JTG

Recommended Industry Standards of
the People's Republic of China

中华人民共和国行业推荐性标准

JTG/T D70/2-01—2014 (EN)

Guidelines for Design of Lighting of Highway Tunnels

公路隧道照明设计细则

(英文版)

Issue date: July 14, 2014 Effective date: August 1, 2014

Issued by Ministry of Transport of the People's Republic of China

Recommended Industry Standards of the People's Republic of China

中华人民共和国行业推荐性标准

Guidelines for Design of Lighting of Highway Tunnels

公路隧道照明设计细则

(英文版)

JTG/T D70/2-01—2014(EN)

Editing organization in charge: China Merchants Chongqing Communications Technology Research & Design Institute Co., Ltd.

Issuing authority: Ministry of Transport of the People's Republic of China

Effective date: August 1, 2014

中华人民共和国交通运输部

公　　告

第 50 号

交通运输部关于发布《公路隧道设计规范　第一册　土建工程》英、法文版等 7 项公路工程行业标准外文版的公告

为促进公路工程行业标准的国际合作与共享，现发布《公路隧道设计规范　第一册　土建工程》英文版[JTG 3370.1—2018（EN）][代替标准号 JTG D70—2004(E)]及法文版[JTG 3370.1—2018(FR)]、《公路隧道设计规范　第二册　交通工程与附属设施》法文版[JTG/T D70/2—2014(FR)]、《公路隧道照明设计细则》英文版[JTG/T D70/2-01—2014(EN)]、《公路隧道通风设计细则》英文版[JTG/T D70/2-02—2014(EN)]、《公路隧道抗震设计规范》英文版[JTG 2232—2019(EN)]、《公路隧道养护技术规范》英文版[JTG H12—2015(EN)]。

上述标准外文版的管理权和解释权归中华人民共和国交通运输部，日常管理和解释工作均由编译单位招商局重庆交通科研设计院有限公司负责。

标准外文版与中文版如在技术内容上出现异议时，以中文版为准。

如在使用过程中发现问题或有修改建议，请函告招商局重庆交通科研设计院有限公司（地址：重庆市南岸区学府大道 33 号隧道与地下工程研究院，邮编：400067，电子邮件：chengliang@cmhk.com）。

特此公告。

中华人民共和国交通运输部

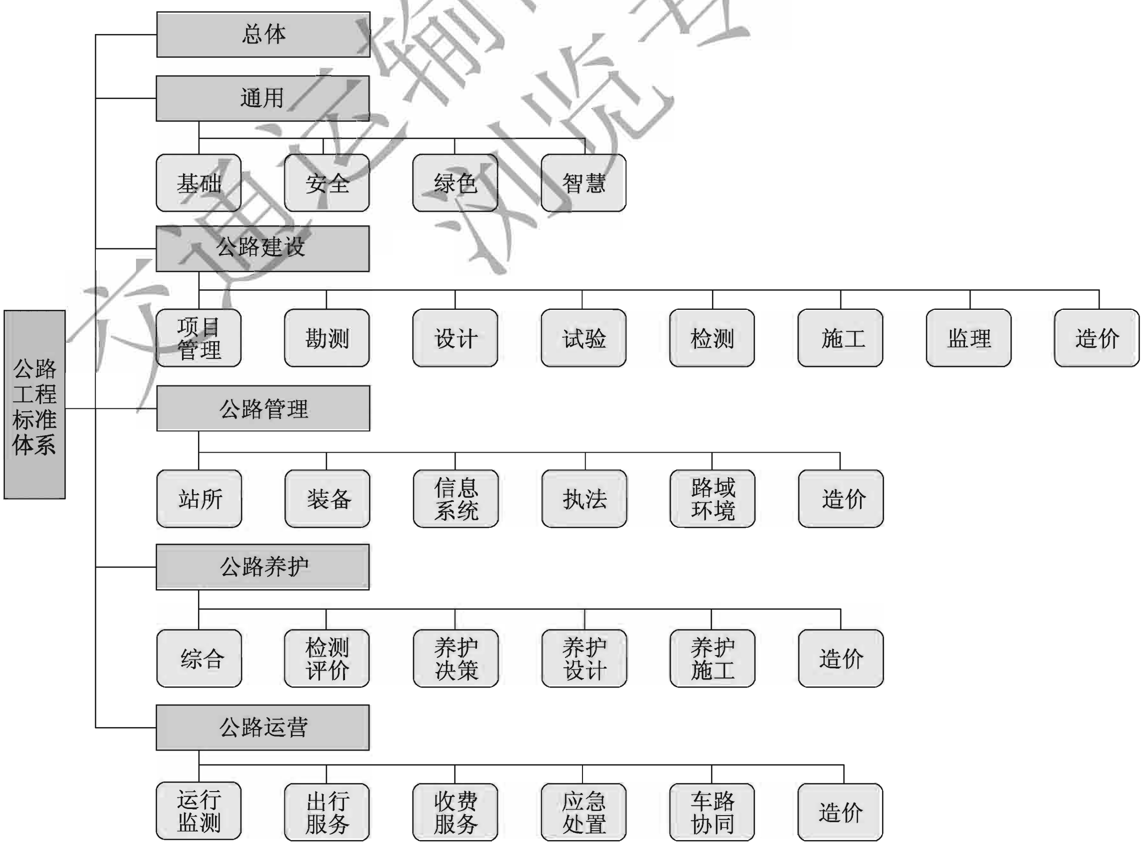
2023 年 9 月 20 日

交通运输部办公厅　　2023 年 9 月 21 日印发

英文版编译出版说明

标准是人类文明进步的成果,是世界通用的技术语言,促进世界的互联互通。近年来,中国政府大力开展标准化工作,通过标准驱动创新、协调、绿色、开放、共享的共同发展。在丝绸之路经济带与21世纪海上丝绸之路,即“一带一路”倡议的指引下,为适应日益增长的全球交通运输发展的需求,增进世界连接,促进知识传播与经验分享,中华人民共和国交通运输部组织编译并发布了一系列中国公路行业标准外文版。

中华人民共和国交通运输部发布的公路工程行业标准代号为JTG,体系范围涵盖公路工程从规划建设到养护和运营管理全过程所需要的设施、技术、管理与服务标准,也包括相关的安全、环保和经济方面的评价等标准。



《公路隧道照明设计细则》(简称《细则》)是公路隧道照明设计有关的重要技术标准,主要用于各等级的新建和改扩建山岭公路隧道照明设计和运营,可供隧道运营管理企业、设计院、施工企业、工程监理等使用。2000 年由交通部首次发布实施《公路隧道通风照明设计规范》(JTJ 026.1—1999),作为公路隧道照明设计首部专业规范,对规范设计行为、保障我国公路隧道运营安全和推进公路隧道照明科技进步均起到了重要作用。细则》在充分总结中国相关科研成果和大量工程经验的基础上,吸收借鉴国际先进的公路隧道照明技术,进行改进与修订,2014 年发布修订版《细则》。《细则》以科学合理、经济安全、利用高效为基本制订原则,重点对公路隧道照明设计和运营的技术要求进行统一和规范,主要内容包括照明设置条件与方法、短隧道照明设计参数、分期实施、运营调光模式、节能标准等。本英文版的编译发布便是希望将中国的工程经验和技术成果与各国同行进行交流分享,为其他国家山岭公路隧道照明设计与运营提供参考借鉴。

《公路隧道照明设计细则》英文版的编译工作由中华人民共和国交通运输部委托招商局重庆交通科研设计院有限公司主持完成,并由中华人民共和国交通运输部公路局组织审定。本规范在编译过程中得到欧美多名专家的支持,特别感谢巴基斯坦专家 Asim Amin、澳大利亚专家 Arnold Dix、中国专家黄梦琪,以及巴基斯坦专家 Abu Bakar、Saif Ali Tahir 等在编译与审定期间给予的协助与支持。

本英文版标准的内容与现行中文版一致,如出现异议时,以中文版为准。

感谢中文版主要编写者蒋树屏、陈建忠先生在本英文版编译与审定期间给予的指导与支持。

如在执行过程中发现问题或有任何修改建议,请函告英文版主编单位(地址:重庆市南岸区学府大道 33 号隧道与地下工程研究院,邮政编码:400067,电子邮箱:chengliang@ cmhk. com),以便修订时研用。

英文版主编单位:招商局重庆交通科研设计院有限公司

英文版主编:胡学兵

英文版参编人员:丁浩、陈建忠、刘帅、杨孟、邓欣、张琦

英文版主审: Asim Amin(巴基斯坦)、Bedi Anmol(澳大利亚)

英文版参审:张慧彧(中国), 黄梦琪(中国),
Abu Bakar(巴基斯坦), Saif Ali Tahir(巴基斯坦)

The People's Republic of China

Ministry of Transport

Public Notice

No.50

Public Notice on Issuing the English and French Versions of Seven Highway Engineering Industrial Standards including *Specifications for Design of Highway Tunnels Section 1 Civil Engineering*

The English and French versions of *Specifications for Design of Highway Tunnels Section 1 Civil Engineering* [JTG 3370.1—2018 (EN), substituting JTG D70—2004 (E); and JTG 3370.1—2018(FR)], the French version of *Specifications for Design of Highway Tunnels Section 2 Traffic Engineering and Affiliated Facilities* [JTG D70/2—2014(FR)], the English version of *Guidelines for Design of Lighting of Highway Tunnels* [JTG/T D70/2-01—2014(EN)], the English version of *Guidelines for Design of Ventilation of Highway Tunnels* [JTG/T D70/2-02—2014 (EN)], the English version of *Specifications for Seismic Design of Highway Tunnels* [JTG 2232—2019(EN)], and the English version of *Technical Specifications of Maintenance for Highway Tunnel* [JTG H12—2015(EN)] are issued hereby for promoting international cooperation and sharing of standards in highway engineering industry.

The general administration and final interpretation of theforeign language versions of the above mentioned standards belong to Ministry of Transport, while particular interpretation for application and routine administration shall be provided by China Merchants Chongqing Communications Technology Research & Design Institute Co., Ltd.

Inevent of any ambiguity or discrepancies between the foreign language versions and Chinese version, the Chinese version should be referred and accepted.

Comments, suggestions and inquiries are welcome and should be addressed to China Merchants Chongqing Communications Technology Research & Design Institute Co., Ltd. (Address: Institute of Tunnel and Underground Engineering, No.33 Xuefu Avenue, Nan'an District, Chongqing, P. R. China; Postal Code: 400067; E-mail: chengliang@cmhk.com).

It is hereby announced.

Ministry of Transport of the People's Republic of China

September20, 2023

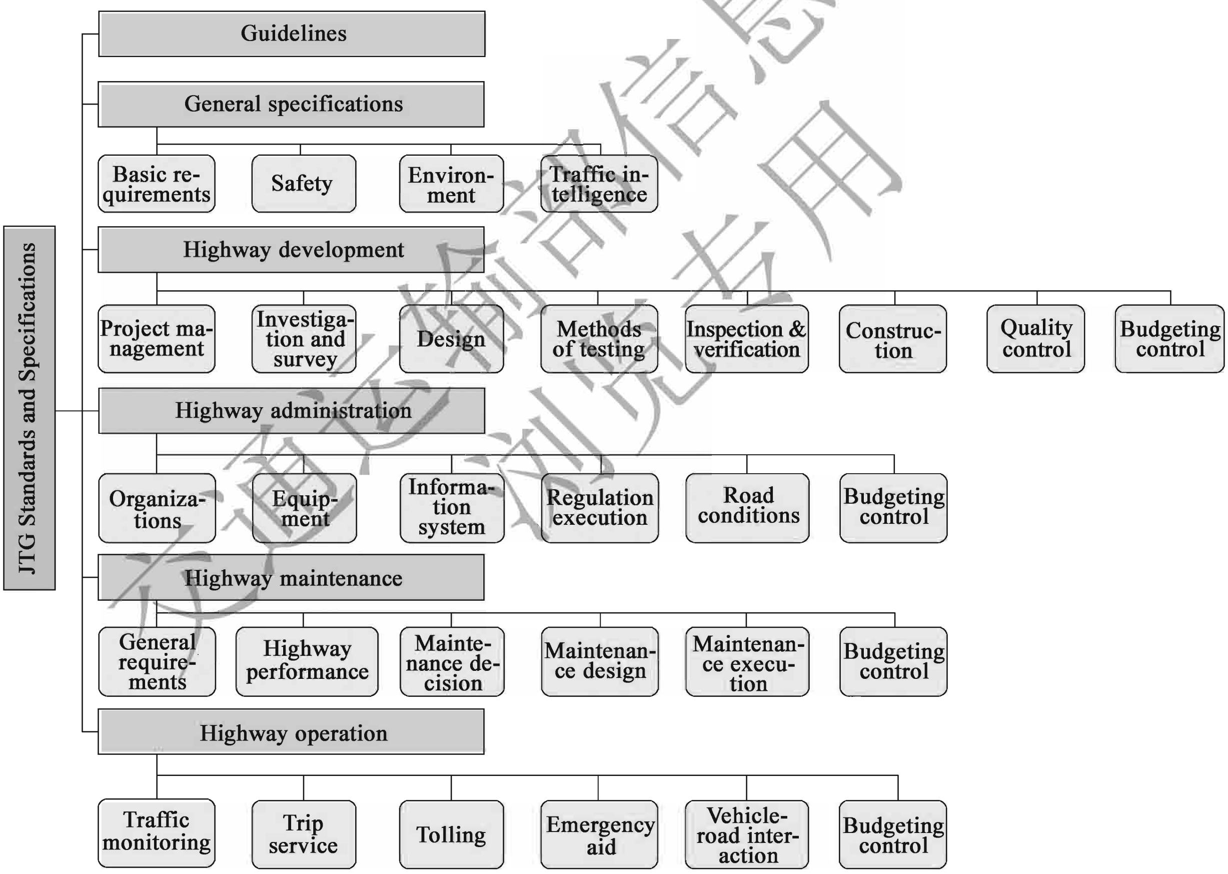
General Office of Ministry of Transport Printed on September 21, 2023

Introduction to English Version

Standards reflect the achievement of civilization and progress, provide common languages for technical communications and improve global connectivity. In recent years, Chinese government has been proactively implementing the standardization to stimulate innovation, coordination, greening and opening up for shared development in China and worldwide. In light of mutual development along the Silk Road Economic Belt and the 21st – Century Maritime Silk Road (so called the "One Belt One Road" initiative), the Ministry of Transport of the People's Republic of China organized translation and published international version of Chinese highway industry standards and specifications to cope with the increasing demands for international cooperation in world transportation, achieve interconnected development and promote knowledge dispersion and experience sharing.

JTG is the designation referring to the standards and specifications of highway transportation industry, issued by the Ministry of Transport of the People's Republic of China. It covers the standards and specifications in terms of facilities, technology, administration and service forthe whole process from highway planning through to highway maintenance. The criteria for safety, environment and economy assessment are also included.

