surface. The effect can be increased by using reflectors with a strongly retro-reflective surface in the road stripes.
- To avoid monotony in long tunnels, the lighting should vary in level or colour over short stretches at suitable intervals.
- The road alignment of the exit ramp should be a curve, and the external ramp wall, visible from inside the tunnel, should be as dark as possible.
- The tunnel entrance should be as large as possible and funnel-shaped so that it fills as much of the visual field as possible and at the same time admits the maximum amount of daylight into the tunnel.
- To reduce distractions in the visual field, the tunnel ceiling and the installations in it should be dark and nonspecular.

10 Emergency power

In the event of a power failure the permissible speed in the tunnel should be reduced and the corresponding illumination should be supplied by emergency power.

The installation for the emergency-powered part of the lighting should incorporate fireproof cables. This also applies to any lighting for use in connection with reversible operation.

11. Daylight screens at the entrance

The artificial lighting in the threshold zone - and possibly in the transition zone - can be wholly or partly replaced by daylight; this can be done by establishing a covered road stretch in front of the tunnel entrance, with a daylight screen that dims the daylight to the level required in the first part of the tunnel.

A daylight screen can thus reduce the consumption of electricity for the tunnel lighting. However, it is not easy to get a screen with the usual lattice or slat construction to function correctly, as the transmittance in sunny weather differs greatly from that in cloudy conditions.

If the screen is sunlight-tight, the transmittance in cloudy conditions is 4-5 times greater than in sunny weather, when it is approx. 2%. The difference increases the further south the screen is located. If the lattice/slat construction is opened to such an extent that it is not completely sunlight-tight when the sun is high, the transmittance can reach 30%. On the other hand, it can be opened to an extent such that the transmittance when the sun is low is 4-8% in sunny weather and 15-20% in cloudy conditions.

By combining the two types of screen, so that an open, not quite sunlight-tight lattice is followed by a stretch with a sunlight-tight lattice, it is possible to obtain a satisfactory distribution of luminance, avoiding the sensation of driving into a black hole under certain daylight conditions, yet dimming the adaptation luminance so that a significant part of the artificial lighting can be dispensed with.

The form of the screens must be determined by calculations for the specific case.

The possibility of a substantial reduction in the artificial lighting by means of daylight screens increases the further north the location, as the lattice can be opened to an increasing amount of sky.

The advantage of using daylight screens is greatest in open terrain and least in mountainous areas or with high buildings in the vicinity. In areas with snow and ice, problems can arise with icicles and slippery carriageway on the stretch under the screens.

12 Maintenance

The lighting installations should be dimensioned with a maintenance factor of 0.75, and maintained so that the calculated operational values are obtained.

The tunnel walls and the accessible parts of the luminaires should be cleaned at intervals determined on the basis of the daily accumulation of dust and dirt.

The luminaires must be sufficiently watertight (IP class) to enable high-pressure washing down to be used.

The internal surfaces of the luminaires are maintained by light-source series replacement.

The light-sources are replaced in series when they have burned for their economic service life. Information on the service life can be obtained from the manufacturer. The burning time for each illumination level of the installation should be registered.

Burned-out light-sources should be replaced if they result in a carriageway area that is clearly darker than the surrounding areas.

When the road pavement is replaced, the new pavement should not be darker than the pavement it replaces.

The monitoring equipment that controls the lighting should be checked and calibrated at least once per year. The settings of the coupling-in and uncoupling levels for the illumination steps should also be checked and adjusted.

13 Examples of the determination of the adaptation luminance by Method 3

The adaptation luminance is determined on the basis of a tunnel photograph taken from the centre of the right-hand traffic lane at a stopping distance from the tunnel entrance.

The polar diagram (Figure 2) can be used to divide the visual field into areas that contribute equally to the adaptation luminance if the photo format is 10 x 15 cm and the picture was taken with an objective of 28 mm focal length. The polar diagram is laid over the picture as shown in Figures 3, 4 and 5; the centre of the diagram corresponds to the line of sight.

The luminances of the various surfaces in the visual field should be measured in broad daylight, but if these values are not available the following approximate values can be used. These values are adapted to conditions in the Nordic countries, and therefore differ slightly from the CIE values given in Sect. 4.1.

	kcd/m ²
Sky	6 - 12
Carriageway	3 - 6
Rocks	2 - 4
Buildings	1 - 8
Fields, trees	1 - 2
Snow-covered surfaces	8 - 12

The calculation is carried out by first dividing the visual field into the various types of surface (sky, carriageway, etc.), and then in the polar diagram's net, for each surface type, counting the number of sector elements that include that surface type.

