Guide to the Lighting of Road Tunnels in Armenia

Road Tunnel Lighting Guide

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The project objective is to reduce energy consumption and greenhouse gas emissions in lighting sector of Armenia via enabling application of modern energy saving technologies and solutions.
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1. Introduction

1.1. Scope

Designs for Lighting Ltd have been commissioned by UNDP to produce this brief guide addressing the practical aspects and considerations for the lighting requirements of road tunnels in Armenia.

With no two tunnels ever being the same in construction or usage this guide should be read as being general guidelines outlining the principles of road tunnel lighting where any unique site specific issues can be addressed alongside the same principles accordingly.

This guide is based on the assumption that any tunnel structures being considered for the installation of a lighting system are as a whole:

- Of a sound construction.
- Structure able to support lighting infrastructure.
- Sufficient maximum traffic envelope to allow lighting infrastructure above.
- Have a power supply of sufficient capacity available.

1.2. Aim of this guide

The aim of this guide is to illustrate to the reader the processes involved in the development, design and analysis of road tunnel lighting together with, in the professional opinion and experience of the author, current best practice recommendations for the lighting scheme and potential equipment involved in achieving energy efficiency for the installation.

From this guide the reader will be able to understand some of the complexities that can occur in producing a compliant road tunnel lighting scheme and any additional or specific considerations that may have to be made during scheme concept, specification, design, installation and operation & maintenance.
2. Terms and Definitions

Access zone
Part of the open road immediately outside (in front of) an entrance portal, covering the distance over which an approaching driver should be able to see into a tunnel.

Access zone length
Distance between the stopping distance point ahead of an entrance portal, and the entrance portal itself.

Access zone luminance \( (L_{20}) \)
Average luminance contained in a conical field of view, subtending an angle of 20° with the apex at the position of the eye of an approaching driver and aimed at the centre of the entrance portal from a point at a distance equal to the stopping distance from the entrance portal at the middle of the relevant carriageway or traffic lane.

Carriageway (aka “Pavement”)
Part of a road normally used by vehicular traffic

Daylight screen
Device that transmits (part of) the ambient daylight
NOTE: Daylight screens may be applied for the lighting of the threshold zone of a tunnel.

Design speed
Speed adopted for a particular stated purpose in designing a road

Emergency lane (aka “hard shoulder”)
Lane parallel to the traffic lane(s), for emergency vehicles and/or for broken-down vehicles

Entrance portal
Part of the tunnel construction that corresponds to the beginning of the covered part of a tunnel or, when open daylight screens are used, to the beginning of the daylight screens

Entrance zone
Combination of threshold zone and transition zone(s)

Exit portal
End of the covered part of a tunnel or, when open daylight screens are used, end of the daylight screens

Exit zone
Part of a tunnel where, during daytime, the vision of a driver approaching the exit is influenced predominantly by the brightness outside the tunnel

Interior zone
Part of a tunnel following directly after the transition zone

Interior zone luminance \( (L_{int}) \)
Average road surface luminance of a transverse strip at a given location in the interior zone of a tunnel

Longitudinal uniformity \( (U_L) \)
Ratio of the minimum to the maximum road surface luminance

Look-through percentage \( (LTP) \)
Area of the apparent exit portal of a tunnel, as a percentage of the area of the apparent entrance portal, when viewed in perspective from the stopping sight distance.
Mixed traffic
Traffic that consists of motor vehicles, cyclists, pedestrians etc.

Overall uniformity \( (U_o) \)
Ratio of the minimum to the average road surface luminance

Parting zone
First part of the open road directly after the exit portal of a tunnel

Portal Luminance \( (L_{20}) \)
The initial principle requirement for the design of a tunnel lighting scheme. The \( L_{20} \) is the luminance through a 20° conical field of view that the driver is exposed to from the stopping distance on the approach to a tunnel.

Speed limit
Maximum legally allowed speed on any given road

Stopping sight distance \( (SSD) \)
Distance needed to bring a vehicle, driving at design speed, to a complete standstill

Threshold zone
First part of a tunnel, directly after the entrance portal

Threshold zone lighting
Lighting of the threshold zone of a tunnel, which allows drivers to see into the tunnel whilst in the access zone

Threshold zone luminance \( (L_{th}) \)
Average road surface luminance of a transverse strip at a given location in the threshold zone of a tunnel

Traffic flow
Number of vehicles passing a specific point in a stated time in a stated direction

Traffic lane
Strip of carriageway intended to accommodate a single line of moving vehicles

Transition zone
Part of a tunnel following directly after the threshold zone

Transition zone luminance \( (L_t) \)
Average road surface luminance of a transverse strip at a given location in the transition zone of a tunnel

Visual guidance
Optical and geometrical means of providing drivers with information on the course of the road in a tunnel
3. Road Tunnels - Overview

3.1. Tunnel Considerations

Road tunnel lighting has a perceived mystique surrounding the specific requirements involved and how to meet them due to the various lighting zones and levels required. The lighting installation within a road tunnel is designed to enable drivers to enter, pass-through and exit the structure in comfort and safety without the need for changing speed or course.

To achieve this during the day and at night, the lighting levels within the structure must consider the ambient lighting on the access and parting zones. This section aims to present the integral components making up a road tunnel lighting installation and principle issues and challenges encountered for the lighting specifier and designer.

A significant issue that all parties must be conscious of is that in the event of an incident within a road tunnel, the potential implications to life and property can be significantly more serious than the same incident occurring on the open road. So much so that life threatening scenarios can develop very quickly within a road tunnel especially in the event of fire.

3.2. What is a Tunnel?

In essence a tunnel can be simply described as a covered road of varying lengths, formed from rock tunnels through a hillside, submerged tubes beneath waterways to structures constructed over the highway.