The*Guidelines for Design of Lighting of Highway Tunnels* (hereinafter referred to as the *Guidelines*) are important technical standards for the lighting design of highway tunnels. It is mainly used by tunnel operation management enterprises, design institutes, construction enterprises and engineering supervisors for lighting design and operation of new, modified and expanded mountain highway tunnels at different levels. In 2000, the *Guidelines for Design of Lighting of Highway Tunnels* (JTJ 026.1—1999) were first issued for implementation by the Ministry of Transport. As the first professional specifications for the lighting design of highway tunnels, they have played an important role in standardizing the design behaviors, ensuring the operation safety of highway tunnels in China, and promoting the scientific and technological progress of highway tunnel lighting. On the basis of fully summarizing the relevant scientific research achievements and rich engineering experience of China, the *Guidelines* were improved and revised with reference to international advanced highway tunnel lighting techniques. In 2014, the revised version of the *Guidelines* was released. Based on the basic principles of scientific rationality, economic safety and high utilization efficiency, the *Guidelines* focus on unifying and standardizing the technical requirements for lighting design and operation of highway tunnels, and involve lighting setting conditions and methods, short tunnel lighting design parameters, implementation by stages, operating dimming modes, and energy-saving standards. The purpose of compiling and publishing this English version is to exchange and share China' s engineering experience and technical achievements with counterparts in other countries, and to provide reference for lighting design and operation of mountain highway tunnels in other countries.



The Ministry of Transport of the People' s Republic of China entrusted China Merchants Chongqing Communications Technology Research & Design Institute Co., Ltd. to preside over the compilation of the English version of *Guidelines for Design of Lighting of Highway Tunnels*, and the Highway Bureau of the Ministry of

Transport of the People's Republic of China organized the review. These Specifications were supported by many experts in Europe and America during compilation. Special thanks are also given to Pakistani expert Asim Amin, Australian expert Arnold Dix, Chinese expert Huang Mengqi, Pakistani experts Abu Bakar and Saif Ali Tahir for their assistance and support during the editing and approval of these Specifications.

The English version of this standard is consistent with the current Chinese version. Inthe event of any ambiguity or discrepancies, the Chinese version shall be referred and accepted.

Gratitude is given here to Mr. Jiang Shuping and Mr. Chen Jianzhong, the editors in charge ofthe Chinese version, for their guidance and support during the editing and approval of the English version.

Comments, suggestions and inquiries are welcome and should be addressed to the editing organization in charge ofthe English version (address: Tunnel and Underground Engineering Research Institute, Merchants Chongqing Communications Technology Research & Design Institute Co., Ltd., No. 33, Xuefu Avenue, Nan'an District, Chongqing, postal code: 400067, e-mail: chengliang@cmhk.com).

Editing organization in charge for English version:

China Merchants Chongqing Communications Technology Research & Design Institute Co., Ltd.

Chief editor for English version: Hu Xuebing

Associate editors for Englishversion:

Ding Hao, Chen Jianzhong, Liu Shuai, Yang Meng, Deng Xin and Zhang Qi

Review editor for English version:

Asim Amin (Pakistan) and Bedi Anmol (Australia)

Associate review editors for English version:

Zhang Huiyu (China) Huang Mengqi (China)

Abu Bakar (Pakistan) Saif Ali Tahir (Pakistan)

Foreword to Chinese Version

According to the *Notice on* 2007 *Compilation and Revision Plan of Highway Engineering Standard* (JGLF [2007] No. 378) issued by the Ministry of Transport, China Merchants Chongqing Communications Technology Research & Design Institute Co., Ltd. is responsible for the compilation of *Guidelines for Design of Lighting and Ventilation of Highway Tunnels*.

As the first professional standard for the design of lighting of highway tunnels, the *Specifications for the Design of Ventilation and Lighting of Highway Tunnels* (JTJ 026.1—1999) has played an important role in the design standardization, operation safety safeguard and lighting technology promotion of highway tunnels since its issuance on June 1, 2000. For more than ten years, as the scale of highway tunnel enlarged and the types of highway tunnel enriched, we have gained rich experience in the construction, operation and management and developed new energy-conservation lighting technologies. On the basis of engineering practice and new scientific achievements in recent years, the *Guidelines* actively introduces new theories, new technologies, new materials and new equipment, and draws lessons from foreign experience and advanced technologies in the lighting of highway tunnel. With consideration to the energy-conservation technology development trend of highway tunnel and the status of tunnel lighting construction in China, tunnel lighting requirements in the *Specification for Design of Traffic Engineering of Highway Tunnels* (JTG/T D71—2004) and *Specifications for Design of Ventilation and Lighting of Highway Tunnels* (JTJ 026.1—1999) are amended and expanded and the *Guidelines for Design of Lighting of Highway Tunnels* (JTG/T D70/2-01—2014) is hereby issued after approval for implementation.

The *Guidelines* consists of eleven chapters and two appendixes: 1 General Provisions, 2 Glossary and Symbols, 3 General, 4 Lighting of Threshold Zone, 5 Lighting of Transition Zone, 6 Lighting of Interior Zone, 7 Lighting of Exit Zone, 8 Emergency Lighting and Approach Lighting, 9 Energy-conservation Standard and

Measures, 10 Lighting Calculation, 11 Design Principles of Dimming, Appendix A Pre-digestion Luminance Factor of Road Surface and Appendix B Examples of Lighting Calculation.

Compared with the*Specifications for Design of Ventilation and Lighting of Highway Tunnels* (JTJ 026. 1—1999), the lighting indicators, dimming system, energy-conservation standard and other items are materially revised, the lighting layout requirements of tunnel, lighting setting at threshold zone and luminance of interior zone adjusted and the adaptation luminance indicators, tunnel dimming system and indicators revised herein. Meanwhile, requirements on staged lighting, parameters of short tunnel lighting and indicators of energy-conservation light sources are newly added too.

All unitsrelated shall inform the routine management team of the problems and suggestions found in implementation for reference in revision by writing to the contact person Tu Yun at 33 Xuefu Avenue, Nan'an District, 400067, Chongqing Municipality via Tel. No. 023-62653440, Fax No. 023-62653078 and E-mail No. tuyun@cmhk.com.

Editing organization in charge:

China Merchants Chongqing Communications Technology Research & Design Institute Co.,Ltd.

Associate editing organizations:

ChongqingJiaotong University

Zhejiang Provincial Institute of Communications Planning, Design & Research

Chang'an University

SouthwestJiaotong University

Chief editor: JiangShuping

Associate editors:

Tu Yun	Qu Zhihao	WangXiaowen	WuDexing
VXie Yongli	ChenJianzhong	DengXin	WangMingnian
LiWeiping	WangYaqiong	LiKe	WangShaofei
ZhouJian	WangXiaojun		

Contents

1 General Provisions

1.0.1 These *Guidelines* are intended to implement the national technical and economic policies, unify the lighting design standards of highway tunnels, guide the highway tunnel lighting design to conform to the principles of scientific, reasonable, economic, safe and efficient utilization and provide a lighting technical reference for tunnel operation.

***Background*:**

To ensure a visible environment, lighting shall be equipped within tunnels. The luminance shall be compatible with the real-time trafficflow and adaptation of luminance. Thus, illumination dimming is significant in tunnel operation. The Guidelines provides a technical basis for the lighting design and operation of highway tunnels so as to realize safe operation and energy-conservation.

1.0.2 These *Guidelines* shall be applicable to the newly-built and re-built mountain tunnels of expressway, Class-1, Class-2, Class-3 and Class-4 highways.

***Background*:**

The Guidelines is prepared for the mountain tunnels of highways at different grades. Other tunnels, such as submerged tunnel, urban tunnel and mountain tunnel have no fundamental difference in lighting sectioning, lighting calculation and other aspects, but their main difference lies in luminance indicators.

1.0.3 The lighting design of highway tunnel shall be incorporated into the overall design of tunnel.

***Background*:**

Tunnel lighting directly affects the operation safety and energy consumption of tunnels. The scale of lighting facilities is related to the tunnel length, horizontal curve, vertical curve and traffic volume. The adaptation luminance is related to the height of side and front slopes and vegetation at the *tunnel portal as well tunnel frame type and decoration. Luminaires setting outside the tunnel are related to the structures of road segment. Therefore, lighting design shall be included in the overall design of tunnel.*

1.0.4 The design hourly volume (DHV) in the lighting design of highway tunnel shall be the design peak hourly volume (PHV) of hybrid vehicles.

***Background*:**

In feasibility study report of engineering, passenger car unit (pcu) is used for traffic volume forecast. During lighting design, PCU traffic volume shall be converted into PHV of hybrid vehicles.

1.0.5 Lighting design of highway tunnel shall be subject to the principle of comprehensive planning and integrated design; and lighting facilities may be implemented in stages according to the traffic volume forecast changes.

***Background*:**

To ensure operation safety, reduce initial investment and decrease energy consumption, lighting system of tunnel may beimplemented in stages according to the traffic volume forecast changes.

According to surveys, lighting facilities are normally implemented in two stages: lighting design of expressway and Class-1 arterial highways phases in by ten years; that of Class-1, Class-2 and Class-3 collector-distributor highways phases in by seven years; that of Class-4 highways is confirmed according to individual cases. Since traffic volume develops differently, to reasonably set up the lighting system, it may be built in stages according to the traffic volume forecast changes. Taking a three-staged lighting system for an example, for expressway and Class-1 arterial highway, DHV of the first stage is 350veh/(h · ln), that of the second and third stages is confirmed according to the traffic volume forecast in ten years and twenty years respectively; for Class-1, Class-2 and Class-3 collector-distributor highways, DHV of the first stage is 180veh/(h · ln), that of the second and third stages is confirmed according to the traffic volume forecast in seven years and fifteen years respectively.

Duringthe staged program of lighting design, light sources, lighting layout, power change and other factors are generally considered. An optimal program meeting the lighting requirements of each stage is selected according to the comprehensive economic analysis and comparison.

1.0.6 Lighting design of highway tunnels shall be based on normal traffic conditions and abnormal traffic conditions.

***Background*:**

Abnormal traffic conditions include traffic accident, fire and other conditions requiring emergency evacuation and rescue as well as maintenance, overhauling, construction and other situations requiring special lighting.

1.0.7 Lighting design of highway tunnels shall include dimming.

***Background*:**

Reliable and advanceddimming is important for safe operation and energy conservation of a tunnel. By dimming, the luminance level can be more compatible with real-time traffic flow and adaptation luminance so as to ensure the operation safety and energy conservation.

1.0.8 New theories, new technologies, new materials and new equipment shall be actively and reliably adopted for the lighting design of highway tunnel.

***Background*:**

Since the turn of the 21 century, a great number of studies on lighting of highway tunnel have been carried out at home and abroad. With the proposal of theories or methods such as "permeation ratio", "mesopic vision" and "smart dimming" and the development and application of new light sources such as LED and single-capped electrodeless fluorescent tube, the lighting technologies of highway tunnel have made great progress. The application of new theories, new technologies, new materials and new equipment improves lighting quality, saves energy, and makes tunnel lighting more scientific and reasonable.

1.0.9 In addition to these *Guidelines*, lighting design of highway tunnels shall also comply with the relevant provisions of current national and industrial standards.

2 Terms and Symbols

2.1 Terms

2.1.1 Illuminance

Illuminance of a point refers to the ratio of the luminous flux of surface element to the area of the surface element.

2.1.2 Luminance

Luminance refers tothe luminous intensity of the projected unit area.

2.1.3 Access zone

Access zone refers to the segment of onestopping distance outside the tunnel entrance.

2.1.4 Threshold zone

Threshold zone refers to the first lighting section ofa tunnel, where drivers' visual adaption changes from bright environment outside the tunnel to a darker environment in the tunnel.

2.1.5 Transition zone

Transition zone refers to the lighting section between threshold zone and interior zone, where drivers shall adapt to the change from high luminance at the threshold zone to low luminance in the tunnel.

2.1.6 Interior zone

Interior zone refers to the lighting section connectingwith threshold zone or transition zone along the driving direction, where the required luminance for drivers is the lowest among all zones.

2.1.7 Exit zone

Exit zone refers to the lighting section near to tunnel exit, where drivers' visual adaption changes from low luminance in the tunnel to high luminance outside the tunnel.

2.1.8 Adaptation luminance

Adaptation luminance refers to the average luminancethrough a 20° conical field of view, one stopping distance to tunnel portal and 1.5m above the road surface.

2.1.9 Emergency lighting

Emergency lighting refers to the lighting enabled in the event of power failure, which ensures lighting during pedestrian evacuation to ensure tunnel occupant safety.

2.1.10 Average road surface illuminance

Average road surfaceilluminance refers to the measured or calculated illuminance average of points pre-set on the road surface.

2.1.11 Average road surface luminance

Average road surface luminance refers tothe measured or calculated average luminance average of points pre-set on the road surface.

2.1.12 Overall uniformity of the luminance of road surface

Overalluniformity of the luminance of road surface refers to the ratio of the minimum luminance to the average luminance on road surface.

2.1.13 Longitudinal uniformity of the luminance of road surface

Longitudinaluniformity of the luminance of road surface refers to the ratio of the minimum luminance to the maximum luminance on road surface centerline.

2.1.14 Maintenance factor

Maintenance factor refers tothe ratio of the average road surface luminance provided after a certain service time, which is affected by Lamp Lumen Depreciation (LLD), dirt deposits of luminaires and others, to the average road surface luminance at initial installation.

2.1.15 Utilization factor

Utilization factor refers tothe ratio of total luminous flux projected on road surface to total luminous flux generated by all light sources.

2.2 Symbols

E_{av}—average road surface illuminance;

f—flicker frequency;

H—height from the light source center to road surface;

I_{cr}—luminous intensity of luminaires at calculation point;

k—LLD factor of luminance at threshold zone;

L—tunnel length;

$L_{20}(S)$—adaptation luminance;

L_{av}—average road surface luminance;

L_{ex}—luminance at exit zone;

L_{in}—luminance at interior zone;

L_{min}—the minimum road surface luminance;

L'_{min}—the minimum luminance of road surface centerline;

L'_{max}—the maximum luminance of road surface centerline;

L_{th}—luminance at threshold zone;

L_{tr}—luminance at transition zone;

N—design hourly volume (DHV);

M—maintenance factor;

S—luminaire spacing.

3 General

3.0.1 Design of lighting of highway tunnels shall meet the requirements on average road surface luminance, overall uniformity of the luminance of road surface, longitudinal uniformity of the luminance of road surface, flicker and guidance.

Background:

Driversvisually perceive the luminance of road surface during driving, therefore, it is comparatively scientific and reasonable to take luminance of road surface as the principle lighting indicator. By now, the International Commission on Illumination (CIE) and many countries take luminance indicator as the basis for compilation of standards on tunnel lighting.

Flicker frequency of lighting system is related to the luminance, luminaires' layout, vehicle speed and other factors. Reasonable flicker frequency can avoid visual discomfort and psychological interference so as to ensure driving safety.

Guidance refers tothe guidance of lighting facilities, providing visual guidance such as road direction, alignment, and gradient to drivers.

3.0.2 Lighting facilities of highway tunnels at different classes shall meet the following requirements:

1 Expressway tunnels and Class-1 highway tunnels with a length more than 200m shall be equipped with lighting facilities.

2 Optically long tunnels of expressway with a length more than 100m but shorter than or equal to 200m and that of Class-1 highway shall be equipped with lighting facilities.

3 Class-2 highway tunnels with a length more than 1000m shall be equipped with lighting

facilities; Class-2 highway tunnels with a length more than 500m but shorter than or equal to 1000m should be equipped with lighting facilities; Class-3 and Class-4 highway tunnels shall be installed with lighting facilities according to the actual conditions.

4 The tunnels with pedestrian passageway shall be set up with lighting facilities according to tunnel length and environmental conditions.