The contribution of each surface type to the adaptation luminance is given by:

$$L_{A1} = \frac{n_1}{108} \cdot L_1$$

where n_1 is the number of sector elements in all 9 rings that contain surface type 1.

L_1 is the luminance of surface type 1.

The adaptation luminance is then found by summing the contributions of the various surface types

$$L_A = L_{A1} + L_{A2} + \dots$$

Example 1 The Limfjord Tunnel

The following luminances are estimated from Figure 3:

kcd/m²

A	Sky	10	
B	Carriageway	6	
C	Bushes	2	
D	Road shoulder	4	
E	Bridge facade	2	
F	Tunnel opening	0.1	

Ring	A	B	C	D	E	F	Σ sectors
1		1				11	12
2		3			4	5	24
3	0,5	4,5			5	2	36
4	2,5	4,5			5		48
5	3,5	6		0,5	2		60
6	4	5	0,5	1,5	1		72
7	4,5	3,5	1,5	1,5	1		84
8	5	4	2	1			96
9	5	3	2,5	1,5			108
Ialt	25	34,5	6,5	6	18	18	108

$$\text{Sky: } \frac{25}{108} \cdot 10 = 2,31 \text{ kcd/m}^2$$

$$\text{Carriageway: } \frac{34,5}{108} \cdot 6 = 1,92 \text{ kcd/m}^2$$

$$\text{Bushes: } \frac{6,5}{108} \cdot 4 = 0,24 \text{ kcd/m}^2$$

$$\text{Road shoulder: } \frac{6}{108} \cdot 2 = 0,11 \text{ kcd/m}^2$$

$$\text{Bridge facade: } \frac{18}{108} \cdot 2 = 0,33 \text{ kcd/m}^2$$

Tunnel opening: $\frac{18}{108} \cdot 0,1 = 0,02 \text{ kcd/m}^2$

$L_A =$ $\frac{4,93 \text{ kcd/m}^2}{5000 \text{ cd/m}^2} \approx$

Example 2 The Tingstad Tunnel

The following luminances are estimated from Figure 4:

		kcd/m ²
A	Sky	10
B	Carriageway	6
C	Bushes	2
D	Shoulder	6
E	Bridge	4
F	Tunnel opening	0.1

Ring	A	B	C	D	E	F	Σ sectors
1		2,5			2,5	7	12
2		3,5			3	5,5	24
3	2	4			1,5	4,5	36
4	2,5	5			1,5	3	48
5	3,5	5	1	1	1	0,5	60
6	4,5	5	1	0,5	0,5	0,5	72
7	4,5	5	1	0,75	0,5	0,25	84
8	5	5	1	1			96
9	5,5	5	0,5	1			108
Ialt	27,5	40	4,5	4,25	10,5	21,25	108

$$\text{Sky: } \frac{27,5}{108} \cdot 10 = 2,54 \text{ kcd/m}^2$$

$$\text{Carriageway: } \frac{40}{108} \cdot 6 = 2,22 \text{ kcd/m}^2$$

$$\text{Bushes: } \frac{4,5}{108} \cdot 6 = 0,25 \text{ kcd/m}^2$$

$$\text{Shoulder: } \frac{4,25}{108} \cdot 2 = 0,08 \text{ kcd/m}^2$$

$$\text{Bridge: } \frac{10,5}{108} \cdot 4 = 0,39 \text{ kcd/m}^2$$

$$\text{Tunnel opening: } \frac{21,25}{108} \cdot 0,1 = 0,02 \text{ kcd/m}^2$$

$$\underline{\underline{L_A = 5,51 \text{ kcd/m}^2 \approx 5500 \text{ cd/m}^2}}$$

Example 3 The Gnistäng Tunnel

The following luminances are estimated from Figure 5:

	kcd/m ²
A Sky	8
B Carriageway	5
C Bushes	2
D Shoulder	3
E Mountainside	3
F Tunnel opening	0.1