For all tunnels the lighting designer has no influence on the orientation the tunnel route forms. This is normally dictated by the site geology and the route required, i.e. the reason for the tunnel in the first place. Due to higher external ambient luminance, approaching a tunnel in a Southerly direction (when in the Northern Hemisphere) would be considered the most onerous with regard to the tunnel lighting requirement where threshold lighting levels \( (L_{th}) \) in excess of 400cd/m\(^2\) could potentially be necessary, especially if there is significant sky in the driver’s field of view on approaching the tunnel portal.

Existing tunnels requiring new lighting installations or refurbishment presents additional challenges, with the lighting designer potentially having to cope with restricted head-room due to limitations of the existing structure as well as road curvatures and gradients.

3.3. Tunnel or Underpass?

The distinction between a ‘long’ or ‘short’ tunnel has always been a debatable subject, all tunnels are different in construction, orientation and usage, as such every tunnel needs to be evaluated independently on any site specific unique arrangements. Where there are any uncertainties an engineering judgement will need to be made which becomes exclusive to that particular structure.

It is generally accepted that tunnels shorter than 25m do not normally require daytime lighting whilst tunnels longer than 200m always require daytime lighting, the issue of scale and degree of lighting arises for structures between these lengths.
Such issues are that a structure that is considered short by physical length alone may in fact be considered an optically long structure when the driver, at the stopping sight distance (SSD) from the entrance portal, cannot see the full extent of the exit portal. In such cases additional tunnel lighting more akin to a long tunnel or a hybrid solution would potentially be required.

A typical long tunnel will consist of a lighting scheme performance as illustrated in figure 1.

3.4. Visual Task

Transiting from daylight into a tunnel the ‘black-hole’ effect formed by the entrance portal has to be mitigated with the driver becoming further adapted to lower lighting levels ahead and within the tunnel. For longer tunnels the lighting level is continually and gradually reduced at a rate relative to traffic speed until an appropriate interior level is reached. Lower lighting levels within the tunnel’s interior are considered necessary as lighting a long tunnel to the high levels required at the entrance throughout the tunnel is considered unsustainable.

Lighting at the entrance and throughout the tunnel must cater for driver’s ability to fully see the road ahead, other vehicles as well as any obstacles there may be on the carriageway.

When drivers exit the tunnel during daylight hours, the driver’s eye will adapt much faster with little anxiety to the higher lighting levels at the exit. For a normal exit on a straight road this is an acceptable situation, however should there be merging traffic at or close to the exit of the tunnel, exit lighting would support rearward vision effectively back into the tunnel, to allow for any manoeuvres necessary to be undertaken safely.

Tunnel lighting schemes have to cater for drivers by both day and by night when driver’s vision will be in the Photopic or Mesopic states respectively. The Photopic state is when the eye has become fully adapted to lighting levels generally above 3.5 cd/m² with the Mesopic state being between 0.035 & 3.5 cd/m².

The lighting in the entrance zone of road tunnel would normally be continually variable and relational to the current outside lighting conditions, from the initial night time to dawn lighting conditions increasing through the day to reducing again at dusk back to the night time requirement as depicted in the chart below.

Boost Lighting duration variable dependant on actual daytime seasonal conditions.
During the day the eye’s Photopic state when approaching and entering the entrance portal is addressed by the application of the CIE entrance lighting reduction curve.

By night, providing the approach roads are lit and the tunnel interior level is at least equal to but no more than 3 times the approach road level, the visual task of drivers will be able to be conducted satisfactorily. However should the tunnel be over-lit especially at night or the parting zone of the exit road is unlit, drivers could perceive the aforementioned ‘black-hole’ effect on emerging from the tunnel exit.

**Physiological Considerations**

Flicker effect of dark/light areas can be induced by the installed tunnel lighting if luminaire spacing’s and/or switching patterns are incorrect. As a minimum this effect could cause visual discomfort to drivers and passengers of vehicles, in the worst case potentially causing photosensitive epilepsy (PSE) to those susceptible.

This effect can be minimised by ensuring critical spacing’s are outside a 2.5-15Hz range and is usually only applicable to the longer interior zone lighting installed for night-time and basic daytime lighting where the entire tunnel is in essence an interior zone at these times. Flicker effect considerations can normally be discounted when transit time through the structure or constant level zone at the design speed is less than 20 seconds.

**3.5. Lighting Arrangements**

As previously mentioned the objective of good tunnel lighting allows users to enter, transit and exit a structure in safety and in comfort therefore the driving task being as if on the open approach road. For economical reasons of both infrastructure materials and subsequent energy costs it is not practical to maintain the required high levels of entrance lighting throughout long tunnels, therefore a gradual reduction of luminance is applied which enables the drivers eyes reaction to cope with the transition from daylight levels to the tunnels, lower interior levels.

Guidance from different countries standards for tunnel lighting vary to some degree, but commonly state that the amount of lighting required within a tunnel is dependent on the level of ambient lighting on the tunnel approach and inside the tunnel at which visual adaptation for the driver is possible. To achieve this, the lighting of a tunnel is divided in to specific ‘Zones’ as depicted in Fig 1 above and outlined below:
Access Zone:
The access zone which is formed by the approach road itself so outside the tunnel, is considered where approaching drivers should be able to see clearly in to the tunnel to detect any obstacles there may be and safely react accordingly whilst not being confronted by a black-hole when travelling at the design speed for that road.

Threshold Zone:
This is the first Zone within the actual tunnel which extends for the same length as the stopping sight distance for the design or speed limit of approach road. The target luminance level for this zone when using the \( L_{20} \) method is derived from the portal luminance (\( L_{20} \)) value factored for the determined class of tunnel (see Section 6). This level is maintained at 100% for the first half of the Threshold zone reducing to 40% by the end of the zone.

Transition Zone:
Following the Threshold zone the Transition zone starts which continues to reduce the lighting levels until the specified daytime Interior zone level is reached. Throughout the Transition zone the luminance levels are gradually and continually reduced at a rate not exceeding a ratio of 3:1 to enable the human eye to accommodate the lowering lighting levels. From a practical perspective the Transition Zone may be sub-divided in to Transition Zone 1, 2 etc. The total length of the Transition zone is speed/time dependant.