5 The tunnels without lighting facilities shall be equipped with guiding devices.

Background:

Tunnel managementauthorities and design authorities of some Chinese provinces (cities) have made requirements on the length of electric lighting with consideration to the operation of built tunnels. Please refer to Table 3-1.

In consideration of the relatively small traffic volume and lower vehicle speed accommodated by Class-2, Class-3 and Class-4 highway tunnels, requirements on the length of electric lighting are made on the basis of operation safety and energy conservation.

The lighting facilities of Class-3 and Class-4 highway tunnels shall be decided according to the highway function, importance, local economy, power supply and other conditions.

Table 3-1 Tunnel lengthrequirements for lighting facilities in some Chinese provinces (cities)

Province (city)	Requiredtunnel length (m)
Chongqing	>300
Zhejiang	>200
Guangdong	>200
Liaoning	>200
Gansu	>350
Shaanxi	>300

Note: lengths in the table are for straight tunnels.

Guiding devices favor the marking of tunnel alignment and profile and the improvement of driving safety. Self-luminous guiding devices or active guiding devices are normally adopted.

3.0.3 Lighting design of highway tunnels shall be comprehensive based on the collection of adequate data on civil works and traffic engineering design, and comply with the following principles:

1 The tunnel portal orientation and exterior environment shall be surveyed.

2 Adaptation luminance shall be primarily decided or measured on site; and exterior luminance-reduction program may be formulated if necessary.

3 Luminance indicators of threshold zone, transition zone, interior zone and exit zone at each stage shall be confirmed according to the change of traffic volume.

4 Energy-conservation light sources and efficient luminaires shall be adopted; and their installation methods and locations of luminaires shall be decided according to the type of tunnel sections and luminaires.

5 Luminaire spacing, the uniformity of the luminance of road surface and others shall be calculated according to the road surface materials and table of luminous intensity distribution.

6 Adaptation luminance should be measured and verified on site after the completion of civil works of tunnel portal.

Background:

The parameters selected, light sources selected, luminaires' layout and others for the lighting design of highway tunnels are related to tunnel portal orientation, exterior environment, road surface materials, traffic volume and others. Therefore, lighting design shall be based on comprehensive considerations.

Exterior environment includestopography of tunnel location, vegetation, vertical and horizontal alignments, meteorological conditions and so on.

Adaptation luminance isone of key considerations for tunnel lighting. It is greatly affected by tunnel orientation, sky percentage through a 20° conical field of view, vegetation and portal decorations; and shall be primarily considered at the beginning of design or measured on site. If there exists sky through a 20° conical field of view or has bright portal decorations, the adaptation luminance will be increased, and thus aggravating the "black hole effect" and increasing the energy consumption. By this time, luminance-reduction measures may be adopted to decrease the adaptation luminance.

3.0.4 The DHV of expressway tunnel lighting shall be converted according to the annual average daily traffic (AADT) proposed in the feasibility study report of the road segment where the tunnel is located, and should meet the following requirements:

1 The DHV factor should be the data provided in the feasibility study report; when the feasibility study report does not explicitly put forward this data, that of the tunnel in mountainous and hilly terrains is preferable to be 12%, level and rolling terrains 10%, and near town 9%.

2 The directional distribution factor of unidirectional traffic tunnel should be the data provided in the feasibility study report. When the feasibility study report does not explicitly put forward this data, 55% is recommended.

Background:

After extensivesurveys, the DHV factor proposed by feasibility study reports of expressway projects varies from 9% to 12%. In order to avoid the waste of lighting system caused by excessive DHV, this Clause is made according to the summary of surveys and feasibility study reports.

In lighting design, thetraffic volume of passenger car unit (PCU) is converted into the PHV of hybrid vehicles in accordance with "Representative Vehicle Types and Vehicle Conversion Factor" in the*Technical Standard of Highway Engineering* (JTG B01-2003) and specific traffic composition of projects as per the following steps:

Step 1: convert the AADT (pcu/d) proposed in the feasibility study report into the PHV of PCU (pcu/h);

Step 2: respectively calculate thePHV of PCU corresponding to each vehicle type according to the traffic composition percentage proposed in the feasibility study report; and

Step 3: convert thetraffic volume of PCU of each vehicle type into the PHV (veh/h) of hybrid vehicles in accordance with "Representative Vehicle Types and Vehicle Conversion Factor" in the*Technical Standard of Highway Engineering* (JTG B01-2003).

3.0.5 Unidirectional traffic tunnel lighting consists of the lighting at threshold zone, transition zone, interior zone and exit zone and approach and the luminance-reduction facilities at access zone. Lighting sections are shown in Figure 3.0.5.

3.0.6 Bidirectional traffic tunnel lighting is divided into the lighting of threshold zone, transition zone, interior zone and approach and the luminance-reduction facilities near to tunnel portal. Lighting sections are shown in Figure 3.0.6.

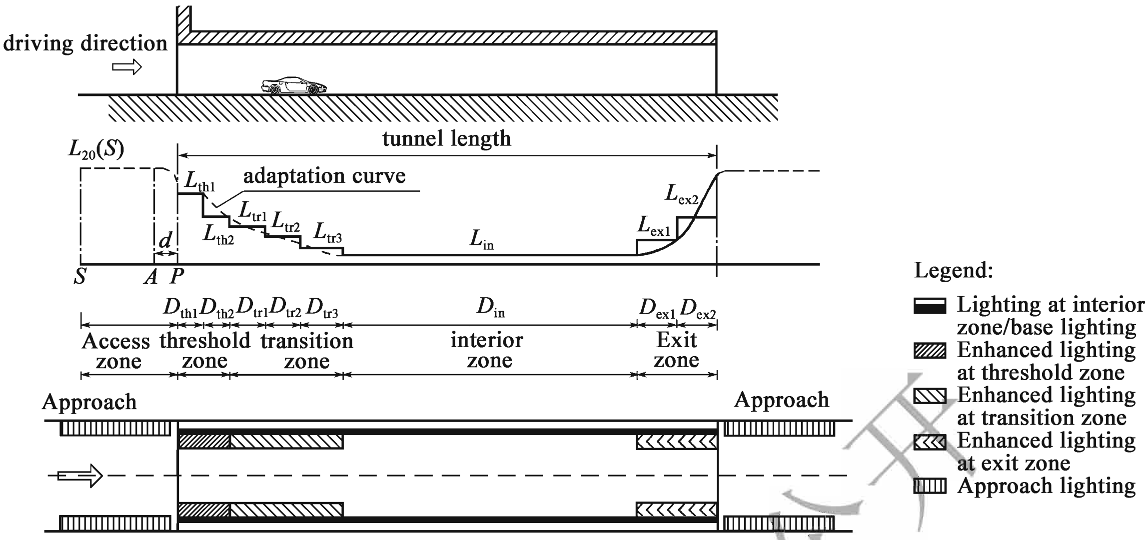


Figure 3.0.5 Lighting sections of unidirectional traffic tunnel

P-tunnel portal; S-start of access zone; A-adaption point; d-adaption distance; $L_{20}(S)$-adaptation luminance; L_{th1}, L_{th2}-luminance at threshold zone; L_{tr1}, L_{tr2} and L_{tr3}-luminance at transition zone; L_{in}-luminance at interior zone; L_{ex1}, L_{ex2}-luminance at exit zone; D_{th1}, D_{th2}-respective length of access zone I (TH_1) and access zone II (TH_2); D_{tr1}, D_{tr2} and D_{tr3}-respective length of transition zone I (TR_1), transition zone II (TR_2) and transition zone III (TR_3); D_{in}-length of interior zone; D_{ex1} and D_{ex2}-respective length of exit zone I (EX_1) and exit zone II (EX_2)

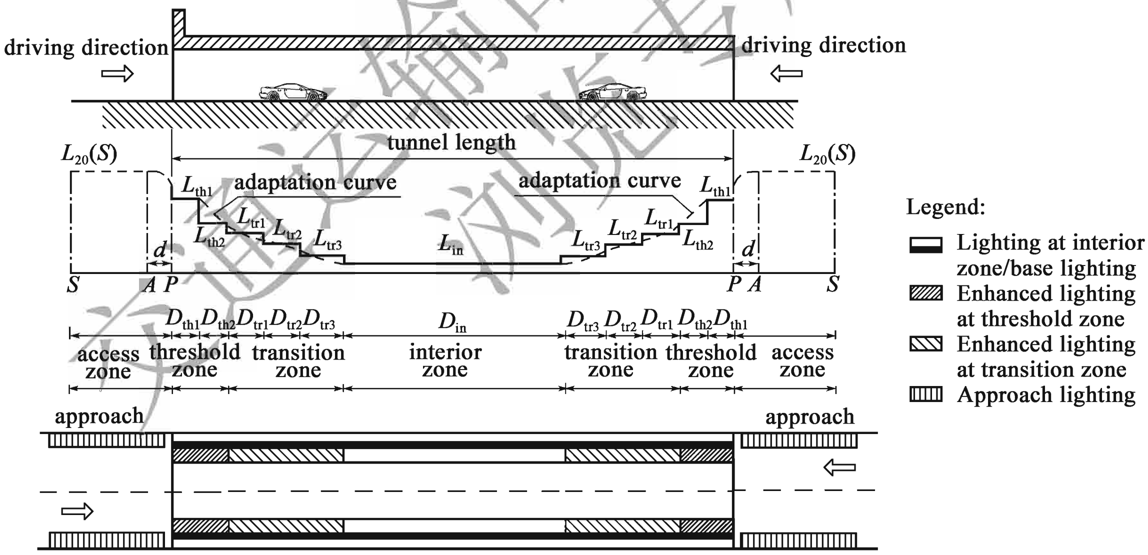


Figure 3.0.6 Lighting sections of bi-directional traffic tunnel

***Background*:**

3.0.5 ~ 3.0.6 Sectional lighting aims to meet drivers' vision adaption demands from high/low luminance to low/high luminance. The adaption time from high luminance to low luminance is normally longer than that from low luminance to high luminance. Therefore, enhanced lighting section at entrance is longer than that at exit.

3.0.7 Lighting at threshold zone, transition zone and exit zone consists of base lighting and enhanced lighting; and the base lighting shall be consistent with lighting at interior zone.

Background:

Base lighting aims to providethe basic luminance along the whole tunnel so as to ensure driving safety while the enhanced lighting aims to reduce the luminance difference generated by driving into and out of tunnel at daytime.

3.0.8 Average luminance of tunnel walls within 2m should not be lower than 60% of the average road surface luminance.

Background:

Luminance of tunnel walls forms part of the tunnel background luminance, which satisfies the requirements of visual adaptation and visual guidance for drivers. The*Guide for Lighting of Highway Tunnels and Underpasses* (CIE 88-2004) and *Lighting Applications-Tunnel Lighting* (CR 14380:2003) are referred to in the compilation of this Clause.

3.0.9 The conversion coefficient between average luminance and average illuminance should be measured on site; if site measurement is impossible, 15lx/(cd · m^{-2}) is recommended for black bituminous pavement while 10lx/(cd · m^{-2}) is recommended for cement concrete pavement.

Background:

Conversion coefficient between average road surface luminance and averageilluminance is related to materials and color of road surface. Conversion coefficient listed in this Clause has referred to the requirements in the*Standard for Lighting Design of Urban Road* (CJJ45-2006).

3.0.10 Dirt deposits and maintenance of luminaires shall be considered during lighting design of highway tunnels. A maintenance factor should be 0.7. The recommended maintenance factor of extra-long tunnels with a longitudinal slope greater than 2% and a ratio of large vehicles greater than 50% should be 0.6.

Background:

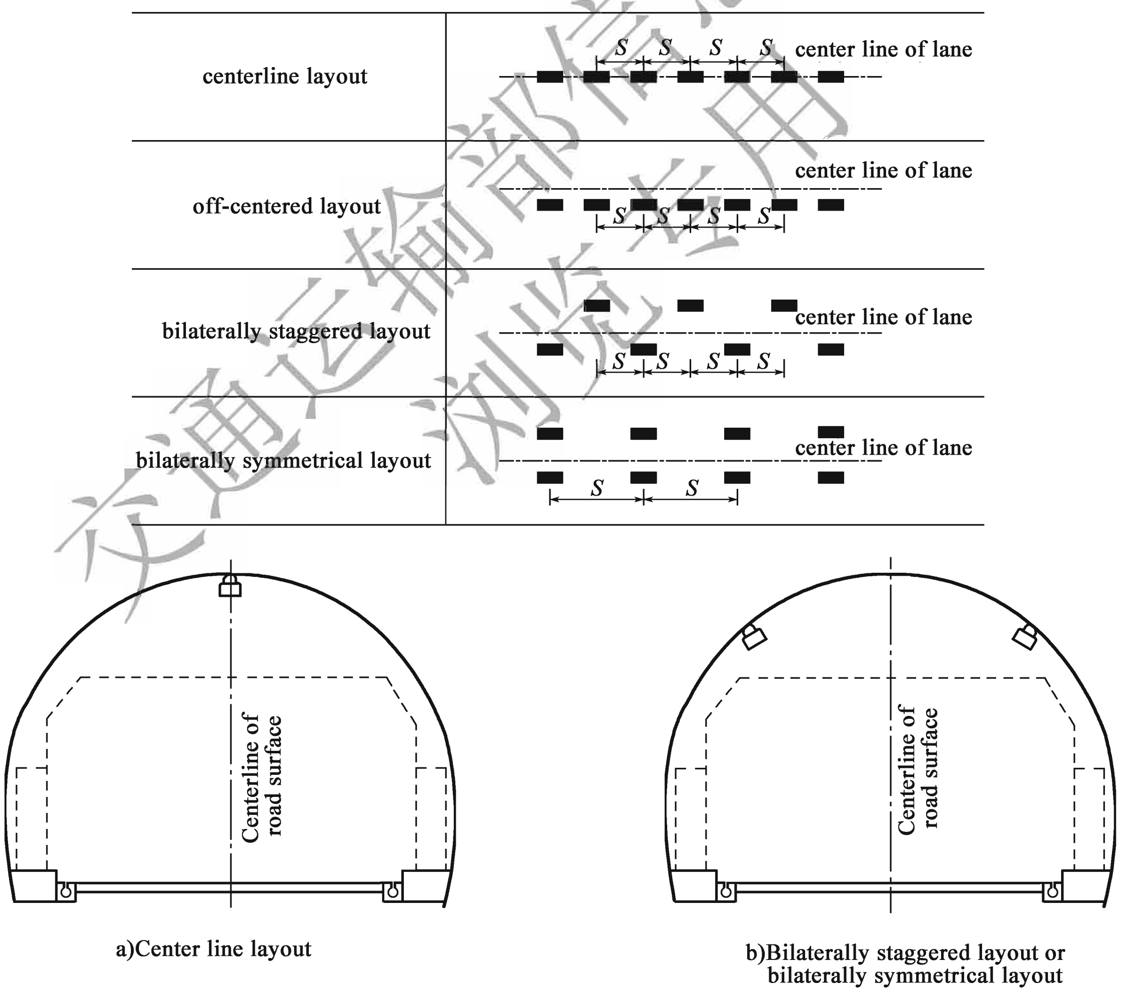
Luminaires management and regular maintenance are significant for tunnel operation. Detailed and thorough maintenance management can keep the luminance level of lighting systems, extend the service life of light sources and luminaires, reduce operation cost and ensure an economical and energy-conservation operation of the lighting system.