Ring	A	B	C	D	E	F	Σ sectors
1		3				9	12
2		4			2	6	24
3		4		2	6		36
4		4,5		2,5	5		48
5	2	4,5		0,5	5		60
6	2,5	4,75	0,25	0,5	4		72
7	3,75	4,75	0,5	0,5	2,5		84
8	4	4,75	0,75	0,5	2		96
9	4,5	4,75	0,75	0,5	1,5		108
Ialt	16,75	39	2,25	7	27	15	108

$$\text{Sky: } \frac{16,75}{108} \cdot 8 = 1,24 \text{ kcd/m}^2$$

$$\text{Carriageway: } \frac{39}{108} \cdot 5 = 1,81 \text{ kcd/m}^2$$

$$\text{Bushes: } \frac{2,25}{108} \cdot 3 = 0,06 \text{ kcd/m}^2$$

$$\text{Shoulder: } \frac{7}{108} \cdot 2 = 0,13 \text{ kcd/m}^2$$

$$\text{Mountainside: } \frac{27}{108} \cdot 3 = 0,75 \text{ kcd/m}^2$$

$$\text{Tunnel opening: } \frac{15}{108} \cdot 0,1 = 0,01 \text{ kcd/m}^2$$

$$\underline{\underline{L_A = 4,00 \text{ kcd/m}^2 \approx 4000 \text{ cd/m}^2}}$$

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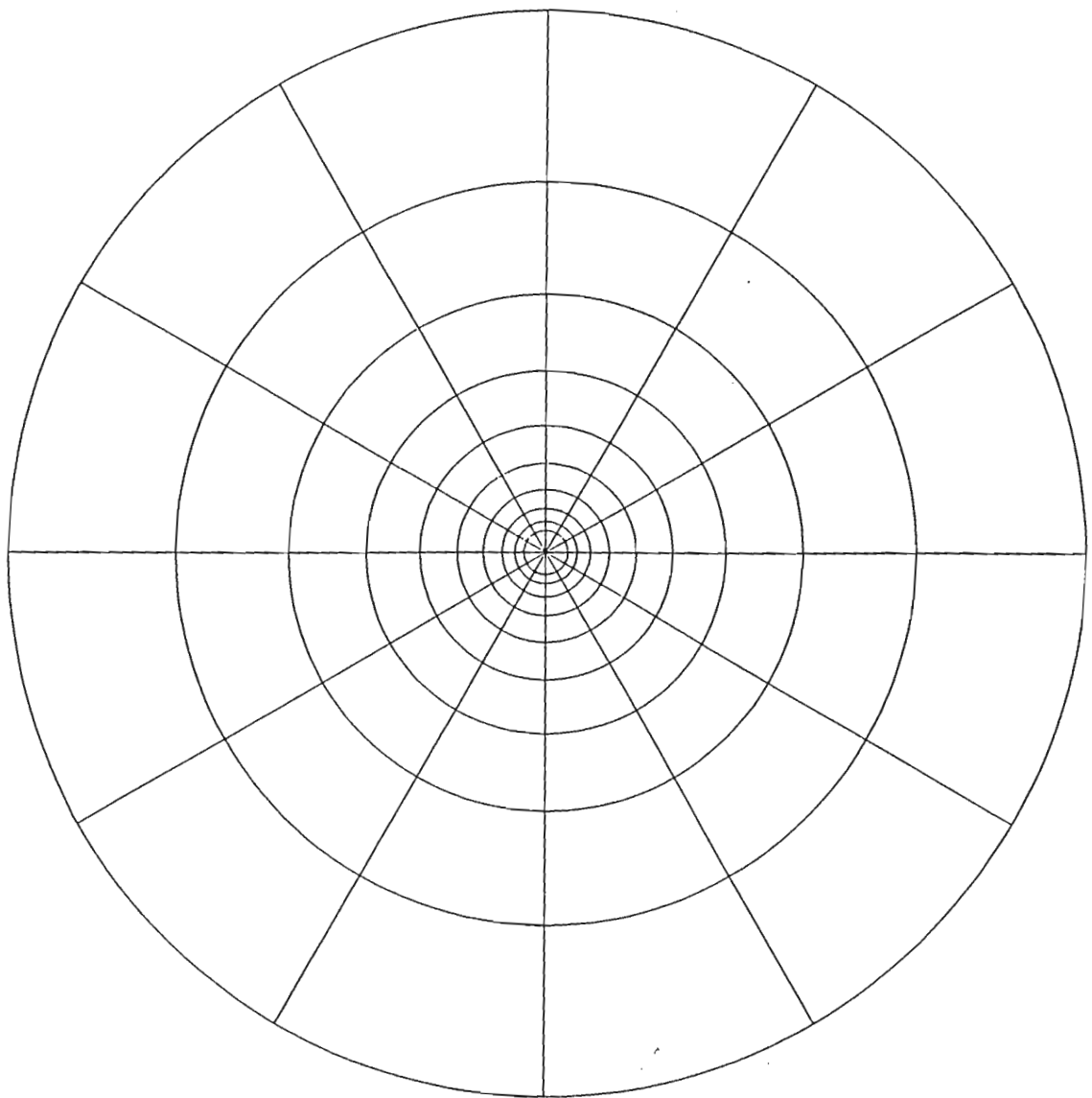