Interior Zone:
The Interior zone during the day stretches from the end of the total Transition zone to the beginning of the Exit zone when used. The lighting levels required within the Interior zone will be dependent on considerations of the characteristics of the tunnel use. Note that the Interior zone stretches the whole length of the tunnel during the night time.

Exit Zone:
The final zone within the tunnel is the Exit zone which normally stretches for the length in meters equal to the speed in kph with a luminance level of 5 times that of the Interior zone. The eye adapts much more quickly to increasing lighting levels with exit lighting assisting rearward vision on departing the tunnel as well as preventing smaller vehicles being hidden behind trucks within the tunnel against the then bright exit portal during the daytime.

Parting Zone:
This is a stretch of open road immediately following the end of the Exit zone.

Overall Control:
The lighting within the Threshold, Transition and Exit zones will also be subject to multiple stage switching and/or continuous dimming to maintain the correct correlation between the entrance portal approach luminance and the luminance levels within the tunnel. The Interior zone will generally have two active stages, one for the night and one for basic day time.

For longer tunnels a percentage of the Interior lighting would normally be powered by an uninterruptable power supply (UPS) which allows for some lighting to remain energised in the event of a power failure of the normal power supply. This allows for the safe egress of traffic within the tunnel but not for continued normal use of the route.

In essence the above assumes a perfect scenario for a ‘long tunnel’ where all the unique aspects of the structure ‘fits’ the recommendations employed. It can be the case that during the day time the actual tunnel can finish before any interior levels have been reached, only at lower lighting requirements pre and post peak boost levels does an interior section develop.
Where the tunnel being considered doesn’t fit the recommendations or is an optically longer or shorter tunnel, professional engineering judgement will be required to ensure a lighting scheme is designed and installed that fully meets the objective of tunnel lighting thus enabling drivers to conduct the visual task safely as well as providing an economic solution in terms of energy usage and carbon footprint.

4. Styles of Tunnel Lighting

4.1. Linear / Line Lighting

Linear lighting is formed of luminaires having their lamps orientated parallel with the road axis with the luminous distribution perpendicular to the road axis, mounted either in rows along the tunnel roof or within the cornice area when an asymmetrical distribution across the carriageway is adopted.

This style of lighting lends itself to most lamp types, and has been historically used for fluorescent lamps (now LED) forming the basic day and night time levels within the tunnel. Visual guidance and driver comfort is high with schemes surpassing uniformity requirements.

4.2. Point Source, Symmetrical

The point source luminaire previously had a single HID lamp within a 3D optic (now LED modules) dedicated for road tunnels. Historically a popular style of lighting for road tunnels albeit providing less visual driver comfort due to extended spacing’s.

4.3. Point Source, Counter-beam

The principle distribution from a counter-beam luminaire is via a tightly controlled asymmetric optical system towards oncoming drivers, this creates a greater contrast between objects and the road background than a symmetrical distribution. Counter-beam luminaires are most efficient for the provision of high boost luminance required within the tunnel threshold and subsequent transition zones with a minimum number installed.

Due to the luminaire performance being biased towards oncoming traffic, counter beam lighting is not suitable for bi-directional tunnels or where contra-flow is envisaged.
5. Current Practice

Innovation can at times be stifled by contractual issues dependant on who the decision-makers are. Builders will want the most competitive build solution whilst the owner/operator wants the best ongoing total running costs which could cause conflicts of interest when a specification is poorly drafted. Additionally new developments are sometimes slow to be applied due to concerns on reliability due to any subsequent changes being costly to instigate in road tunnels.

The driving force in the current climate is for the most efficient use of energy and reducing CO\textsubscript{2} emissions. As tunnel lighting schemes have high energy consumption, the use of more energy efficient light sources are being developed, in particular the use of LED solutions for all tunnel zones.

The use of LED luminaires specifically designed for tunnels is realising significant reduced energy usage with an added benefit of a ‘white’ full spectrum light source aiding visual acuity. When arranged in a pseudo linear installation good driver comfort and visual guidance is achieved.

A further development is closer control and monitoring of the lighting installation itself via intelligent control systems. Intelligent CMS not only improves system integrity but can achieve installation time and cost savings over conventional methods whilst facilitating an opportunity of post-installation fine-tuning of the scheme, which could potentially mitigate any uncertainties there may have been at design stage. Development of active dynamic regimes could further contribute to potential savings where appropriate.

With the recent developments in LED technology several tunnels are now also being equipped with orientation units at low level mounting positions. These low level units are intended to aid guidance for both vehicles and pedestrians in normal and in emergency situations.

Evacuation lighting could also be required for longer tunnels for use by drivers and passengers in cases where they would be required to leave their vehicles and egress the tunnel on foot. New installations are now also capable of dealing with disabled tunnel users to safely exit with or without special assistance.

Historical features may also be considered where for example, the installation of sun-tight screens at entrance portals was commonplace. Their application allows natural daylight to filter through the screen structure to the road surface in a controlled manner thus reducing the quantity of artificial lighting required in what is a high luminance requirement area.

The brighter the day becomes the higher daylight values automatically filterers through to the road surface, thereby potentially eliminating or substantially reducing the need for significant numbers of high power luminaires in the Threshold zone.

The then reported negative aspects of sun-tight screens was that roads beneath were prone to form surface ice during the winter months as well as potential for icicle formation on the structure itself, whilst build and maintenance costs of the structure was considered high. However with ongoing development of structural materials the use of sun-tight screens or taut canopies, a variation of screens, could potentially be considered in a holistic approach within a multi-discipline platform where all disciplines design options and full life-time costs as well as total cost of ownership could be evaluated for the total-tunnel.
5.1. HID vs. LED

When considering the energy usage for an existing long tunnel in particularly in Western Europe, the energy using elements were assessed as depicted in the first pie chart. The tunnel evaluated here would be considered a typical arrangement for this area with the presence of multi-discipline services.