Maintenance factorevaluation is affected by many aspects, such as decrease of luminaires, lampshade and reflector efficiency, decrease of the reflectivity of tunnel walls and damage of luminaires' fittings due to the luminous flux attenuation of light sources as well as the long-term erosion of dust and other contaminants deposited on light sources and luminaires. Maintenance factor, M reflects the comprehensive influence of the above aspects. In consideration of the differences in the longitudinal slope, ratio of large vehicle, operation and management methods of each tunnel, the maintenance and management requirements on luminaires and light sources are different. Therefore, this Clause is hereby compiled.

3.0.11 Luminaires should be arranged in centerline layout, off-centered layout, bilaterally staggered layout or bilaterally symmetrical layout.

Background:

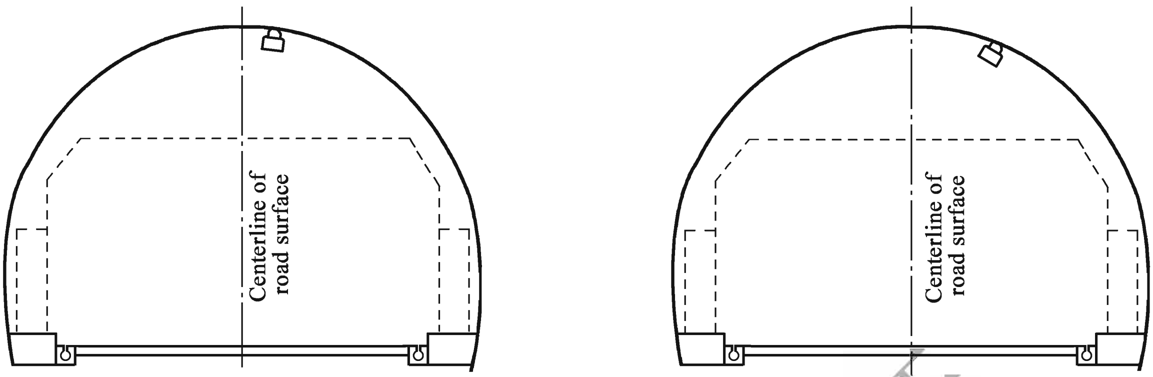
Layoutof luminaires will affect the efficiency of lighting system. Among them, the efficiency of centerline and off-centered layouts is higher than that of bilaterally staggered and symmetrical layouts; and the efficiency of bilaterally staggered layout is higher than that of bilaterally symmetrical layout. The common layouts are shown in Figure 3-1.



a)Center line layout

b)Bilaterally staggered layout or bilaterally symmetrical layout

Figure 3-1



c)off-centered layout

Figure 3-1 Examples of lighting layouts

3.0.12 Enhanced luminaires at threshold zone and exit zone should be arranged from a point within 10m to portal top.

Background:

Due to the casting of natural light outside the tunnel, luminance near to the portal is higher. Study shows that the natural light can be a part of the enhanced lighting of the threshold zone. This Clause incorporates the role of natural lighting in the threshold zone. This is also mentioned in the standards and technical documents of the United Kingdom, Japan and other countries as well as CIE, CEN and other international organizations.

3.0.13 The performance of tunnel luminaires shall meet the following requirements:

1 Their ingress protection (IP) shall not be lower than IP65.

2 They shall be equipped with glare screens applicable to highway tunnel.

3 Their light sources and accessories can be replaced easily.

4 Their parts and accessories are of good antiseptic property.

5 Their installation angles are easy to be adjusted.

6 Luminaire efficiency of gas-discharge luminaires shall not be less than 70% and power factor shall not be less than 0.85.

7 Power factor of LED luminaires shall not be less than 0.95.

Background:

1 IP65 means that: the dustproof property reaches level 6, without entry of dust; and the waterproof property reaches level 5, without adverse effect of water spray from any directions.

2 Power factor of gas-discharge luminaires normally ranges between 0.4 and 0.6, which can be increased by capacitance compensation or electronic ballast. From an economical perspective, the compensated power factor should be between 0.8 and 0.9, and thus 0.85 is adopted herein.

4 Lighting of Threshold Zone

4.1 Luminance of threshold zone

4.1.1 Two lighting sections (TH_1 and TH_2) should be set up at the threshold zone. The corresponding luminance shall be calculated by using formula (4.1.1-1) and formula (4.1.1-2) respectively:

$$L_{th1} = k \times L_{20}(S) \quad (4.1.1\text{-}1)$$

$$L_{th2} = 0.5 \times k \times L_{20}(S) \quad (4.1.1\text{-}2)$$

Where:

L_{th1}—luminance (cd/m^2) of threshold zone TH_1;

L_{th2}—luminance (cd/m^2) of threshold zone TH_2;

k—LLD factor of threshold zone, may be subject to Table 4.1.1;

$L_{20}(S)$—adaptation luminance (cd/m^2).

Table 4.1.1 LLD factor of threshold zone

Design hourlyvolume$N$ [veh./(h · ln)]		Designspeedv_t (km/h)				
Unidirectional traffic	Bi-directional traffic	120	100	80	60	20 ~ 40
⩾1200	⩾650	0.070	0.045	0.035	0.022	0.012
⩽350	⩽180	0.050	0.035	0.025	0.015	0.010

Note: in case of a mediumtraffic volume, the result shall be calculated by linear interpolation.

Background:

This Clause requires that two lighting sections (TH_1 and TH_2) shall be set up at threshold zone. According to the surveys of highway tunnels constructed in recent ten years, the luminance of the second half of the threshold zone is higher, thus, sectional lighting is adopted. This is also mentioned in the standards and technical documents of the United Kingdom, Japan and other countries and CIE, CEN and other international organizations.

K-value Method is adopted in the*Guidelines* to calculate the enhanced lighting luminance of the threshold zone. The lighting standards of international organizations such as CIE and CEN and some countries are referred to for the LLD factorof threshold zone. Besides, economic development and tunnel lighting status in China are fully considered.

4.1.2 The luminance of TH_1 and TH_2 for non-optically long tunnel with a length more than 500m and that of the optically long tunnel with a length more than 300m shall be calculated by formula (4.1.1-1) and formula (4.1.1-2) respectively.

4.1.3 The luminance of TH_1 and TH_2 of non-optically long tunnel with a length more than 300m but shorter than or equal to 500m and that of the optically long tunnel with a length more than 100m but shorter than or equal to 300m should be 50% of the results calculated by formula (4.1.1-1) and formula (4.1.1-2) respectively.

4.1.4 The luminance of TH_1 and TH_2 of non-optically long tunnel with a length more than 200m but shorter than or equal to 300m should be 20% of the results calculated by formula (4.1.1-1) and formula (4.1.1-2) respectively.

***Background*:**

4.1.2 ~ 4.1.4 *The tunnels excluded from optically long tunnels herein are non-optically long tunnels.*

*Lighting requirements for short tunnels are not the same as that for long tunnels, and mainly related to tunnel's inter-visibility. Tunnel inter-visibility mainly depends on tunnel length. For short tunnel, it also depends on the width, height, vertical and horizontal alignments and so on. Lighting of short tunnel is related to highway classification, design speed, traffic volume, length, horizontal alignment, sunlight intensity and others. This is also mentioned in the standards and technical documents of international organizations such as CIE and CEN and some countries. According to lighting requirements in the*Guide for Lighting of Highway Tunnels and Underpasses (*ClE*88-2004), *the luminance of short tunnel varies by the horizontal alignment, sunlight intensity, reflectivity of tunnel walls, traffic volume and others.*

4.1.5 *When the driving time between two tunnels at the design speed is shorter than* 15*s and the driving time passing through the former tunnel is larger than* 30*s, the LLD factor of the threshold zone of the next tunnel may be in line with Table* 4.1.5.

Table 4.1.5 LLD factor of the threshold zone of the next tunnel

Driving time*t*(*s*) between two tunnels	$t<2$	$2 \leqslant t<5$	$5 \leqslant t<10$	$10 \leqslant t<15$
LLD factor of the threshold zone of the next tunnel (%)	50	30	25	20

4.2 Adaptation luminance

4.2.1 Adaptation luminance L_{20}(S) in lighting design of highway tunnel may be subject to Table 4.2.1.

Table 4.2.1 Adaptation luminance L_{20}(S) (cd/m²)

Sky percentage	Tunnel portal orientation or exterior environment	Designspeed v_t (km/h)				
		20 ~ 40	60	80	100	120
35% ~ 50%	Southportal			4000	4500	5000
	Northportal			5500	6000	6500
25%	Southportal	3000	3500	4000	4500	5000
	Northportal	3500	4000	5000	5500	6000
10%	Dark environment	2000	2500	3000	3500	4000
	Bright environment	3000	3500	4000	4500	5000

Table 4.2.1 (Cont'd)

Sky percentage	Tunnel portal orientation or exterior environment	Designspeed v_t (km/h)				
		20 ~ 40	60	80	100	120
0	Dark environment	1500	2000	2500	3000	3500
	Bright environment	2000	2500	3000	3500	4000

Notes: 1. Thesky percentage refers to the sky area ratio through a 20° conical field of view.
2. Southportal refers to the entrance of vehicles driving toward north while north portal refers to the entrance of vehicles driving toward south.
3. The requirements for east and westportals shall be the median of south and north portals.
4. Dark environment refers to an exterior environment with surroundings (including the portal) of low reflectivity while bright environment refers to an exterior environment with surroundings (including the portal) of high reflectivity.
5. When thesky percentage is between two levels, the result shall be calculated by linear interpolation.

***Background*:**

Adaptation luminance L_{20}(S) is the average luminance measured at the start of the access zone (S) where is 1.5m above the road surface and within a 20° conical field of view directly against the portal, as shown in Figure 4-1. Adaptation luminance L_{20}(S) is one of the basic parameters for lighting system design. Its reasonability greatly affects the engineering investment and power consumption, and thus shall not be neglected. During the design of the subsea tunnel at Tokyo Bay of Japan, detailed comparison has been done. Under the same conditions (including vehicle speed), for L_{20}(S) of 4000cd/m^2 and 6000cd/m^2, the equipment cost differs by 34% and the annual kWh differs by 30%. Therefore, the adaptation luminance is suggested to be reduced by greening at tunnel portal or luminance-reduction treatment of structures.

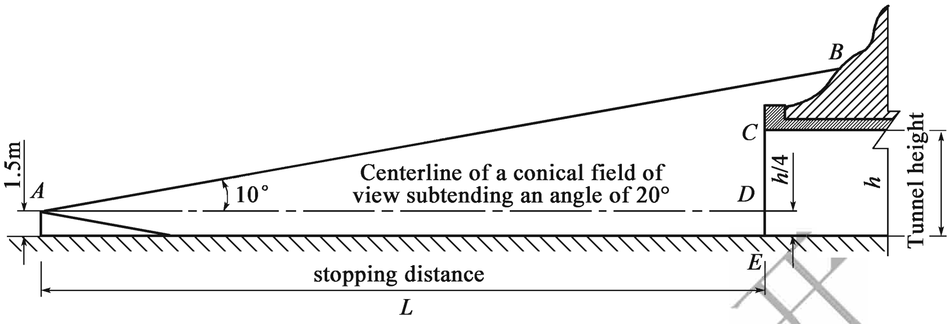


Figure 4.1　Test diagram of adaptation luminance L_{20}(S)

Reasonable adaptation luminance shall be measured and confirmed after the completion of tunnel portal; therefore the adaptation luminance shall be estimated at the beginning of design. According to the results of site measurement and analysis on the adaptation luminance of nearly 100 tunnels in Fujian, Guangdong, Chongqing, Shaanxi and other provinces (cities), generally, the sky percentage at the portal of mountain highway tunnel is zero, the measured results are between 2300 ~3300cd/m^2, the adaptation luminance of bamboo-truncating portal is about 2500cd/m^2, and that of headwall portal is about 3000cd/m^2. Besides, the survey of many built mountain tunnels on expressway and Class-1 highway and those under construction in China shows that the sky percentage through a 20° conical field of view is basically zero. The recommended adaptation luminance is given in this Clause.

Since L_{20}(S) changes from latitudes, seasons and weathers, the recommended luminance is just for reference during lighting design. Although the L_{20}(S) of snow environment is higher, the vehicle speed decreases accordingly. Therefore, the L_{20}(S) of snow environment is not mentioned here.

4.2.2　Adaptation luminance should be measured after the civil works of portal are finished. When the difference between the measured result and design result varies from-25% to +25%, the design of lighting system shall be adjusted.

Background:

After thecivil works of portal are finished, the design adaptation luminance may differ significantly from the measured result. To avoid potential safety hazards and overdesign, the adaptation luminance shall be measured and confirmed on site. When the difference between the measured result and design result varies from-25% to +25%, the design of lighting system need to be adjusted.

Fast and accurate methods shall be adopted for adaptation luminance measurement, such as sketch of the environment, blackness method and digital camera method. Currently, the digital camera method is popular due to its convenient operation and accurate results.

4.2.3 The stopping distance may be subject to Table 4.2.3.

Table 4.2.3 Stopping distance D_s (m)

Design speed v_t (km/h)	Longitudinal slope (%)								
	−4	−3	−2	−1	0	1	2	3	4
120	260	245	232	221	210	202	193	186	179
100	179	173	168	163	158	154	149	145	142
80	112	110	106	103	100	98	95	93	90
60	62	60	58	57	56	55	54	53	52
40	29	28	27	27	26	26	25	25	25
20 ~ 30	20	20	20	20	20	20	20	20	20

Background:

The related CIE and CEN standards and technical reports are referred toin the compilation of stopping distances in this Clause.

4.3 Length of threshold zone

4.3.1 The length of TH_1 and TH_2 shall be calculated by formula (4.3.1):

$$D_{th1} = D_{th2} = \frac{1}{2}\left(1.154D_s - \frac{h-1.5}{\tan 10°}\right) \tag{4.3.1}$$

Where:

D_{th1}—length of TH_1 (m);

D_{th2}—length of TH_2 (m);

D_s—stopping distance (m), may be subject to Table 4.2.3;

h—clearance height of tunnel (m).

Background:

The length of threshold zoneD_{th} is calculated according to the stopping distance, minimum required contrast, clearance height of tunnel portal and adaptation distance. To ensure the visibility to obstacle (0.2m × 0.2m × 0.2m) on road surface, a bright road segment with the minimum length of$b$ shall be set up behind the obstacle, as shown in Figure 4-2.

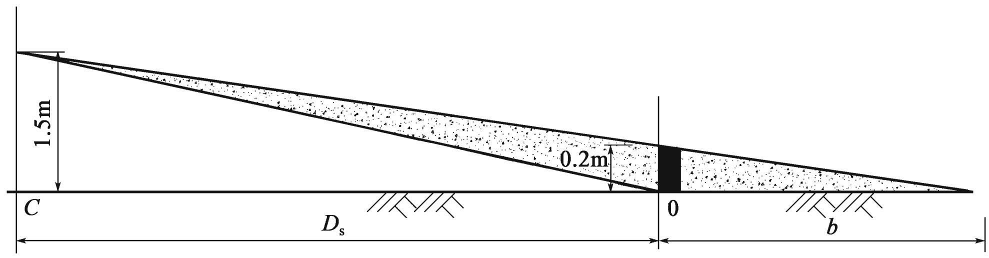


Figure 4-2　Stopping distance and the minimum required contrast

The*Guide for Lighting of Highway Tunnels and Underpasses* (CIE 88-2004) is referred to for the obstacle size requirement of tunnel lighting, that is to adopt a small square target with a dimension of 0.2m × 0.2m × 0.2m and a reflection coefficient of 0.2.