Figure 2

Polar diagram dividing the visual field into segments of equal weight in the calculation of the adaptation luminance. The innermost area (the centre of the visual field) is not taken into account in the calculation.

The scale of the diagram corresponds to a picture format of 10 x 15 cm and an objective of focal length 28 mm. The picture is to be taken at a braking length from the tunnel entrance, at the centre of the right-hand traffic lane, and at a height above the carriageway corresponding to the position of the driver's eye.

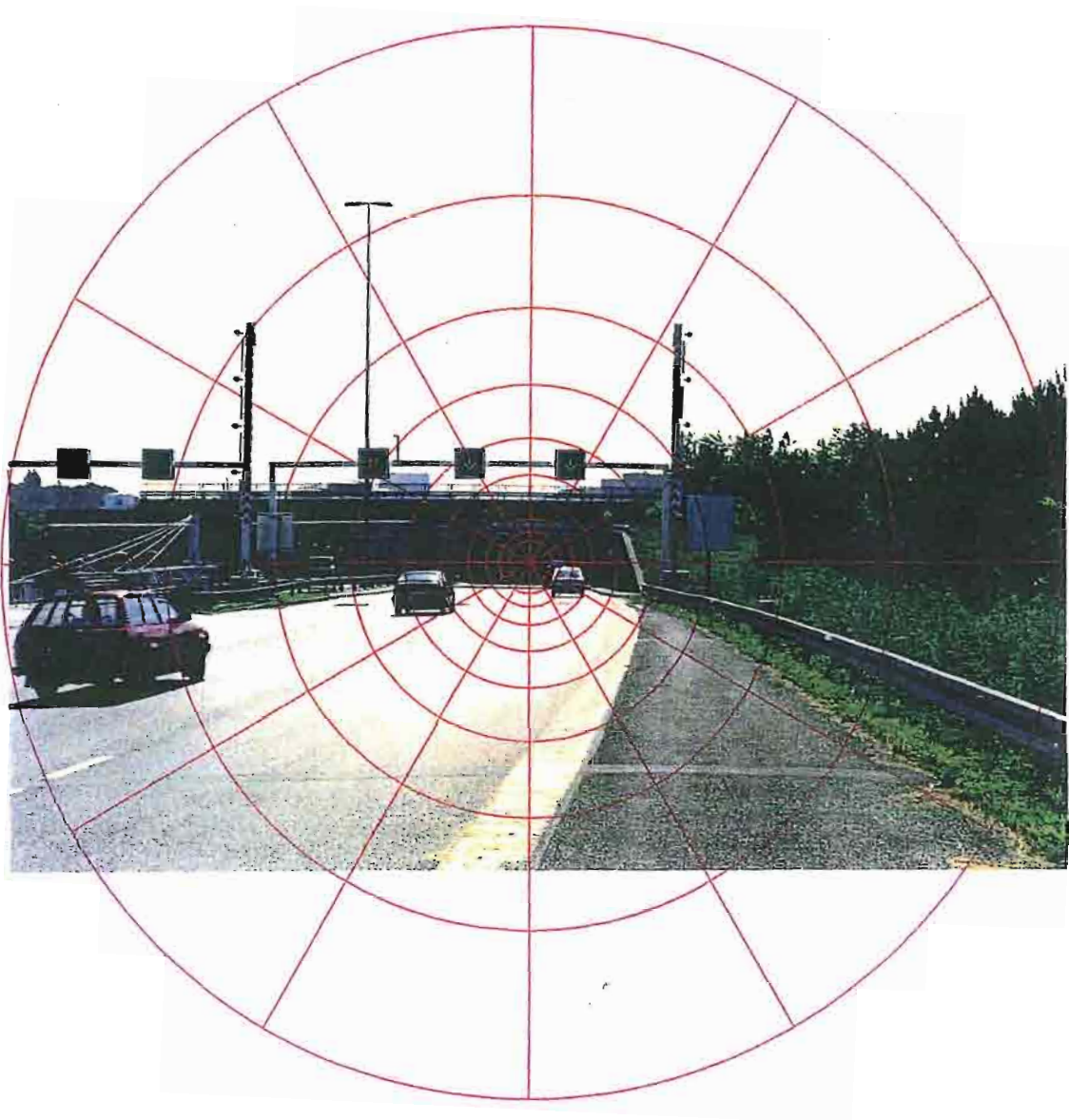


Fig. 3 The Limfjord Tunnel. Photograph taken 100 m from the tunnel entrance

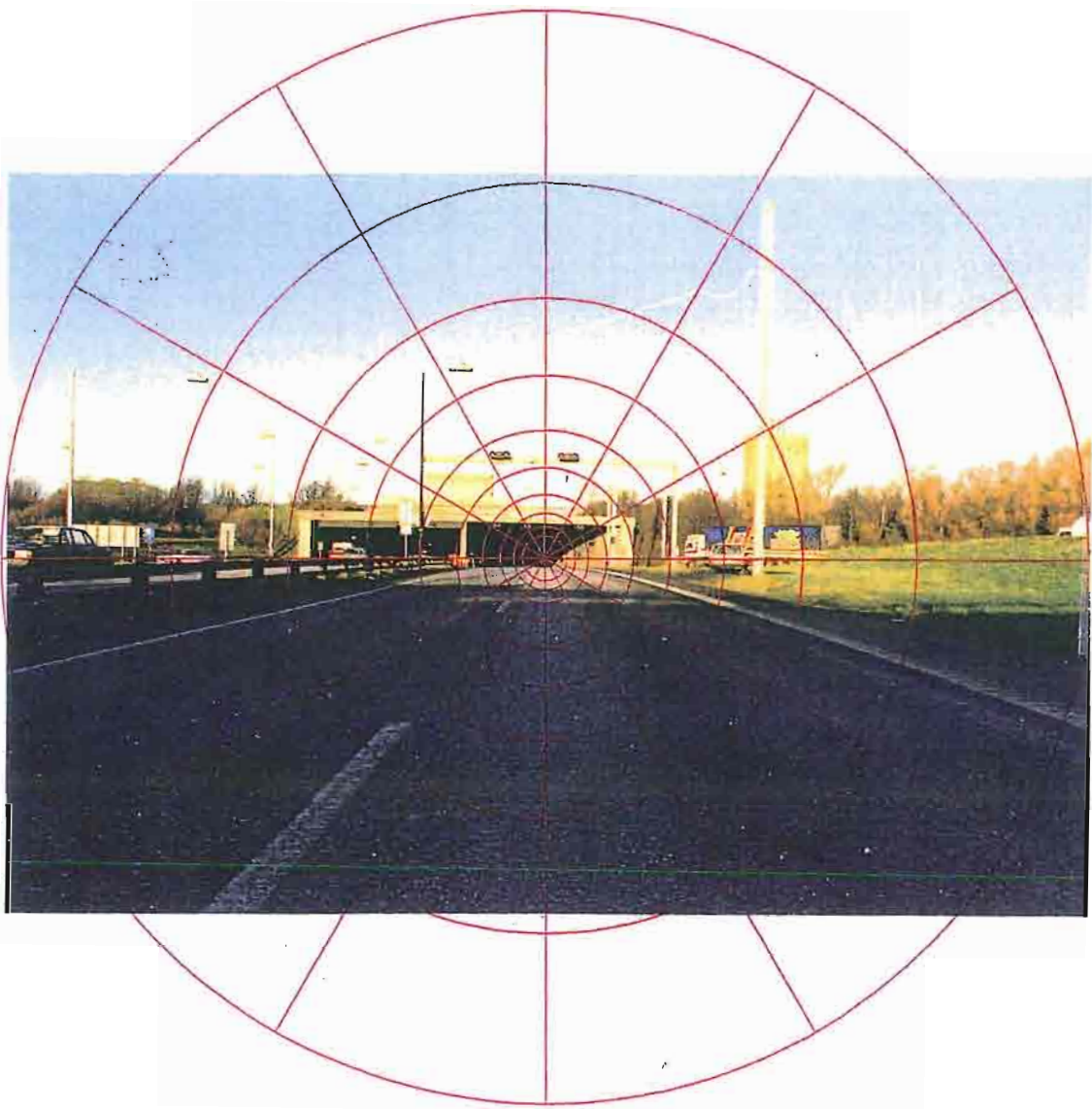