As can be seen the highest single user of energy is the HPS lighting installation at 53% of the total.  

(Research Eindhoven University)

Refurbishment of the lighting system to an LED installation would see the energy used in this sector significantly reduced.

Based on this and similar evaluations, the use of LED technology for the lighting of new and refurbished road tunnels is considered the state of the art and current best practice realising the most significant energy savings of any discipline.
6. Road Tunnel Lighting – Design & Performance

The fundamentals for road tunnel lighting are determined by CIE 88:2004 which is generally considered as the basis for most countries official standard for tunnel lighting. The following principle recommendations are considered proven good practice within Europe and summarised here.

6.1. Initial Design Requirements

Prior to embarking on a lighting design or a lighting design specification for a road tunnel the following criteria will be required to be established:

- Structural details of the tunnel.
- Design / speed limit of approach road(s).
- Stopping Distance (m)
- Tunnel Class based on:
  - Traffic Flow Rate
  - Traffic Mix
- Access Zone Luminance \( L_{20} \) (cd/m\(^2\))
- \( K \) factor value based on Tunnel Class & Speed Limit
- Threshold Zone Luminance based on \( L_{20} \times K \) (cd/m\(^2\))
- Total Threshold Zone Length = Stopping distance (m)
- Interior Zone Luminance based on Tunnel Class & Speed Limit (cd/m\(^2\))
- Exit Zone Luminance = 5 x Interior Luminance (cd/m\(^2\))
- Exit Zone Length (m)
- Road Surface Category (R1, C2 etc)

6.2. Performance Requirements

On calculation of a tunnel lighting design the following parameters should be evaluated for conformity.

- Compliance with entrance reduction curve (CIE 88:2004)
- Road Overall Uniformity (\( U_o \))
- Road Longitudinal Uniformity (\( U_l \))
- Wall Luminance to 2m height, dependent on tunnel class
- \( TI < 15\% \) for all situations
- Flicker Frequency Outside 2.5Hz to 15Hz if transit time > 20 seconds.
### 6.3. Tunnel Classification and associated design tables

#### Design and Performance Requirements:

Tables presented here are intended to demonstrate criterion involved and should only be used in the actual design process in association with and referenced to applicable standards where they have originated, such as BS 5489-2:2003+A1:2008, CR 14380 : 2003 & CIE 88:2004

#### Traffic Intensity and Determining Tunnel Class:

<table>
<thead>
<tr>
<th>Intensity</th>
<th>Traffic Type</th>
<th>Tunnel Class</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>Mixed</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>High</td>
<td>3</td>
</tr>
<tr>
<td>Medium</td>
<td>Mixed</td>
<td>2</td>
</tr>
<tr>
<td>Low</td>
<td>Motor</td>
<td>1</td>
</tr>
</tbody>
</table>

#### Traffic Intensity (Peak V/h/la)

<table>
<thead>
<tr>
<th>Traffic Intensity</th>
<th>one way</th>
<th>two way</th>
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</thead>
<tbody>
<tr>
<td>High</td>
<td>&gt;1500</td>
<td>&gt;400</td>
</tr>
<tr>
<td>Medium</td>
<td>500-1500</td>
<td>100-400</td>
</tr>
<tr>
<td>Low</td>
<td>&lt;500</td>
<td>&lt;100</td>
</tr>
</tbody>
</table>

#### Determining K for speed limits & tunnel lighting class:

<table>
<thead>
<tr>
<th>Speed Limit</th>
<th>kph</th>
<th>kph</th>
<th>kph</th>
</tr>
</thead>
<tbody>
<tr>
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<td>80-100</td>
<td>&gt;120</td>
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<tr>
<td>4</td>
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#### Interior Luminance (cd/m²):

<table>
<thead>
<tr>
<th>Speed Limit</th>
<th>kph</th>
<th>kph</th>
<th>kph</th>
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<td>80-100</td>
<td>&gt;120</td>
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<td>1.5</td>
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</tr>
<tr>
<td>1</td>
<td>-</td>
<td>0.5</td>
<td>1.5</td>
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</table>

#### Wall Luminance

<table>
<thead>
<tr>
<th>Class</th>
<th>% of adjacent road</th>
</tr>
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<tbody>
<tr>
<td>4</td>
<td>100%</td>
</tr>
<tr>
<td>3</td>
<td>60%</td>
</tr>
<tr>
<td>2</td>
<td>Orientation &gt;25%</td>
</tr>
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</table>

#### Road surface Luminance Uniformity: (Continuous Zones)

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<th>Uniformity</th>
<th>Class</th>
<th>Uniformity</th>
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<tr>
<td></td>
<td>4</td>
<td>U₀ 0.4</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>U₀ 0.4</td>
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<td>U₀ 0.4</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>U₀ 0.4</td>
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<table>
<thead>
<tr>
<th>Class</th>
<th>Uniformity</th>
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<tbody>
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<td>Uₐ 0.7</td>
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<td>3</td>
<td>Uₐ 0.6</td>
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<tr>
<td>2</td>
<td>Uₐ 0.6</td>
</tr>
<tr>
<td>1</td>
<td>Uₐ 0.6</td>
</tr>
</tbody>
</table>
**Entrance Zone Performance Requirements:**

CIE Luminance Reduction Curve for Tunnel Entrances:

Typical design results for a 6 stage tunnel entrance lighting scheme showing relevant results per stage and per zone of the tunnel conforming to the CIE reduction curve with all stages being accumulative.