Whena driver drives to the adaption point (A) outside the tunnel, exterior surroundings within a 20° conical field of view is basically invisible and the driver begins to adapt to the dark environment in tunnel. The distance (d) between adaptation point (A) and portal (P) is called adaptation distance, $d = \frac{h - 1.5}{\tan 10°}$, as shown in Figure 4-3.

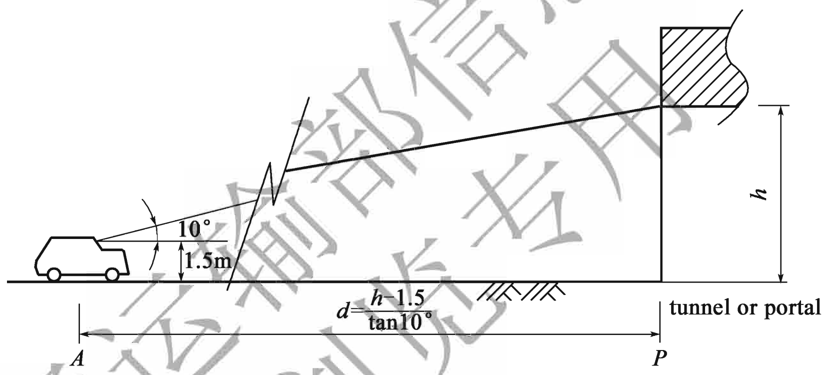


Figure 4-3　Adaptation distance

4.3.2　Under a design speed of 20 ~ 40km/h, the total length of threshold zone may be one time of stopping distance.

***Background*:**

The related CIE and CEN standards and technical reports are referred toin the compilation of stopping distances under a design speed of 20 ~ 40km/h. When formula (4.3.1) is adopted for calculation, the length of threshold zone is negative. Therefore, this Clause is hereby compiled.

5 Lighting of Transition Zone

5.0.1 Three lighting sections (TR_1, TR_2 and TR_3) should be set up at the transition zone in line with the gradual change and decrease principle. The corresponding luminance shall be calculated by formula (5.0.1-1) ~ formula (5.0.1-3) respectively:

$$L_{tr1} = 0.15 \times L_{th1} \tag{5.0.1-1}$$

$$L_{tr2} = 0.05 \times L_{th1} \tag{5.0.1-2}$$

$$L_{tr3} = 0.02 \times L_{th1} \tag{5.0.1-3}$$

***Background*:**

The sectional luminance of the transition zone herein refers to the luminance adaptation curve $L_{tr} = L_{th1}(1.9 + t)^{-1.4}$ in the relevant CIE standards. In transition zones, the luminance ratio of the three transition zones TR_1, TR_2 and TR_3 is 3:1, as shown in Figure 5-1.

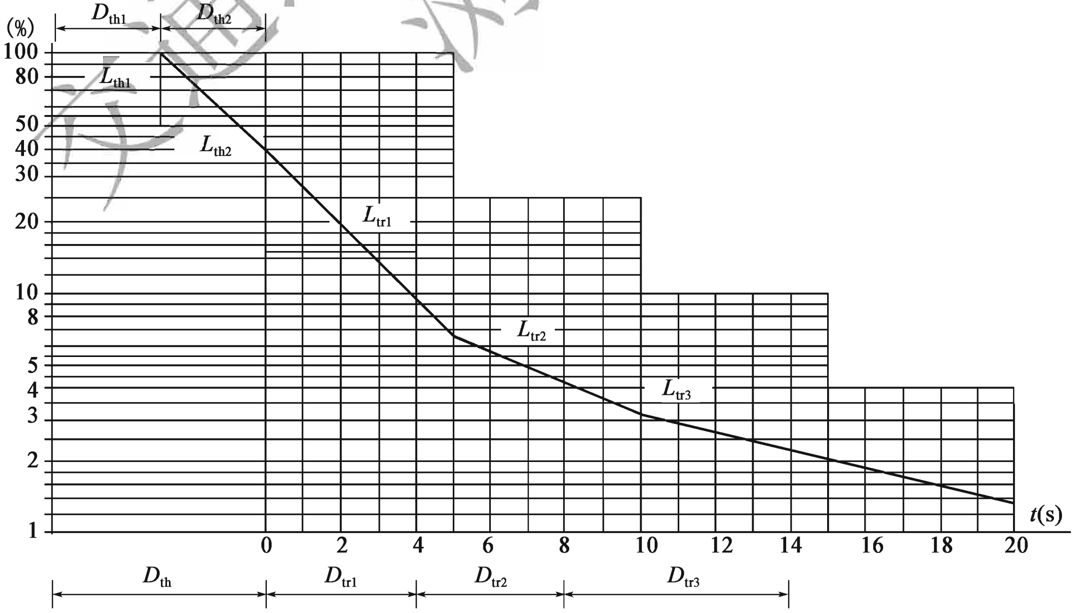


Figure 5-1 Length and luminance of transition zones

5.0.2 For the tunnel with a length shorter than or equal to 300m, the enhanced lighting of transition zone may not be required; for the tunnel with a length more than 300m but shorter than or equal to 500m, if the tunnel exit is fully visible at TR_1, then enhanced lighting of TR_2 and TR_3 may not be required; when luminance of TR_3 (L_{tr3}) is smaller than or equal to two times of the luminance of interior zone (L_{in}), the enhanced lighting of TR_3 may not be required.

Background:

For the tunnel with a length more than 300m but shorter than or equal to 500m, the setting of transition zone mainly depends on the inter-visibility of tunnel. For the non-optically long tunnel, when traffic volume is small, the tunnel exit visibility is higher; stark contrast between the low luminance in tunnel and high luminance at exit makes vehicles and other objects evident, one transition zone (TR_1) is generally set up; when traffic volume is large, the luminance contrast is not enough, two more transition zones (TR_2 and TR_3) are generally set up.

For the optically long tunnel, when traffic volume is small and tunnel exit is fully visible at TR_1, one transition zone (TR_1) is generally set up; when traffic volume is large, the luminance contrast between tunnel and exit is not enough and the tunnel exit is not fully visible at TR_1, two more transition zones (TR_2 and TR_3) are generally set up.

5.0.3 The length of transition zone shall be calculated by formula(5.0.3-1) ~ formula(5.0.3-3):

1 The length of TR_1 shall be calculated by formula (5.0.3-1):

$$D_{tr1} = \frac{D_{th1} + D_{th2}}{3} + \frac{v_t}{1.8} \tag{5.0.3-1}$$

Where:

v_t—design speed (km/h);

$\frac{v_t}{1.8}$—driving distance within 2s.

2 The length of TR_2 shall be calculated by formula (5.0.3-2):

$$D_{tr2} = \frac{2v_t}{1.8} \tag{5.0.3-2}$$

3 The length of TR_3 shall be calculated by formula (5.0.3-3):

$$D_{tr3} = \frac{3v_t}{1.8} \tag{5.0.3-3}$$

Background:

The length of each transition zone is divided in line with the adaptation curve required in CIE standards. The length of TR_1 is the driving distance within 4s; that of TR_2 is the driving distance within 4s and that of TR_3 is the driving distance within 6s.

The length of each transition zone shall be calculated by formula (5.0.3-1) ~ formula (5.0.3-3). Please refer to Table 5-1.

Table 5-1 Calculation of transition zone length D_{tr} (m)

Designspeed v_t (km/h)	D_{tr1}			D_{tr2}	D_{tr3}
	Clearance height of tunnel h (m)				
	6	7	8		
120	139	137	135	133	200
100	108	106	103	111	167

Table 5-1 (Cont'd)

Designspeed v_t (km/h)	D_{tr1}			D_{tr2}	D_{tr3}
	Clearance height of tunnel h (m)				
	6	7	8		
80	74	72	70	89	133
60	46	44	42	67	100
40	26	26	26	44	67

6 Lighting of Interior Zone

6.1 Luminance of interior zone

6.1.1 Please refer to Table 6.1.1 for the luminance of interior zone.

Table 6.1.1 Luminance of interior zone L_{in} (cd/m²)

Designspeed v_t (km/h)	L_{in}		
	Unidirectional traffic		
	$N \geq 1200$veh/(h·ln)	350veh/(h·ln) $< N <$ 1200veh/(h·ln)	$N \leq 350$veh/(h·ln)
	Bi-directional traffic		
	$N \geq 650$veh/(h·ln)	180veh/(h·ln) $< N <$ 650veh/(h·ln)	$N \leq 180$veh/(h·ln)
120	10.0	6.0	4.5
100	6.5	4.5	3.0
80	3.5	2.5	1.5
60	2.0	1.5	1.0
20 ~ 40	1.0	1.0	1.0

Notes: 1. When the design speed is 100km/h, the luminance of interior zone may be set up at that for the design speed of 80km/h.

2. When the design speed is 120km/h, the luminance of interior zone may be set up at that for the design speed of 100km/h.

***Background*:**

The EURO STD *Lighting Applications ——Tunnel Lighting* (1997) and *Japan's Guidelines for Tunnel Lighting* (1990) are used for reference during the compilation of parameters in this Clause. Besides, the highway tunnel operation in China and test results of human biological reaction to illumination based on small target visibility are thoroughly considered. At a design speed of

120km/h, please refer to the luminance of interior zone recommended in the*Guide for Lighting of Highway Tunnels and Underpasses* (CIE 88—2004) and *Lighting Applications-Tunnel Lighting* (CR 14380:2003).

6.1.2 For the tunnel where people and vehicles pass through, the luminance of interior zone shall not be lower than 2.0cd/m^2.

6.1.3 For a unidirectional traffic tunnel with a travel time of over 135s at the design speed, two lighting sections should be set up at the interior zone and the corresponding length and luminance shall not be lower than that listed in Table 6.1.3.

Table 6.1.3 Length and luminance of each lighting section in interior zone

<table>
<tr><th>Item</th><th>Length (m)</th><th>Luminance (cd/m^2)</th><th>Conditions</th></tr>
<tr><td>Lighting section I of interior zone</td><td>Driving length at the design speed within 30s</td><td>L_{in}</td><td rowspan="2">—</td></tr>
<tr><td rowspan="2">Lighting section II of interior zone</td><td rowspan="2">Length of the left interior zone</td><td>L_{in} ×80%, and not less than 1.0cd/m^2</td></tr>
<tr><td>L_{in} ×50%, and not less than 1.0cd/m^2</td><td>The way to arrange luminaires into continuous light band is adopted and the reflection coefficient of tunnel walls is not less than 0.7</td></tr>
</table>

***Background*:**
The*Guide for Lighting of Highway Tunnels and Underpasses* (CIE 88-2004) is referred to in the compilation of this Clause. When the travel time passing through the tunnel is more than 135s, the driver has enough adaption time, thus, the luminance of the second lighting section may be appropriately reduced.

6.2 Luminaires' layout of interior zone

6.2.1 When it takes more than 20s to pass through the tunnel at the design speed, the luminaire spacing shall reach a flicker frequency less than 2.5Hz or higher than 15Hz.

***Background*:**
The flicker frequency isthe ratio of design speed to luminaire spacingv_t/S. When the flicker frequency is 4 ~ 11Hz, it is uncomfortable for human. Therefore, this Clause is hereby compiled.

6.2.2 The overall uniformity of the luminance of road surface shall not be lower than that in Table 6.2.2.

Table 6.2.2 Overalluniformity of the luminance of road surface U_0

Design hourly volume$N$ [veh/(h·ln)]		U_0
Unidirectional traffic	Bi-directional traffic	
≥1200	≥650	0.4
≤350	≤180	0.3

Note: in case of a mediumtraffic volume, the result shall be calculated by linear interpolation.

6.2.3 The longitudinal uniformity of the luminance of road surface centerline shall not be lower than that in Table 6.2.3.

Table 6.2.3 Longitudinaluniformity of the luminance of road surface centerline U_1

Design hourlyvolume$N$ [veh/(h·ln)]		U_1
Unidirectional traffic	Bi-directional traffic	
≥1200	≥650	0.6
≤350	≤180	0.5

Note: in case of a mediumtraffic volume, the result shall be calculated by linear interpolation.

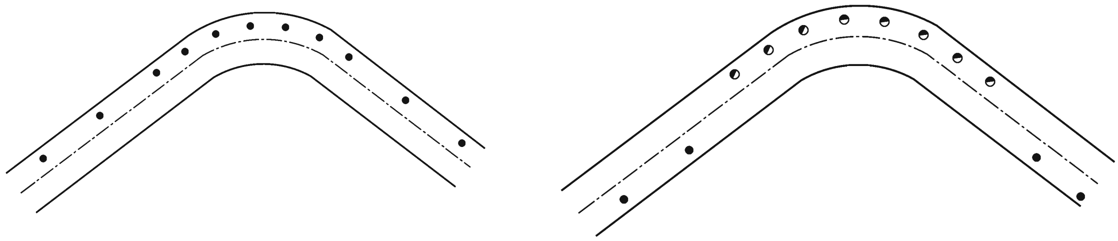
Background:

6.2.2 ~ 6.2.3 The requirements on luminance uniformity are to provide good visibility and visual comfort for drivers. Since there exists areas of different luminance in the field of view, it takes a certain amount of time for the eyes to adapt from one area to another with varied luminance, and the visual capacity will be impacted during the adaptation process. In case of frequent alternative adaptation, the flicker effect due to luminance change will cause visual fatigue to driver.

6.2.4 In case of a curve interior zone, the layout of luminaires shall meet the following requirements:

1 For the curve zone with a radius of horizontal curve not less than 1000m, the layout of luminaires may refer to that at straight zone.

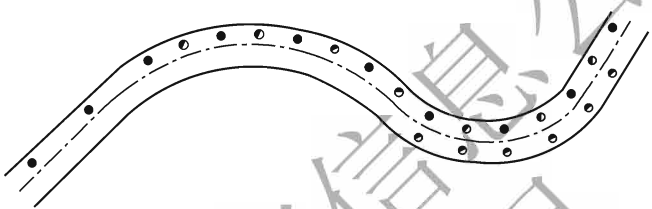
2 For the curve zone with a horizontal curve radius less than 1000m, when luminaires are arranged at two sides of the road, the symmetrical layout should be adopted; when luminaires are arranged at the outer edge of the curve zone, the off-centered layout shall be adopted, and the luminaire spacing should be 0.5 ~ 0.7 times of that at straight zone. The smaller the radius is, the shorter the spacing shall be. See Figure 6.2.4-1.



a)Layout of luminaires on the left of centerline   b)Layout of luminaires on the right of centerline

Figure 6.2.4-1　Off-centered layouts at curve zone

3　At the reverse curve zone, luminaires should be arranged at the fixed side. In case of sight obstacle, additional luminaires should be arranged along the outer side of the curve zone. See Figure 6.2.4-2.



gure 6.2.4-2　Layout of luminaires at reverse curve zone

***Background*:**
Compared withluminaires arranged along the interior side of curve zone, the arrangement along the outer side can provide a good driving guidance. To better indicate the tunnel alignment and ensure the uniformity of the luminance of road surface, it is hereby required that "the smaller the radius is, the shorter the spacing shall be". For the reverse curve zone of a tunnel, luminaires should be arranged at the fixed side so as to improve the guidance and facilitate the installation and maintenance of luminaires.