Fig. 4 The Tingstad Tunnel. Photograph taken 110 m from the tunnel entrance

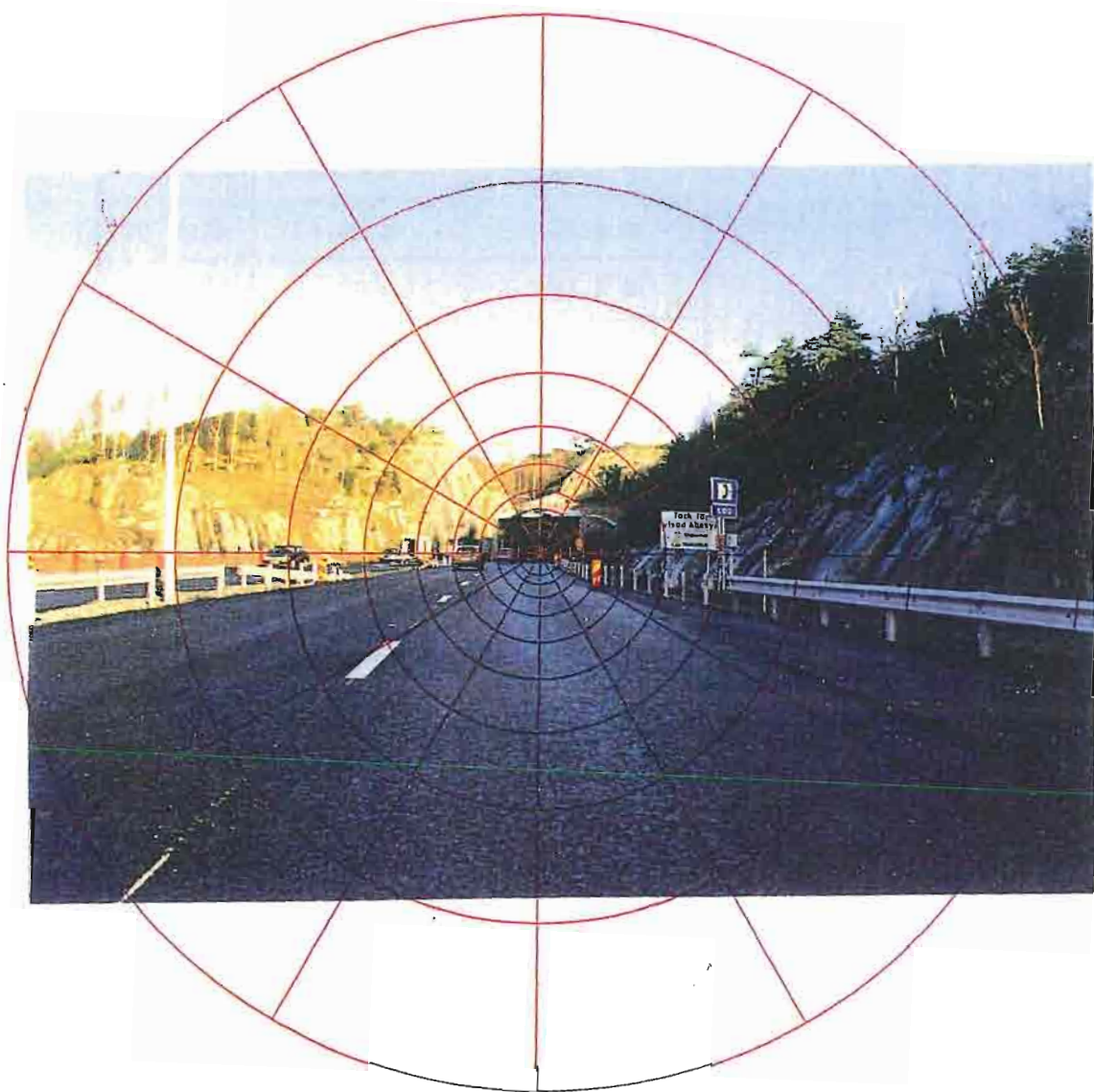
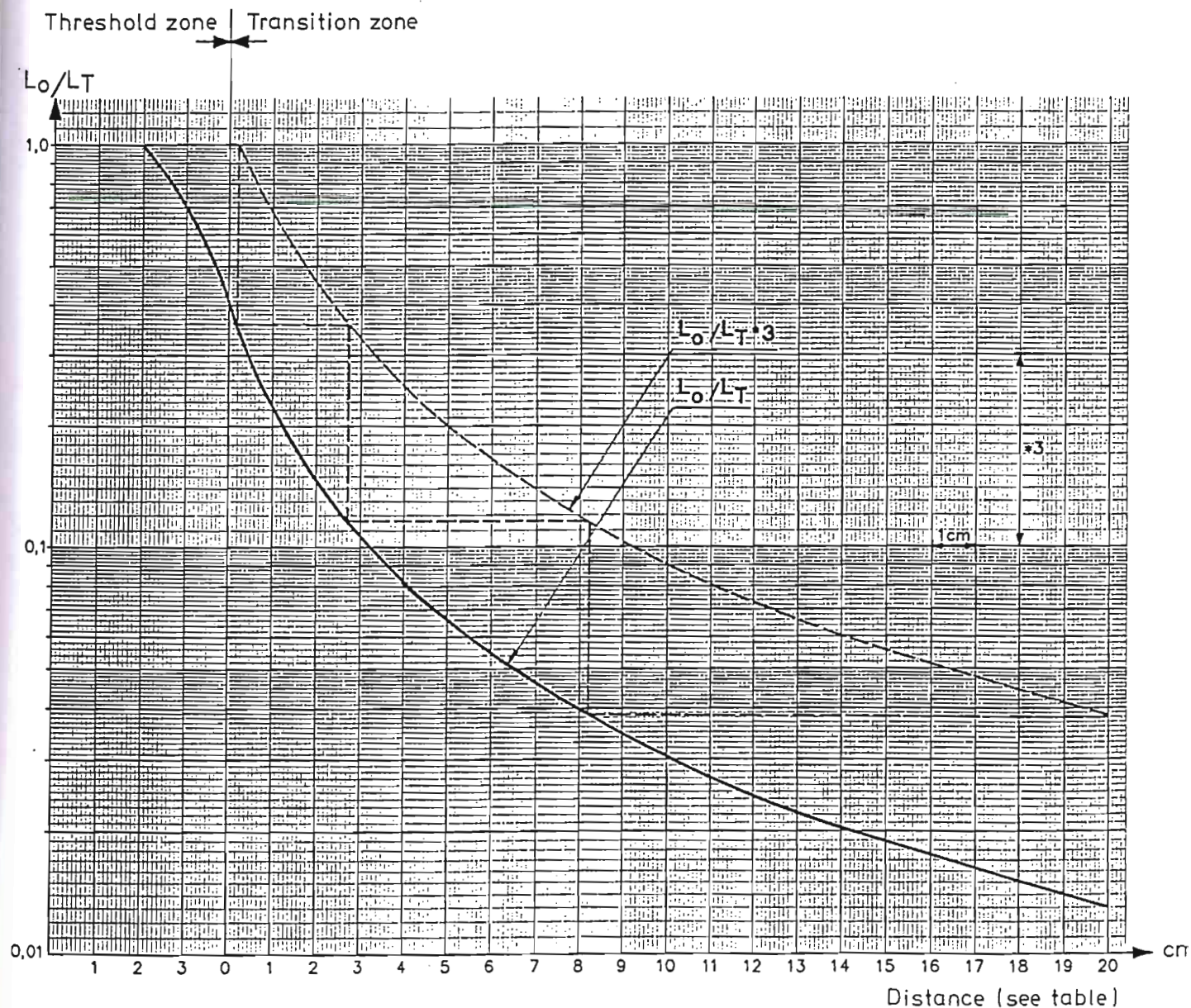


Fig. 5 The Gnistäng Tunnel. Photograph taken 110 m from the tunnel entrance

Graph 1: Needed luminance in the different positions in the threshold and transition zones

Speed	1 cm on the abscissa of the graph corresponds to: In the threshold zone In the transition zone	
50 km/h	10 m	13,9 m
60 km/h	12,5 m	16,7 m
70 km/h	16,25 m	19,4 m
80 km/h	20 m	22,2 m
90 km/h	25 m	25 m
100 km/h	30 m	27,9 m
110 km/h	37,5 m	30,6 m



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ISSN 0347-2485

ISBN 951-726-118-7