<table>
<thead>
<tr>
<th>% $L_{th}$</th>
<th>Stage</th>
<th>Tunnel Entrance Zones</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Th(1)</td>
</tr>
<tr>
<td>100</td>
<td>6</td>
<td>184</td>
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<td>45</td>
<td>5</td>
<td>73</td>
</tr>
<tr>
<td>16</td>
<td>4</td>
<td>25</td>
</tr>
<tr>
<td>5.5</td>
<td>3</td>
<td>11</td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
6.4. Entrance Portal Luminance \( (L_{20}) \)

The initial evaluation for all tunnel lighting designs and the most critical criteria, is the daytime luminance value of the entrance portal as would be experienced by drivers entering a road tunnel during the day. The required lighting levels within the Threshold zone of the tunnel and consequently following Transition zones are directly dependent on and relational to the portal luminance.

The assessment of the portal luminance \( (L_{20} \text{ Method}) \) is best conducted by the use of a dedicated \( L_{20} \) portal luminance meter having the requisite 20° field of view and measured from the stopping sight distance (SSD) during the brightest mid-summer months thereby recording the maximum portal luminance present at the structure.

However, from a practical viewpoint it is not always possible to conduct such site measurements due to various issues, as such an assessment may be conducted by the following procedure. This is an approximation and should be confirmed by actual measurements wherever possible.

There are other methods of assessing the portal luminance such as \( L_{SEQ} \) which also considers the atmosphere between the driver and the portal as well as a vehicle windscreen factor; however the \( L_{20} \) method is a more widely used and accepted method.

Perspective view of a tunnel entrance with superimposed 20° subtended circle

20° field of view divided into assessment areas

1 = centre of entrance portal for driving on the left.
Each area is attributed a luminance value, typically from BS5489:

<table>
<thead>
<tr>
<th>Background</th>
<th>Luminance cd/m²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Earth/sand</td>
<td>3,500</td>
</tr>
<tr>
<td>Grass</td>
<td>2,000</td>
</tr>
<tr>
<td>Hill (Rock, Scree)</td>
<td>3,500</td>
</tr>
<tr>
<td>House (Brick)</td>
<td>3,500</td>
</tr>
<tr>
<td>Portal (Dark)</td>
<td>1,000</td>
</tr>
<tr>
<td>Road (Asphalt)</td>
<td>4,000</td>
</tr>
<tr>
<td>Road (asphalt) in sun when</td>
<td>6,000</td>
</tr>
<tr>
<td>facing in southerly direction</td>
<td></td>
</tr>
<tr>
<td>Road (Concrete)</td>
<td>8,000</td>
</tr>
<tr>
<td>Sky (Clear)</td>
<td>8,000</td>
</tr>
<tr>
<td>Sky (hazy, bright) occurs when</td>
<td>20,000</td>
</tr>
<tr>
<td>facing in southerly direction</td>
<td></td>
</tr>
<tr>
<td>Tree</td>
<td>1,000</td>
</tr>
<tr>
<td>Wall (Dark)</td>
<td>1,000</td>
</tr>
<tr>
<td>Wall (Light)</td>
<td>6,000</td>
</tr>
</tbody>
</table>

NOTE: These values are for midsummer in full sun with horizontal illuminance approximately 100 000 lx. Where a surface is in shadow at the time that the value of \( L_{20} \) is at a maximum, then the value of \( L \) given for that surface should be multiplied by 0.25.

Worked example against above perspective view:

<table>
<thead>
<tr>
<th>Segment</th>
<th>Background</th>
<th>Area ( A )^a</th>
<th>Luminance ( L ) cd/m²</th>
<th>A x L</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>Sky (Clear)</td>
<td>2,600</td>
<td>8,000</td>
<td>20,800,000</td>
</tr>
<tr>
<td>b</td>
<td>Dark wall</td>
<td>1,150</td>
<td>1,000</td>
<td>1,150,000</td>
</tr>
<tr>
<td>c</td>
<td>Dark wall over Portal</td>
<td>300</td>
<td>1,000</td>
<td>300,000</td>
</tr>
<tr>
<td>d</td>
<td>Road (Asphalt) in sun</td>
<td>3,300</td>
<td>4,000</td>
<td>13,200,000</td>
</tr>
<tr>
<td>e</td>
<td>Road in Shadow</td>
<td>80</td>
<td>1,000</td>
<td>80,000</td>
</tr>
<tr>
<td>f</td>
<td>Dark wall in shadow</td>
<td>128</td>
<td>250</td>
<td>32,000</td>
</tr>
<tr>
<td>g</td>
<td>House (Brick) in shadow</td>
<td>130</td>
<td>875</td>
<td>114,000</td>
</tr>
<tr>
<td>h</td>
<td>Trees</td>
<td>90</td>
<td>1,000</td>
<td>90,000</td>
</tr>
<tr>
<td>i</td>
<td>Sandy medians</td>
<td>800</td>
<td>3,500</td>
<td>2,800,000</td>
</tr>
<tr>
<td>j ^c</td>
<td>Tunnel interior</td>
<td>922</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Totals</strong></td>
<td></td>
<td><strong>9,500</strong></td>
<td></td>
<td><strong>38,566,000</strong></td>
</tr>
</tbody>
</table>

Average luminance \( L_{20} = AL/A = 4060 \) cd/m²

---

a As shown in perspective figure
b The units of area for \( A \) are relative, with all areas in a given exercise using the same units, and may be whatever is convenient to the size of the drawing or photograph in use.
c Where daytime lighting is to be provided to short tunnels where the exit portal is visible at the stopping distance SD before the entrance portal, due to light penetration the tunnel interior \( j \) will have a luminance value. This luminance value should be entered as a negative value in the table, and will give a slight reduction in the value of \( L_{20} \).
Comment:
It would be advantageous to minimise the impact of high value luminance areas and materials wherever possible thus contributing to a lower overall $L_{20}$ value with subsequent lower artificial lighting requirement within the tunnel.

This could be achieved by reducing the amount of sky in the field of view via screening by various means as well as darkening of the entrance portal structure itself.