6.2.5　The luminance of diverging zone and merging zone should not be lower than 3 times of that of the interior zone.

6.3　Lighting oflay-by and horizontal adit

6.3.1　The light sources of high color-rendering index should be adopted for the lighting of lay-by; and the luminance shall not be less than 4.0cd/m^2.

***Background*:**
Lay-by is for the maintenance of vehicle with abnormalities, and certain delicate work may be done here. The luminance and color rendering required are not the same as that of the main tunnel.

Therefore, this Clause is hereby compiled.

6.3.2 The luminance of horizontal adit shall not be less than 1.0cd/m^2.

Background:

The lighting of horizontal adit is for pedestrian evacuation and rescue.

7 Lighting of Exit Zone

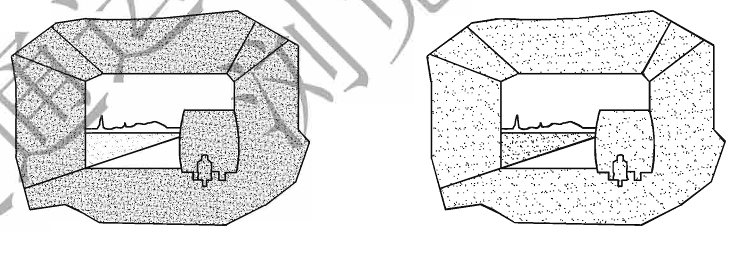
7.0.1 Two lighting sections (EX_1 and EX_2) should be set up at the exit zone, with a length of 30m respectively. The corresponding luminance shall be calculated by formula (7.0.1-1) and formula (7.0.1-2) respectively:

$$L_{ex1} = 3 \times L_{in} \tag{7.0.1-1}$$

$$L_{ex2} = 5 \times L_{in} \tag{7.0.1-2}$$

***Background*:**

Around the tunnel exit zone, it is hard to notice and identify the small vehicle behind, which is easy to cause accident. However, the enhanced lighting of the exit zone is helpful for solving such visual difficulty. Please refer to Figure 7-1.



a)without enhanced lighting b)with enhanced lighting

Figure 7-1 Enhanced lighting effect of exit zone

The *Guide for Lighting of Highway Tunnels and Underpasses* (CIE 88-2004) recommends that the luminance of tunnel exit zone shall increase linearly during the daytime. Within 20m of the tunnel exit, the luminance shall be 5 times of that of the interior zone. Therefore, this Clause is hereby compiled.

7.0.2 For the straight tunnel with a length (L) not more than 300m, the enhanced lighting of exit zone may not be required. For the straight tunnel with a length (L) more than 300m but shorter than or equal to 500m, only enhanced lighting of EX_2 is required.

8 Emergency Lighting and Approach Lighting

8.1 Emergency lighting

8.1.1 The highway tunnel with a length more than 500m shall be equipped with an emergency lighting system and adopt the uninterrupted power supply (UPS) system; the Class-1 and Class-2 highway tunnel with a length more than 1000m shall be equipped with an emergency lighting system and the lighting interruption duration shall not be more than 0.3s; the installation of the emergency lighting system of Class-3 and Class-4 highway tunnels shall be decided according to the actual conditions.

8.1.2 A part of the base luminaires may be used for emergency lighting. The power supply duration of the emergency lighting shall be not less than 30mins.

***Background*:**
A part of the base luminaires may be used for emergency lighting. When the daily lighting power supply fails, the UPS power supply shall power the emergency lighting.

8.1.3 Under emergency lighting, the lighting condition within the tunnel should be issued in a timely manner; and a real-time information board may be adopted for information update if possible.

8.1.4 The illuminance of emergency lighting shall not be less than 10% of that of the interior zone in Table 6.1.1 and shall not be lower than 0.2cd/m^2.

8.2 Approach lighting

8.2.1 Approach lighting may be set up at the following sections:

1 The approach section with a curve radius smaller than normal radius;

2 The approach section of a tunnel with night-time lighting, but at unlit road segment; and

3 The section at the joint of tunnel and bridge & between continuous tunnels.

Background:

In case that a tunnel locates atan unlit road segment, visual deviation often occurs due to the difference between the luminance inside and outside the tunnel. Therefore, the approach shall be reasonably equipped with lighting facilities as required, so that drivers can notice in advance the tunnel conditions and road conditions outside the tunnel.

8.2.2 The luminance and length of approach should not be lower than that in Table 8.2.2.

Table 8.2.2 Luminance and length of approach

Designspeed v_t (km/h)	Luminance (cd/m^2)	Length (m)
120	2.0	240
100	2.0	180
80	1.0	130
60	0.5	95
20 ~ 40	0.5	60

8.2.3 When the road segment between continuous tunnels is shorter than the length in Table 8.2.2, approach lighting may be set up according to the actual length of the section outside the tunnel.

8.2.4 The layout of luminaires along an approach may be designed according to lighting requirements.

Background:

For road lighting, luminaires are normally installed on lampposts with a height less than 15m and orderly set up along one side, two sides of road or on the median strip at a certain distance. In this layout, the longitudinal axis of luminaires shall be perpendicular to the road axis. Thus, most of the lamplight can be directed onto the road.

9 Energy-conservation Standards and Measures

9.1 General

9.1.1 Reasonable parameters shall be selected during the lighting design of highway tunnels. A reasonable and energy-conservation program shall be decided after the economic and technical analysis and demonstration of programs.

Background:

Reasonable design is the key forthe energy conservation of tunnel lighting. Under the premise of meeting lighting standards, the location, size, traffic volume and other factors of tunnel shall be analyzed for the selection of design parameters. Besides, the light sources, luminaire selection and layout and life-cycle economy and technology of staged programs shall be compared so as to formulate the optimal tunnel design program in accordance with the local conditions and avoid experiential stereotyped design.

For example, the luminaires at the interior zone of a tunnel adopt off-centered centerline layout for the preliminary stage, more programs may be compared and selected in later stage, including additional row of luminaires, replacement of luminaires, change of light sources' power and other practical matters. .

9.1.2 During the lighting design of highway tunnels, the dimming and operation management programs shall be formulated according to different conditions, including traffic volume, adaptation luminance, season and other related factors.

Background:

Generally, the tunnel lighting system design is based on the most unfavorable condition. Working without consideration to the specific circumstance will cause more energy consumption or potential hazards. Dimming and operation management programs shall be formulated according to the traffic volume, adaptation luminance, season and other factors so as to ensure the safety and energy conservation under different conditions and realize scientific management.

Staged dimming or dynamic dimming is adopted for the lighting of highway tunnel. For example, the four-level dimming program (sunny skies, partly cloudy skies, cloudy skies and heavy cloudy skies) or staged sequential dimming program may be adopted for the lighting of enhanced zone during the daytime; and the dynamic dimming program shall be adopted for the lighting of interior zone at night based on the traffic volume change.

9.2 Energy-conservation standard

9.2.1 When the LED light sources with a rendering index (Ra) of 65 or over and a color temperature of 3500 ~ 6500K are used for the base lighting of a tunnel, the luminance may be set to 50% of that in Table 6.1.1, but shall not be lower than 1.0cd/m^2.

Background:

The luminance standards adopted by the current lighting design in China and many other countries are based on luminance under the photopic vision with a 2° field of view, which cannot accurately reflect the visual sensitivity to luminance. Therefore, the "mesopic vision theory" and "visual performance based on response time to target" are now applied in the research on tunnel lighting. Following the later method and according to tests, the luminance contrast factor of LED to high-pressure sodium (HPS) lamp under the same response time is concluded in Table 9-The equivalent luminance of LED light source mesopic vision can be worked out and the luminance can be deducted accordingly.

Table 9-1 Luminance contrast factor of LED to HPS

Backgroundluminance (cd/m^2)	1.0	1.5	2.0	2.5	3.6	4.5
Luminance contrast factor	0.3107	0.3881	0.4777	0.4613	0.4031	0.3491

9.2.2 When the single-capped electrodeless fluorescent tube with a rendering index (Ra) of 65 or over and a color temperature of 3500 ~ 6500k is used for the base lighting of a tunnel, the luminance may be set to 80% of the luminance standard in Table 6.1.1, but shall not be lower than 1.0cd/m^2.

Background:

Under different adaptation luminance, the relative spectral sensitivity curves of human vision are different. As the adaptation luminance decreases, the sensitivity to blue and green light increases while the sensitivity to yellow and red light decreases. In the tunnel with a low luminance level (base lighting and nighttime lighting of long tunnel), the visual luminance of light sources with much more of short wavelength (single-capped electrodeless fluorescent tube) is higher than that of light sources (high voltage sodium lamp) with the same power but much more light of long wavelengths. Therefore, this Clause is hereby complied with.

9.2.3 When counter-beam lighting (CBL) is adopted for base lighting, the luminance may be set to 80% of that in Table 6.1.1, but shall not be lower than 1.0cd/m^2.

Background:

Thebeam projection direction of CBL is contrary to traffic flow. By negative contrast effect, drivers can observe obstacles and other vehicles. According to the "small target visibility" theory, if the luminance of road surface is the same, the target visibility is higher and the target is more detectable when the luminance of surface facing driver is lower. Therefore, this Clause is hereby compiled.

9.3 Energy-conservation measures

9.3.1 The selection of tunnel light sources shall comply with the following principles:

1 Light sources with high luminous efficacy should be used and their service life shall not be less than 10000h.

2 For the tunnel adopting particulate matter emissions attenuation as ventilation control measure, light sources with a good light transmission in fog should be used. Otherwise, light sources with good color rendering should be used for base lighting.

3 Light sources with good color rendering may be used for lay-by and horizontal adit.

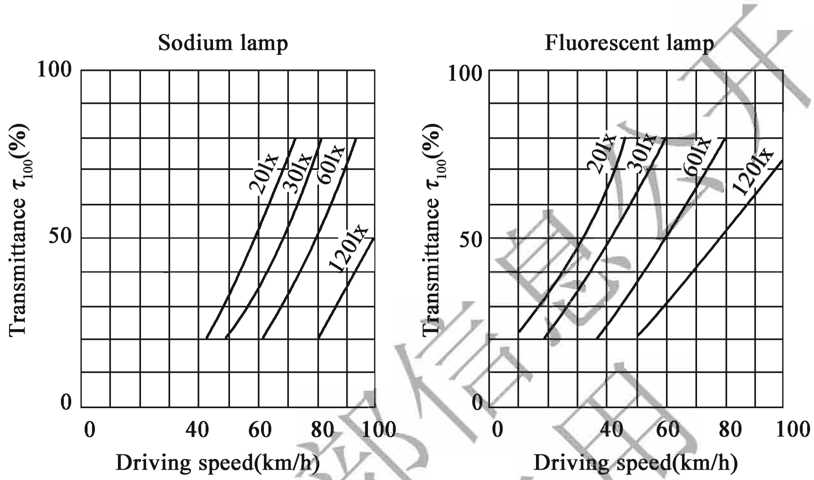
Background:

Currently, high voltage sodium lamps with highluminous efficacy and good light transmission in fog are used as tunnel light sources, while fluorescent tubes are used for the tunnel with high color rendering requirement and special section.

Light sources and transmission factor (particulate matter emissions' concentration) can greatly affect the illuminance. The particulate matter emissions' concentration not only relates to vehicle speed (required sight distance), but also the luminance (or illuminance) and light sources. Please see Table 9-2 for details. According to tests, the lighting experts in Japan concluded the relationship among the particulate matter emissions’ concentration (transmission factor), vehicle speed, illuminance and light sources in Figure 9-1.

Table 9-2 Relationship of design speed-luminance of road surface-particulate matter emissions’ concentration

Design speed(km/h)	100	80	60	40
Averageroad surface luminance (cd/m^2)	9.0	4.5	2.5	1.5
K(m^{-1})	0.0069	0.0070	0.0075	0.0090



1 Relationship amongtransmission factor, vehicle speed, illuminance and light sources

9.3.2 When centerline layout or off-centered layout is adopted for tunnel lighting, CBL should be used for base lighting. When bilaterally staggered layout or symmetrical layout is adopted, symmetrical luminaires with broad light band should be used.

9.3.3 The following luminance-reduction measures may be adopted for access zone:

1 Bamboo-truncating tunnel frame and slope greening may be adopted.

2 When head wall is set at tunnel entrance, the wall may be in dark hue and the reflectivity of its decorations shall be less than 0.17.

3 The hardening side and front slopes of tunnel portal may be darkening.

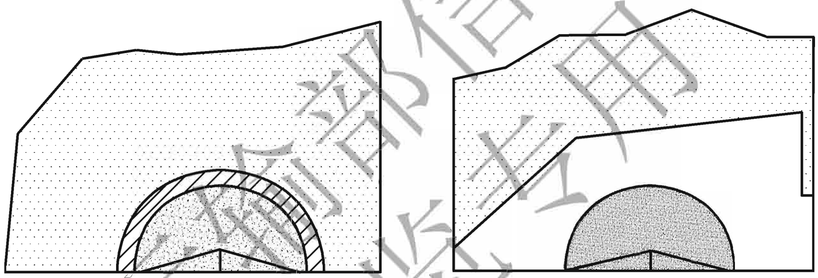
4 At least the road surface with a length of one stopping distance outside the tunnel entrance may be in dark.

***Background*:**
Adaptation luminance L_{20}(S) greatly affects the scope of the enhanced lighting. Bright decorations

of the portal will increase adaptation luminance, amplify the "black hole effect" and increase energy consumption. Luminance-reduction measures for the access zone can decrease the adaptation luminance and realize energy conservation.

Luminance-reduction measures in this Clause are generally adopted. Other measures can be selected according to the tunnel entrance conditions, for example, planting evergreen at the entrance. Besides, the design of the tunnel entrance adopts the principle that "Tunneling shall start in front of mountain and end away from the mountain as far as possible" and advanced entrance construction method so as to realize zero front slope excavation and extensive greening of the entrance greening and reduce the adaptation luminance of the tunnel.

Whenthe bamboo-truncating tunnel portal is adopted, the adaptation luminance is lower than of the headwall entrance, even in the rolling section (sky percentage within a 20° conical field of view is high). Thus, the bamboo-truncating tunnel portal is recommended considering reduction of adaptation luminance. The influence of tunnel portal (frame) type on the adaptation luminance is shown in Figure 9-2.



a)Bamboo-truncating tunnel portal b)Bright decorated tunnel portal

re 9-2 Influence of tunnel portal (frame) type on adaptation luminance

9.3.4 The daytime dimming design of a tunnel shall meet the following requirements:

1 The design of the enhanced lighting of threshold zone, transition zone and exit zone shall be adjusted according to the adaptation luminance and traffic volume. The dimming level may be decided in line with Table 9.3.4.

Table 9.3.4 Dimming level of enhanced lighting

Season andweather	Dimming level	Adaptation luminance (cd/m^2)	Traffic volume N [veh./(h · ln)]	
			Unidirectional traffic	Bi-directional traffic
Sunnyskies in summer	Ⅰ	L_{20}(S)	≤350	≤180
	Ⅱ		$350 < N < 1200$	$180 < N < 650$
	Ⅲ		≥1200	≥650

续上表

Season andweather	Dimming level	Adaptation luminance (cd/m^2)	Traffic volume$N$ [veh./(h·ln)]	
			Unidirectional traffic	Bi-directional traffic
Sunnyskies in other seasons / cloudy skies in summer	Ⅳ	0.5 L_{20}(S)	≤350	≤180
	Ⅴ		350 < N < 1200	180 < N < 650
	Ⅵ		≥1200	≥650
Cloudy skies in other seasons / partly cloudy skies in summer	Ⅶ	0.25 L_{20}(S)	≤350	≤180
	Ⅷ		350 < N < 1200	180 < N < 650
	Ⅸ		≥1200	≥650

Table 9.3.4 (Cont'd)

Season andweather	Dimming level	Adaptation luminance (cd/m^2)	Traffic volume N [veh./(h·ln)]	
			Unidirectional traffic	Bi-directional traffic
Partlycloudy skies / heavy cloudy skies in other seasons	Ⅹ	0.13 L_{20}(S)	≤350	≤180
	Ⅺ		350 < N < 1200	180 < N < 650
	Ⅻ		≥1200	≥650

2 The dimming program of base lighting shall be designed according to the change of traffic volume and the luminance in Articles 6.1.1 ~ 6.1.3 herein.

Background:

1 The luminance level of the threshold zone, transition zone and exit zone of a tunnel shall be adjusted according to the season, weather and traffic volume so that the luminance of enhanced lighting in tunnel is adaptive to the change of adaptation luminance, and the tunnel lighting is more scientific, reasonable and energy-conservation.

2 The luminance level of the base lighting shall be adjusted according to the traffic volume so that the luminance is adaptive to the change of traffic volume and the lighting is energy-conservative.

9.3.5 The night-time dimming design of a tunnel shall meet the following requirements:

1 The enhanced lightings of the threshold zone, transition zone and exit zone shall be turned off at nighttime.

2 All the luminaires of expressway tunnel and Class-1 highway tunnel (L≤500m) with self-luminous guiding devices and directional reflective delineators may be turned off at nighttime.

3 All the luminaires of Class-2 highway tunnel ($L \leqslant 1000$m) with directional reflective delineators may be turned off at night time.

4 When a highway is equipped with luminaires, the luminance of tunnels thereof at nighttime shall be consistent with that of the road surface. When a highway has no luminaires, the luminance of expressway tunnel and Class-1 highway tunnel at nighttime may be set to 1.0cd/m^2 and that of Class-2 highway may be set to 0.5cd/m^2.

5 When the traffic volume of a unidirectional tunnel at nighttime is not more than 350veh/(h-ln) and that of a bi-directional tunnel at nighttime is not more than 180veh/(h-ln), the emergency lighting may be turned on only.

***Background*:**

The enhancedluminaires of the threshold zone, transition zone and exit zone of tunnel are to eliminate black-hole effect, lag of visual adaptation and other phenomena due to a great luminance difference in and outside the tunnel at daytime, therefore, all enhanced luminaires shall be turned off at nighttime. If they are turned on, the energy consumption is enormous, and intense glare drivers may experience when driving into the tunnel and "black hole effect" when driving away are dangerous.

This Clause stipulates the luminance of each grade of highway tunnel at nighttime by reference to requirements on the luminance of road surface in the*Standard for Lighting Design of Urban Road* (CJJ 45-2006).

According to the investigation and surveyof many tunnels in Chinese provinces (cities), the Compilation Team concluded that for the highway tunnel accommodating small traffic volume at nighttime, when all vehicles turn on the lamps and only the emergency lighting in tunnel works to support video surveillance and driving guidance, the operation is normal.

9.3.6 Materials with high reflectivity should be used for the walls within 2m above the road surface.

***Background*:**

Thereflection and contrast of walls are very important and non-negligible for the tunnel lighting. When the reflectivity of tunnel walls reaches 0.7, the luminance of road surface increases by 10%.

10 Lighting Calculation

10.1 General

10.1.1 The following data shall be collected for the lighting calculation:

1 Materials, luminance factor or pre-digestion luminance factor of road surface;

2 Layout, installation height, spacing and elevation angle of luminaires;

3 Types and specifications of light sources and luminaires;

4 Table of luminous intensity distribution, utilization factor curve, iso-luminous intensity curve, luminance generation curve and other photometric data of luminaires.

Background:
Apart from direct factors, including the specifications, types and layout ofluminaires, light sources types and form of tunnel section, the performance index, photometric data and other parameters of luminaires shall also be provided by the manufacturer in line with the related regulations and test methods issued by the State and CIE. According to CIE requirements, the table of luminous intensity distribution with 36 γ angles and 52c angles, totaling 1872 values, shall be provided for the calculation of the luminance values.

10.1.2 The following factors shall be considered in the lighting calculation:

1 Calculating parameters shall be selected according to the characteristics of each tunnel.

2 Energy-conservation standards shall be considered according to the requirements of type, layout and other factors of luminaires and confirmed in line with Article 9.2 herein.

3 The layout of luminaires shall be decided according to the dimming requirements of Article 9.3.4 and Article 9.3.5 herein.

4 Quantity and power of luminaires shall be calculated on the basis of the decided luminance, lighting type and layout.

10.2 Illuminance calculation

10.2.1 On the basis of the table of luminous intensity distribution of luminaires, the average horizontal illuminance of road surface may be calculated in line with the following steps:

1 The horizontal illuminance of a luminaire at the calculation point p in the tunnel may be calculated by formula (10.2.1-1):

$$E_{pi} = \frac{I_{c\gamma}}{H^2}\cos^3\gamma \times \frac{\phi}{1000} \times M \tag{10.2.1-1}$$

Where:

E_{pi}—horizontal illuminance of a luminaire at the calculation point p;

γ—incidence angle (°) of the luminaire light corresponding to the calculation point p;

$I_{c\gamma}$—luminous intensity (cd) of the luminaire at the calculation point p;

M—maintenance factor of the luminaire;

ϕ—rated luminous flux of the luminaire (lm);

H—height from the light sources center to road surface (m).

2 The illuminance of luminaires at calculation point p may be calculated by formula (10.2.1-2):

$$E_p = \sum_{i=1}^{n} E_{pi} \tag{10.2.1-2}$$

Where:

E_p—horizontal illuminance (lx) at the calculation point p;

n—quantity of luminaires. Respectively a group of luminaires on both sides of calculating zone may be included in calculation.

3 The average horizontal illuminance of road surface may be calculated by formula (10.2.1-3):

$$E_{av} = \frac{\sum_{p=1}^{m} E_p}{m} \tag{10.2.1-3}$$

Where:

E_{av}—average horizontal illuminance (lx) of road surface;

m—total calculation points within the calculating zone.

10.2.2 On the basis of utilization factor curve, the average horizontal illuminance of road surface may be calculated in line with formula (10.2.2):

$$E_{av} = \frac{\eta \cdot \phi \cdot M \cdot \omega}{W \cdot S} \tag{10.2.2}$$

Where:

w—luminaire layout factor; 2 for symmetrical layout and 1 for staggered layout, centerline layout and layout of off-centered single light band;

η—utilization factor, from utilization factor curve;

W—width of tunnel road surface (m);

S—luminaire spacing (m).

Background:

There are many methods for lighting calculation, such as empirical formula and tabular methods, iso-illuminance curve method and utilization factor method. However, the accuracy of these traditional methods is not high and the lighting effect and quality cannot be assessed comprehensively. With the development and popularization of computer technology, the illuminance and luminance of any point on tunnel wall or road surface can be worked out on the basis of the table of photometric data provided by the manufacturer. The numerical computation method (CIE method) is recommended here. Meanwhile, the utilization factor curve method is also listed here. Please refer to Figure 10-1 for the luminous intensity diagram of luminaires.

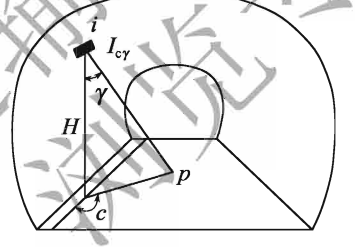


Figure 10-1 Luminous intensity of luminaire

Theluminous intensityI_{cy} in formula (10.2.1-1) is provided by the manufacturer and CIE requiring 1872 numbers. The table of luminous intensity obtained from an elevation angle of 0° and a luminous flux of 1000lm is converted according to the rated luminous flux in the actual calculation, and the attenuation of light sources and maintenance factor of luminaires is considered too.

When theluminaire is with a rotation angle of plane and an elevation angle, the angle corresponding to the measured angle$c$ and γ by formula transformation is worked out; and thenI_{cy} is worked out by interpolation.

With regard to the quantity$n$ of luminaires selected for calculation, according to the relevant calculation, the luminaires being more than 1 time away from the calculating zone (assumed to S_0)

has little influence which may be ignored. Normally, a set of luminaires on both sides of the calculating zone is included; and two to four luminaires outside the calculating zone are included, as shown in Figure 10-2.

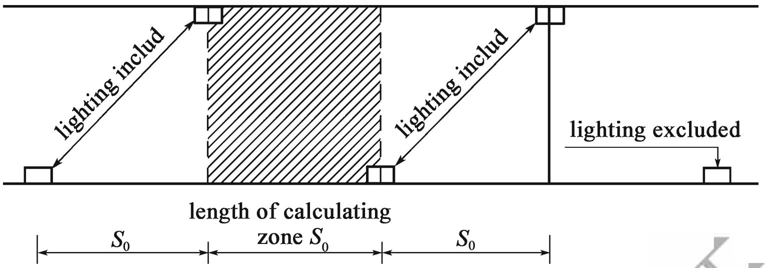


Figure 10-2 Calculating zone

To ensure the accuracy and meet the requirements on averageilluminance and luminance, especially those on the uniformity of luminance and longitudinal uniformity of luminance, enough calculation points are required to be set up within the calculating zone and on the centerline of the lane.

10.3 Luminance calculation

10.3.1 The following requirements for the luminance calculation shall be met:

1 The calculating zone shall not be smaller than the luminaire spacing.

2 The observation point should be 60 ~ 160m away from the calculating zone, 1.5m higher than the road surface and on the centerline of the lane.

3 The spacing of longitudinal calculation points within the calculating zone should be no more than 1.0m and the quantity of transverse calculation points shall not be less than five.

4 A set of luminaires on both sides of the calculating zone shall be included.

10.3.2 The luminance of luminaire$i$ at the calculation point$p$ may be calculated by formula (10.3.2):

$$L_{pi} = \frac{I_{cr}}{H^2} r(\beta, \gamma) \qquad (10.3.2)$$

Where:

L_{pi}—luminance (cd/m^2) of luminaire$i$ at the calculation point$p$;

$r(\beta,\gamma)$—pre-digestion luminance factor, subject to Appendix A;

β—the angle between the observation plane and incidence plane of the light sources.

10.3.3 The luminance of luminaires at the calculation point$p$ may be calculated by formula (10.3.3):

$$L_{\mathrm{p}} = \sum_{i=1}^{n} L_{\mathrm{p}i} \tag{10.3.3}$$

Where:

L_{p}—luminance (cd/m^2) at the calculation point$p$.

10.3.4 The average luminance of road surface within the calculating zone may be calculated by formula (10.3.4):

$$L_{\mathrm{av}} = \frac{\sum_{p=1}^{m} L_{\mathrm{p}}}{m} \tag{10.3.4}$$

Where:

L_{av}—average luminance (cd/m^2) of road surface within the calculating zone.

***Background*:**

The luminance calculation is complicated. Apart fromilluminance, it is also related to the observation points, materials of road surface and others. For reliability, the increase of road surface luminance due to wall reflection is not considered here. According to the related domestic and overseas data, the focus of drivers stays on the zone about 60 ~ 160m ahead of them. Therefore, 60 ~ 160m is set to be the vertical distance between viewpoints and 1/4 of the road width is set to be the lateral distance range while 1.5m is set to be the height of the viewpoint. Since the observation angle is normally 0.5° ~ 1.5°, the influence may be ignored.

For thepre-digestion luminance factor$r$ (β, γ) of road surface, almost all highway tunnels in China adopt cement concrete pavement. The factor recommended by the CIE shall be used when there is no field survey data. The pre-digestion luminance factor$r$ (β, γ) for only one type of road surface is given in Appendix A herein. The values are worked out by settingQ_0 to 1. In calculating, it shall be multiplied byQ_0. The pre-digestion luminance factors in the table are multiplied by 1000. Thus, L_{pi} may be calculated by formula (10-1):

$$L_{\mathrm{p}i} = \frac{I_{\mathrm{c}\gamma}}{H^2} \times \frac{\phi}{1000} \times M \times r(\beta,\gamma) \times \frac{Q_0}{1000} \tag{10-1}$$

Please refer to Appendix B for the examples of lighting calculation.

10.4 Uniformity calculation

10.4.1 The overall uniformity of the luminance of road surface may be calculated by formula (10.4.1):

$$U_0 = \frac{L_{\min}}{L_{\mathrm{av}}} \tag{10.4.1}$$

Where:

U_0—overall uniformity of the luminance of road surface;

L_{min}—the minimum luminance (cd/m^2) of road surface within the calculating zone.

10.4.2 The longitudinal uniformity of the luminance of road surface centerline may be calculated by formula (10.4.2):

$$U_1 = \frac{L'_{min}}{L'_{max}} \tag{10.4.2}$$

Where:

U_1—longitudinal uniformity of the luminance of road surface centerline;

L_{min}—the minimum luminance (cd/m^2) of road surface centerline;

L_{max}—the maximum luminance (cd/m^2) of road surface centerline.

11 Design Principles of Lighting Control

11.0.1 Adaptation luminance, time, traffic volume, design speed, power supply voltage, weather conditions, characteristics of light sources and other factors shall be considered during the design of dimming.

Background:
Effective control ofluminaires not only enhances the tunnel safety, but also realizes energy conservation and emission reduction.

11.0.2 The design of lighting control shall satisfy the demands for normal and abnormal traffic conditions.

11.0.3 The design of lighting control should be mainly dominated by intelligent control or automatic control and assisted by manual control.

Background:
Manual control means that the control program is selected according to the adaptation luminance, traffic volume and other parameters, and it is with the highest priority.

Automatic control means that the lighting luminance is automatically adjusted according to the real-time adaptation luminance, traffic volume and other parameters. The tunnel management personnel can shift the mode from automatic control to manual control according to the actual conditions. The automatic control's priority is lower than manual control.

Intelligent control means that the luminaires in tunnel are under dynamic lighting control via the forecast of the short-time traffic flow based on the automatic control so as to guarantee a safe, comfortable, efficient and economical lighting effects. It is featured on energy conservation, meets the requirements of green lighting and pursue "lighting by need" design.

11.0.4 The luminance of luminaires on sides of tunnel maintenance sites shall be maximum.

11.0.5 In case of any accident, fire or traffic control in tunnel, the luminance of all the luminaires should be maximum.

Appendix A
Pre-digestion Luminance Factor of Road Surface

A. 0. 1 The pre-digestion luminance factor $r(\beta,\gamma)$ of the road surface shall be subject to the values in Table A. 0. 1-1 and Table A. 0. 1-2. The values in Table A. 0. 1-1 are applicable to cement concrete pavement while those in Table A. 0. 1-2 are applicable to bituminous pavement. Please refer to Figure A. 0. 1 for a sketch of the luminance calculation.