### 7. Short Tunnels

#### 7.1. Look Through Percentage

As stated earlier, short tunnels can cause much debate on how best to light such structures in an economical manner whilst providing a viable solution. An initial evaluation of whether such structures need to be lit and to what level can be conducted by using the ‘Look Through Percentage’ (LTP).

The lighting requirements for long and short tunnels differ according to the degree to which the approaching driver can see through the tunnel as seen from a point at a distance equal to the stopping distance in front of the tunnel portal. The ability to see through the tunnel depends primarily on the length of the tunnel but also on other design parameters (width, height, horizontal and/or vertical curvatures, etc).

The "Look Through Percentage" is defined as the ratio between the visible exit and the visible entrance, expressed as a percentage.

![Diagram showing Look Through Percentage](image)

This ratio is based on:
- Geometrical measures of the tunnel as width, height, and length (the length has much more influence than the width and height)
- Horizontal and vertical curves of the tunnel
- The stopping distance
- The influence of day-light penetration at both the entrance and exit portal

When the exit portal is a large part of the scene visible through the entrance other road users and objects can easily been seen as dark against the lighter scene beyond the exit portal. On the other hand artificial lighting is needed when the exit is in a relative large dark frame, in which objects could be hidden.

This can occur when the short tunnel is relatively or optically "long", or when the short tunnel is curved in such a way that only a part of the exit can be seen or when the exit cannot be seen at all. The critical factor is whether approaching drivers when at the stopping sight distance from the entrance portal can see vehicles, other road users or obstacles.
The Look Through Percentage LTP is defined by the formulae:

\[
\text{LTP} = 100 \times \frac{\text{surface EFGH}}{\text{surface ABCD}}
\]

The centre for the perspective drawing is:
- A point on a horizontal line 1.2 m above the road surface,
- In the middle of the driving lane (if more lanes are used to be determined for each lane, although the lanes closest to the walls will provide the most critical situation)
- At the stopping distance for the daylight influenced apparent entrance portal

Daylight penetration shortens the apparent visual length of the tunnel. Therefore an apparent entrance and exit portal is used when determining LTP. The apparent entrance portal normally is inset about 5 m inside the tunnel and the apparent exit portal about 10 m inside the tunnel.

The difference between actual and apparent portals can be seen by viewing the road surface in the tunnel from a long distance before the tunnel, when it will be seen that the road surface brightness at the portals is greater than within the tunnel. However, in practice it is difficult to estimate or measure the inset distances, and the 5m and 10m figures represent good practice and should normally be used.

Based on evaluations, the following conclusions can be formulated:
- where LTP < 20%, artificial daytime lighting should always be provided;
- where LTP > 80%, artificial daytime lighting is generally not needed;
- where LTP is between 20% & 80%, the following additional process should be followed to determine if daytime lighting is needed:

The visibility of a critical relevant object should be considered. This object represents a car if only motor vehicles are permitted to use the tunnel, but where mixed traffic is permitted pedestrians or cyclists should be taken into account.

For cars the critical object is defined as a rectangle of width 1.6 m x height 1.4 m.
For pedestrians/cyclists the critical object is defined as a rectangle of width 0.5 m x height 1.8 m.

The main object is to avoid a collision and therefore the critical object is placed in the middle of the driving lane

Artificial day-time lighting is needed when either:
- Less than 30% of the critical object representing a car can be seen against the apparent exit portal.
- Less than 50% of the critical object representing a pedestrian/cyclist can be seen against the apparent exit portal.

Vehicle 1.4 x 1.6m  
Pedestrian/Cyclist 0.5 x 1.8m
7.2. Influencing the LTP

Promoting good daylight penetration at entrance and exit will shorten the apparent length of the tunnel. This can be done by:

- enlarging the entrance / exit higher or wider
- applying specular covers (tiles) on the tunnel walls
- breaking down the tunnel in shorter parts by leaving open the roof where possible

Both from practice and calculation method it can be concluded that the main influencing factors are the stopping distance and the length of the tunnel, and not the height or widths even taking into account the penetration of daylight.

The appropriate method of providing artificial lighting for a short tunnel during day-time depends on the specific situation. Some possibilities are:

- Using full entrance zone lighting as for long tunnels
- Using "light pools" at some places lengthwise, created by permitting daylight through the roof or by artificial lighting; cars and other road users can be seen as dark objects against these "light pools"
- In tunnels with a horizontal curvature the outer curved wall could be lit in such a way that cars and other road users can be seen as dark objects against the lit wall.
8. Materials & Installation

8.1. Tunnel Environment

Road tunnels by their very nature are harsh environments caused by such factors as vehicle emissions, salting of roads in the winter months, minerals seeping through the structure all within a potentially damp atmosphere. As such care should be taken in choosing equipment that can withstand this unsympathetic environment to fulfil a reasonable serviceable life of circa 25 years with minimal maintenance.

8.2. Luminaires

Particular attention should be paid to the need for separation of dissimilar metals between the luminaire body and the support system. Aluminium alloy is the most popular material used by manufacturers of propriety luminaires which when in direct contact with a steel support system has been a particular source of corrosion and a consequential maintenance issue.

Much research has been undertaken by manufacturers in this field with respect to surface passification of the base metal and durable finishes for alloys and means of support.

The construction of the tunnel luminaires should be designed to withstand the tunnel environment and the corrosive effects of electrolytic action between different materials which can accelerate failure of the luminaire and luminaire suspensions.

The luminaire housings should be constructed to provide a dust proof and water jet proof enclosure with a minimum ingress protection to IP65 effective throughout the design life and should have smooth external surfaces on all sides to prevent the accumulation of dirt and permit easy cleaning.

The sealing gaskets for the any end caps or glazed front covers should be fixed to prevent them inadvertently dislodging and to ensure the mating surfaces correctly align to maintain the integrity of the luminaire for the serviceable period.

Especially important for LED tunnel luminaires, the maximum internal temperature of the luminaire should not exceed the manufacturer's recommendations to prevent premature failures or reduced performance.