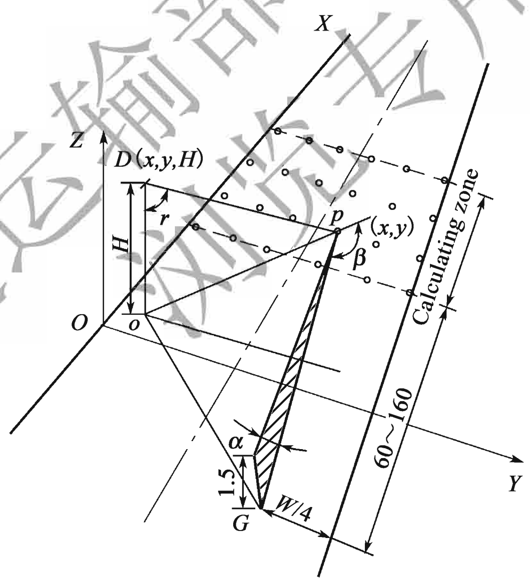


Figure A. 0. 1 Sketch of luminance calculation (unit: m)

Table A. 0. 1-1 Pre-digestion luminance factor$r$ (β, γ) of cement concrete pavement

$\tan\gamma$	β(°)																			
	0	2	5	10	15	20	25	30	35	40	45	60	75	90	105	120	135	150	165	180
0	655	655	655	655	655	655	655	655	655	655	655	655	655	655	655	655	655	655	655	655
0.25	619	619	619	619	610	610	610	610	610	610	610	610	610	601	601	601	601	601	601	601
0.5	619	539	539	539	539	539	521	521	521	521	521	503	503	503	503	503	503	503	503	503
0.75	431	431	431	431	431	431	431	431	431	431	395	386	371	371	371	371	371	386	395	395
1	341	341	341	341	323	323	305	296	287	287	278	269	269	269	269	269	269	278	278	278
1.25	269	269	269	269	260	251	242	224	207	198	189	189	180	180	180	180	180	189	198	207
1.5	224	224	224	215	198	180	171	162	153	148	144	144	139	139	139	144	148	153	162	180
1.75	189	189	189	171	153	139	130	121	117	112	108	103	99	99	103	108	112	121	130	139
2	161	162	157	135	117	108	99	94	90	85	85	83	84	84	86	90	94	99	103	111
2.5	121	121	117	95	79	66	60	57	54	52	51	50	51	52	54	58	61	65	69	75
3	94	94	86	66	49	41	38	36	34	33	32	31	31	33	35	38	40	43	47	51
3.5	81	80	66	46	33	28	25	23	22	22	21	21	22	22	24	27	29	31	34	38
4	71	69	55	32	28	20	18	16	15	14	14	14	15	17	19	20	22	23	25	27
4.5	63	59	43	24	17	14	13	12	12	11	11	11	12	13	14	14	16	17	19	21
5	57	52	36	19	14	12	10	9.0	9.0	8.8	8.7	8.7	9.0	10	11	13	14	15	16	16
5.5	51	47	31	15	11	9.0	8.1	7.8	7.7	7.7	6	—	—	—	—	—	—	—	—	—
6	47	42	25	12	8.5	7.2	6.5	6.3	6.2	—	—	—	—	—	—	—	—	—	—	—
6.5	43	38	22	10	6.7	5.8	5.2	5.0	—	—	—	—	—	—	—	—	—	—	—	—
7	40	34	18	8.1	5.6	4.8	4.4	4.2	—	—	—	—	—	—	—	—	—	—	—	—
7.5	37	31	15	6.9	4.7	4.0	3.8	—	—	—	—	—	—	—	—	—	—	—	—	—
8	35	28	14	5.7	4.0	3.6	3.2	—	—	—	—	—	—	—	—	—	—	—	—	—
8.5	33	25	12	4.8	3.6	3.1	2.9	—	—	—	—	—	—	—	—	—	—	—	—	—
9	31	23	10	4.1	3.2	2.8	—	—	—	—	—	—	—	—	—	—	—	—	—	—
9.5	30	22	9.0	3.7	2.8	2.5	—	—	—	—	—	—	—	—	—	—	—	—	—	—
10	29	20	8.2	3.2	2.4	2.2	—	—	—	—	—	—	—	—	—	—	—	—	—	—
10.5	28	18	7.3	3.0	2.2	1.9	—	—	—	—	—	—	—	—	—	—	—	—	—	—
11	27	16	6.6	2.7	1.9	1.7	—	—	—	—	—	—	—	—	—	—	—	—	—	—
11.5	26	15	6.1	2.4	1.7	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
12	25	14	5.5	2.2	1.6	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—

Note: the averageluminance factor of cement concrete pavementQ_0 is 0.10. The$r$ in the table is expanded by 1000 times and it shall be multiplied by 10^{-3} during calculation.

Table A. 0. 1-2 Pre-digestion luminance factor$r$ (β, γ) of bituminous pavement

$\tan\gamma$	β(°)																			
	0	2	5	10	15	20	25	30	35	40	45	60	75	90	105	120	135	150	165	180
0	329	329	329	329	329	329	329	329	329	329	329	329	329	329	329	329	329	329	329	329
0.25	362	358	371	3643	371	369	362	357	351	349	348	340	328	312	299	294	298	288	292	281
0.5	379	368	375	373	367	359	350	340	328	317	306	280	266	249	237	237	231	231	227	235
0.75	380	375	378	365	351	334	315	295	275	256	239	218	198	178	175	176	176	169	175	176
1	372	375	372	354	315	277	243	221	205	192	181	152	134	130	125	124	125	129	128	128
1.25	375	373	352	318	265	221	189	166	150	136	125	107	91	93	91	91	88	94	97	97
1.5	354	352	336	271	213	170	140	121	109	97	87	76	67	65	66	66	67	68	71	71
1.75	333	327	302	222	166	129	104	90	75	68	63	53	51	49	49	47	52	51	53	54
2	318	310	266	180	121	90	75	62	54	50	48	40	40	38	38	38	41	41	43	45
2.5	268	262	205	119	72	50	41	36	33	29	26	25	23	24	25	24	26	27	29	28
3	227	217	147	74	42	29	25	23	21	19	18	16	16	17	18	17	19	21	21	23
3.5	194	168	106	47	30	22	17	14	13	12	12	11	10	11	12	13	15	14	15	14
4	168	136	76	34	19	14	13	11	10	10	10	8	8	9	10	9	11	12	11	13
4.5	141	111	54	21	14	11	9	8	8	8	8	7	7	8	8	8	8	10	10	11
5	126	90	43	17	10	8	8	7	6	6	7	6	7	6	6	7	8	8	8	9
5.5	107	79	32	12	8	7	7	7	6	5	—	—	—	—	—	—	—	—	—	—
6	94	65	26	10	7	6	6	6	5	—										
6.5	86	56	21	8	7	6	5	5	—											
7	78	50	17	7	7	5	5	5												
7.5	7	41	14	7	4	3	4	—												
8	63	37	11	5	4	4	4													
8.5	60	37	10	5	4	4	4													
9	56	32	9	5	4	3	4													
9.5	53	28	9	4	4	4	—													
10	52	27	7	5	4	3														
10.5	45	23	7	4	3	3														
11	43	22	7	3	3	3														
11.5	44	22	7	3	3	—														
12	42	20	7	4	3															

Note: the averageluminance factor of bituminous pavementQ_0 is 0.07. The r in the table is expanded by 1000 times and it shall be multiplied by 10^{-3} during calculation.

Appendix B
Examples of Lighting Calculation①

General conditions of all examples:

Width of tunnel pavement	$W = 10.8$m
Height of cross section	$h = 7.8$m
Design speed used in lighting design	$v_t = 80$km/h
Design hourlyvolume	$N = 750$veh/(h · ln)
Road surface of tunnel	Cement concrete pavement
Adaptation luminance (It is assumed in bright environment)	$L_{20}(S) = 3000$cd/m^2
Traffic characteristic	Unidirectional traffic
Conversion factor of average luminance and averageilluminance	10l×/(cd/m^{-2})

When high voltage sodium lamp is used, please refer to Table B-1 for the rated luminous flux oflight sources.

Table B-1 Reference for rated luminous flux of luminaires

Power of luminaires (W)	Rated luminous flux of luminaires (lm)	Power of luminaires (W)	Rated luminous flux of luminaires (lm)
400	48000	100	9000
250	28000	70	6000
150	16000		

Example B-1 Non-optically long tunnel with a length of 300m or below

(1) Calculation condition

Tunnel length: $L = 280$m

① * The calculating parameters of luminaires referred to in the examples, including the utilization factor, rated luminous flux, optical performance and others, are provided by a manufacturer. They shall be subject to samples chosen during engineering design.

(2) Luminance of road surface

According to Table 6.1.1, the luminance of interior zone L_{in} is 2.5cd/m^2. In this example, counter-beam lighting (CBL) is adopted in the interior zone and according to Article 9.2.3 herein, the luminance L_{in} is 2.0cd/m^2.

According to Article 4.1.1 and Article 4.1.3 herein:

Luminance of threshold zone TH_1 L_{th1} = 21cd/m^2

Luminance of threshold zone TH_2 L_{th2} = 10.5cd/m^2

According to Article 5.0.2 and Article 7.0.2 herein, no enhanced lighting is set at the transition zone and exit zone.

(3) Layout of lighting system in tunnel

In this example, the lighting system is calculated by utilization factor method. Please refer to Table B-2 for the layout of lighting system.

Table B-2 Layout of lighting system in tunnel (single-tube)

Item	Length (m)	Luminaire model	Layout	Luminaire spacing at one side (m)	Luminance of road surface (cd/m^2)	Qty. (lamp)	Power (kW)
Enhanced lighting L_{th1} of threshold zone TH_1	40	160W high voltage sodium lamp	Layout of off-centered single light band	2.5	21.0	17	2.55
Enhanced lighting L_{th2} of threshold zone TH_2	40	160W high voltage sodium lamp	Layout of off-centered single light band	5.0	10.5	8	1.2
Interior zone L_{in}	180	160W high voltage sodium lamp	Layout of off-centered single light band	10	2.0	28	2.8

Example B-2 Optically long tunnel with a length of 30m < $L \leqslant$ 500m

(1) Calculation condition

Tunnel length: L = 310m

(2) Luminance calculation of road surface

①Luminance of interior zone

According to Table 6.1.1, the L_{in} is 2.5cd/m^2. In this example, counter-beam lighting (CBL) is adopted in the interior zone, and according to Article 9.2.3 herein, the L_{in} is 2.0cd/m^2.

②Luminance of threshold zone

$L_{th1} = k \times L_{20}(S) = 0.026 \times 3000 = 78.0$cd/m^2

$L_{th2} = 0.5 \times k \times L_{20}(S) = 0.5 \times 0.026 \times 3000 = 39.0$cd/m^2

③Luminance of transition zone

$L_{tr1} = 0.5 \times L_{th1} = 0.15 \times 78.0 = 11.7\text{cd/m}^2$

④Luminance of exit zone

$L_{ex1} = 3 \times L_{in} = 3 \times 2.5 = 7.5\text{cd/m}^2$

$L_{ex2} = 5 \times L_{in} = 5 \times 2.5 = 12.5\text{cd/m}^2$

(3) Layout of lighting system in tunnel

In this example, the lighting system is calculated by utilization factor method. Please refer to Table B-3 for the layout of lighting system.

Table B-3 Layout of lighting system in tunnel (single-tube)

Item	Length (m)	Model	Layout	Luminaire spacing at one side (m)	Luminance of road surface (cd/m²)	Qty (lamp)	Power (kW)
Enhanced lighting L_{th1} of threshold zone TH_1	40	400W high voltage sodium lamp	Bilaterally symmetrical layout	4.2	78.0	22	8.8
Enhanced lighting L_{th2} of threshold zone TH_2	40	250W high voltage sodium lamp		5.0	39.0	16	4.0
Enhanced lighting L_{tr1} of transition zone TR_1	70.2	100W high voltage sodium lamp		5.4	11.7	26	2.6
Enhanced lighting L_{ex1} of exit zone EX_1	32	100W high voltage sodium lamp	Bilaterally symmetrical layout	8.0	7.5	8	0.8
Enhanced lighting L_{ex2} of exit zone EX_2	30	100W high voltage sodium lamp		5.0	12.5	14	1.4
Interior zone L_{in}	75.8	100W high voltage sodium lamp	Layout of off-centered single light band	10.0	2.0	31	3.1

Example B-3 Layout of lighting system in long tunnel

(1) Calculation condition

Tunnel length: $L = 2500\text{m}$

(2) Luminance calculation of road surface

① Luminance of interior zoneAccording to Table 6.1.1, the L_{in} is 2.5cd/m^2.

② Luminance of threshold zone

$L_{th1} = k \times L_{20}(S) = 0.026 \times 3000 = 78.0 cd/m^2$

$L_{th2} = 0.5 \times k \times L_{20}(S) = 0.5 \times 0.026 \times 3000 = 39.0 cd/m^2$

③Luminance of transition zone

$L_{tr1} = 0.15 \times L_{th1} = 0.15 \times 78.0 = 11.7 cd/m^2$

$L_{tr2} = 0.05 \times L_{th1} = 0.05 \times 78.0 = 3.9 cd/m^2$

$L_{tr3} = 0.02 \times L_{th1} = 0.02 \times 78.0 = 1.56 cd/m^2 < 2.5 \times 2 = 5 cd/m^2$, transition zone TR_3 may not require enhanced lighting.

④ Luminance of exit zone

$L_{ex1} = 3 \times L_{in} = 3 \times 2.5 = 7.5 cd/m^2$

$L_{ex1} = 5 \times L_{in} = 5 \times 2.5 = 12.5 cd/m^2$

(3) Layout of lighting system in tunnel

In this example, the lighting system is calculated by utilization factor method. Please refer to Table B-4 for the layout ofthe lighting system.

Table B-4 Layout of lighting system in tunnel (single-tube)

Item	Length (m)	Model	Layout	Luminaire spacing at one side (m)	Luminance of road surface (cd/m^2)	Qty (lamp)	Power (kW)
Enhanced lighting L_{th1} of threshold zone TH_1	42	400W high voltage sodium lamp	Bilaterally symmetrical layout	4.2	78.0	22	8.8
Enhanced lighting L_{th2} of threshold zone TH_2	40	250W high voltage sodium lamp		5.0	39.0	16	4.0
Enhanced lighting L_{tr1} of transition zone TR_1	70.2	100W high voltage sodium lamp		5.4	11.7	26	2.6
Enhanced lighting L_{tr2} of transition zone TR_2	96	100W high voltage sodium lamp	Bilaterally staggered layout	16	3.9	12	1.2
Enhanced lighting L_{ex1} of exit zone EX_1	32	100W high voltage sodium lamp	Bilaterally symmetrical layout	8.0	7.5	8	0.8
Enhanced lighting L_{ex2} of exit zone EX_2	30	100W high voltage sodium lamp		5.0	12.5	14	1.4
Interior zone L_{in}	2137.8	100W high voltage sodium lamp	Layout of off-centered single light band	8.0	2.5	311	31.1

Wording Explanation for the *Guidelines*

1 The strictness in execution of the *Guidelines* is expressed by using the wording as follows：

1）MUST—A very restrict requirement in any circumstances.

2）SHALL—A mandatory requirement in normal circumstances.

3）SHOULD—An advisory requirement.

4）MAY—A permissive condition. No requirement is intended.

2 Expressions used for reference to standards are explained as follows：
The standards for which a year is added to the standard number shall be the specific versions to be used. Otherwise they shall be the latest available versions.