It should be noted that LED output depreciation occurs over a very long period of time and can be measured in years. The effect of this depreciation being that although the LED luminaire appears to be lit and functional the resultant road luminance levels may become well below original design requirement, as such road measurements should be undertaken when approaching the end of useful life.

8.3. Suspension Systems

Tunnel luminaire suspension systems should be of corrosion resistant materials suitable to achieve the required design life and should support all luminaires and associated cable trays, trunking and conduits for the system wiring.

The luminaires should be mounted to the suspension system in accordance with the manufacturer’s recommendations. Measures should be taken to ensure that the method used to attach the luminaire to the suspension system does not compromise the integrity of the finish which could result in contact of dissimilar metals and consequential electrolytic corrosion.
9. Summary of Recommendations

To achieve current best practice for the energy efficiency and sustainability as well as minimising total cost of ownership of road tunnel lighting schemes whilst providing for a safe and practical scheme the following recommendations are made applicable for Armenia in general.

Luminaires:
By far the most significant energy savings are realised by the use of LED technology, as such all road tunnel luminaires for all tunnel zones should be of this technology. LED technology is relatively new in the market place with the development rate far exceeding that of previous lamp evolutions. This being said and due to the fast rate of development by many manufacturers, only products from established manufacturers should be considered when warrantees and ongoing support should be more forthcoming.

To achieve maximum efficacy of the system as a whole the latest LED systems should consist of luminaire drivers that are programmable dimmable via 1–10V DALI control. The driver for each LED luminaire should be a high efficient electronic driver which should be continuously dimmable to achieve the varying output performance required.

System Control:
The closer control that a tunnel lighting system has the more controllable the scheme is overall and contributing to overall energy efficiency, as such an intelligent control and monitoring system (CMS) would be recommended as being the state of the art.

The control system would comprise of a PC based user interface (UI) where portal photometer units are connected as the input commands from each portal. The UI can be pre-programmed to achieve the lighting performance as designed for all tunnel zones and subsequent stages.

The benefit of such an integrated CMS and LED luminaires is that installed luminaires can be multi-stage operation control thereby potentially minimising the number of luminaires installed. The UI also has the capability of full monitoring of the lighting system to alert owners of any lighting failures within the tunnel. If required the UI can also be interfaced with a SCADA (Supervisory Control and Data Acquisition) system if required.

Dedicated LED tunnel lighting manufacturers are able to provide both LED luminaires and an integrated CMS system which mitigates potential compatibility issues.
Alternative Control:
In the case of urban tunnels such as those in Yerevan where many are of a physical short length but optically considered long due to the fact that the exit cannot be seen from the SSD. Therefore where the tunnels are of such limited scale a more modest control system could be more suitable. The functionality would be limited to control only without any feedback on the state of the system i.e. no automatic monitoring which would then rely on manual periodic inspections to ensure system integrity.

Systems such as the illustrated PLC unit as standard are configured to multiple stage switching patterns but dimming would not be possible from standard units.

Without dimming via the control system, the full potential of LED luminaires cannot be fulfilled as distinct stage switching will require separate stage circuits to be installed to dedicated stage luminaires resulting in more low power LED luminaires being required. The advantage of this system is that no specialist knowledge is required to install and maintain the resultant system.

However there are ongoing developments for simplified systems promising to retain full control which should be evaluated as they become available.

As an alternative to portal photometer(s) a single ambient illuminance sensor could be installed in the vicinity of the tunnel to regulate tunnel lighting stages energisation.

Guidance Lighting:
Not directly related to a tunnel ‘illumination’ systems low-level guidance lighting may be suitable for particular installations where full tunnel lighting may not be achievable due to structural or other issues and where low level LED guidance lighting units could provide basic visual guidance for users.

Maintenance:
Any installation benefit’s from a regular maintenance regime at a frequency appropriate for the usage and location of the tunnel. Preventative maintenance of all equipment and the structure itself will also allow for checking and audit of all systems state and continued functionality whilst being fit for purpose.

Routine non-invasive maintenance should as a minimum, be wall and luminaire cleaning which ensures that the luminaires operate at correct output whilst the cleaning of the walls up to 2m in height ensures that the wall performance is retained contributing to countering ‘wall shyness’ of drivers.
10. Risk Assessment

Any tasks carried out in the course of activities undertaken should be assessed for risks to both the individuals involved and any other parties present or likely to be present.

The key steps would be:
- Identify any potential hazards
- Define who might be harmed and how
- Evaluate the risks and decide on precaution
- Record findings and implement them
- Review assessment and update as required

A hazard is considered as anything that may cause harm to individuals, such as materials encountered, electric shock, working at heights, working close to live traffic etc.

The risk is the chance, high or low that someone could be harmed by these and other hazards, together with an indication of how serious the harm could be.

To aid the evaluation of the level of risk, the following matrix would be used.

<table>
<thead>
<tr>
<th>PROBABILITY</th>
<th>Very likely</th>
<th>5</th>
<th>M</th>
<th>H</th>
<th>VH</th>
<th>VH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fairly frequent</td>
<td>4</td>
<td>M</td>
<td>M</td>
<td>H</td>
<td>H</td>
<td>VH</td>
</tr>
<tr>
<td>Occasional occurrence</td>
<td>3</td>
<td>L</td>
<td>M</td>
<td>M</td>
<td>H</td>
<td>H</td>
</tr>
<tr>
<td>Remotely possible</td>
<td>2</td>
<td>L</td>
<td>L</td>
<td>M</td>
<td>M</td>
<td>H</td>
</tr>
<tr>
<td>Highly unlikely</td>
<td>1</td>
<td>I</td>
<td>L</td>
<td>L</td>
<td>M</td>
<td>M</td>
</tr>
</tbody>
</table>

Key

<table>
<thead>
<tr>
<th>Key</th>
<th>Insignificant</th>
<th>1</th>
<th>Minor injury</th>
<th>2</th>
<th>Over 3 day injury</th>
<th>3</th>
<th>Temp incapacity / illness</th>
<th>4</th>
<th>Permanent incapacity</th>
<th>5</th>
<th>Fatality</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Insignificant</td>
<td>1</td>
<td>Minor injury</td>
<td>2</td>
<td>Over 3 day injury</td>
<td>3</td>
<td>Temp incapacity / illness</td>
<td>4</td>
<td>Permanent incapacity</td>
<td>5</td>
<td>Fatality</td>
</tr>
<tr>
<td>L</td>
<td>Low</td>
<td>1</td>
<td>Minor injury</td>
<td>2</td>
<td>Over 3 day injury</td>
<td>3</td>
<td>Temp incapacity / illness</td>
<td>4</td>
<td>Permanent incapacity</td>
<td>5</td>
<td>Fatality</td>
</tr>
<tr>
<td>M</td>
<td>Medium</td>
<td>1</td>
<td>Minor injury</td>
<td>2</td>
<td>Over 3 day injury</td>
<td>3</td>
<td>Temp incapacity / illness</td>
<td>4</td>
<td>Permanent incapacity</td>
<td>5</td>
<td>Fatality</td>
</tr>
<tr>
<td>H</td>
<td>High</td>
<td>1</td>
<td>Minor injury</td>
<td>2</td>
<td>Over 3 day injury</td>
<td>3</td>
<td>Temp incapacity / illness</td>
<td>4</td>
<td>Permanent incapacity</td>
<td>5</td>
<td>Fatality</td>
</tr>
<tr>
<td>VH</td>
<td>Very High</td>
<td>1</td>
<td>Minor injury</td>
<td>2</td>
<td>Over 3 day injury</td>
<td>3</td>
<td>Temp incapacity / illness</td>
<td>4</td>
<td>Permanent incapacity</td>
<td>5</td>
<td>Fatality</td>
</tr>
</tbody>
</table>

Risk should always be fully mitigated wherever possible with constant monitoring of any changing circumstances which may affect the initial risk assessment.
Risk assessment example conducted for a site measurement task of a road tunnel:

<table>
<thead>
<tr>
<th>Risk Assessment</th>
<th># Tunnel</th>
<th>Task: Lighting Survey</th>
<th>Project No.</th>
<th>Page</th>
<th>1b</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Ref</strong></td>
<td>J Rands</td>
<td>Date</td>
<td>#</td>
<td>Project No.</td>
<td>300327279</td>
</tr>
<tr>
<td><strong>Hazard</strong></td>
<td>Persons Affected</td>
<td>Initial Risk</td>
<td>Avoidance/Control Measures</td>
<td>Resultant Risk</td>
<td>Inform / control</td>
</tr>
<tr>
<td>0 Site Access</td>
<td>Inspectors</td>
<td>- - -</td>
<td>All personnel to attend site induction</td>
<td>- - -</td>
<td>TM</td>
</tr>
<tr>
<td>1 Unauthorised Areas</td>
<td>Inspectors</td>
<td>1 2 L</td>
<td>All personnel to sign in/out with tunnel manager office</td>
<td>1 2 L</td>
<td>Inspectors</td>
</tr>
<tr>
<td>2 Struck by Moving Vehicles</td>
<td>Inspectors / all</td>
<td>3 4 H</td>
<td>TM to provide traffic control. All staff driving vehicles to be informed of inspectors presence. All inspectors to wear High Visibility Clothing.</td>
<td>1 4 L</td>
<td>TM when changing tubes</td>
</tr>
<tr>
<td>3 Leptospirosis</td>
<td>Inspectors</td>
<td>3 3 M</td>
<td>Personnel hygiene &amp; PPE. Cover abrasions and cuts. Carry issued pocket card</td>
<td>1 3 L</td>
<td>Inspectors</td>
</tr>
<tr>
<td>4 Noise</td>
<td>Inspectors</td>
<td>3 2 L</td>
<td>PPE</td>
<td>2 2 L</td>
<td>Inspectors</td>
</tr>
<tr>
<td>5 Airborne Particulates</td>
<td>Inspectors</td>
<td>2 2 L</td>
<td>PPE</td>
<td>2 2 L</td>
<td>Inspectors</td>
</tr>
<tr>
<td>6 Electric Shock (230 / 400V)</td>
<td>Inspectors</td>
<td>2 2 L</td>
<td>Training, Safe Systems of Work, use correct equipment</td>
<td>2 2 L</td>
<td>Inspectors</td>
</tr>
<tr>
<td>7 Falling</td>
<td>Inspectors</td>
<td>2 2 L</td>
<td>Correct Equipment, Training &amp; PPE</td>
<td>2 2 L</td>
<td>Inspectors</td>
</tr>
<tr>
<td>8 Tripping</td>
<td>Inspectors / all</td>
<td>3 2 M</td>
<td>Safe Systems of Work &amp; Tidy Workplace Policy</td>
<td>2 2 L</td>
<td>Inspectors</td>
</tr>
<tr>
<td>9 Falling Objects</td>
<td>Inspectors</td>
<td>3 2 M</td>
<td>Correct Equipment &amp; PPE</td>
<td>2 2 L</td>
<td>Inspectors</td>
</tr>
<tr>
<td>10 Manual Handling</td>
<td>Inspectors / all</td>
<td>1 2 L</td>
<td>Correct Equipment, Training</td>
<td>2 2 L</td>
<td>Inspectors</td>
</tr>
<tr>
<td>11 Wash Chemical</td>
<td>Inspectors</td>
<td>3 3 M</td>
<td>Vacate cleaning areas</td>
<td>2 2 L</td>
<td>TM</td>
</tr>
</tbody>
</table>
11. Bibliography

       Guide for the lighting of road tunnels and underpasses

       Code of practice for the design of road lighting – Lighting of Tunnels

       Lighting applications – Tunnel lighting

MCHW: Mechanical, electrical and communications work for road tunnels