CDOT Lighting Design Guide

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1 Introduction

The CDOT Lighting Design Guide is based on the Illuminating Engineering Society of North America (IESNA) Lighting Handbook Ninth Edition and the American Association of State Highway and Transportation Officials (AASHTO) 2005 Roadway Lighting Design Guide. It represents the current recommended practice for roadway lighting and includes criteria for typical applications found in the state of Colorado. The CDOT Lighting Design Guide should be used in conjunction with the latest version of these two references. Exceptions to these guidelines should be thoroughly evaluated and documented in accordance with CDOT's design exception policies.

The guide was developed, prepared, and reviewed in 2006 by Clanton and Associates and a team of CDOT engineers representing all CDOT regions.

The warrants described in this guide match those in the AASHTO Design Guide. A lighting warrant is defined as factual evidence justifying or assuring that there is substantial reason for undertaking a proposed lighting project. The meeting of lighting warrants does not, however, obligate the Department to undertake a lighting project on either existing or proposed highways. Lighting warrants should be based on conditions relating to the need for roadway lighting and the benefits that may be derived from lighting. Factors such as nighttime traffic volume, speed, nighttime accident rate, horizontal and vertical alignment, increased capacity, and general nighttime visibility may be used to justify lighting.

This guide uses standard US Customary (inch-feet-mile) units. One exception to this format is made when discussing candela / square meter (cd/m^2), the unit of lighting luminance. The English term for this unit, footlamberts, is no longer current in the lighting industry. While it is inconsistent with other English units, all luminance criteria are given in cd/m^2 only.

Comments on this Design Guide may be sent to:

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2 Overview

The purpose of roadway lighting is to improve nighttime highway safety by reducing the possibility of motor vehicle collisions with pedestrians, fixed objects, or obstructions on the roadway. Quantity of light does not necessarily indicate a good lighting system. Quality of light does. Effective lighting refers to the ability of the light to provide contrast between objects and background so that motorists can detect conflicts in sufficient time to take evasive action. Many interrelated factors contribute to effective lighting. Reducing glare can improve driver performance. Reflected glare conceals some contrast differences and should be reduced.

There are differences of opinion concerning the conditions under which lighting should be installed and the amount of illumination that should be provided. The following discussion represents the Colorado Department of Transportation design guide regarding those sections of highways on which fixed source lighting is warranted and design guidelines for particular lighting installations.

There are three methods by which the roadway lighting system can be designed. One is based on pavement luminance, another on small target visibility (STV), and a third on lighting system illuminance. Luminance refers to the amount of light that is reflected from the pavement towards the eye of the observer. Specifically, pavement luminance refers to how bright the pavement appears. Design based on luminance is preferred to illuminance because it represents what drivers actually see. Illuminance, however, refers to the amount of light falling on the pavement.

Historically, designs are only based on illuminance. Illuminance is a good starting point for a design. STV provides another measure of visibility and is based on how drivers actually view their surrounding environment and detecting small objects on the pavement. However, luminance or pavement brightness should be evaluated with calculations. No matter which method is selected, glare must be evaluated. In summary, both recommended methods of luminance and STV quantify the visual environment with respect to how a motorist will view it. Illuminance, while easy to calculate and an initial starting point in the design process, does not quantify what a motorist sees and is not recommended as the sole basis of design.

In addition to providing adequate visibility, the lighting design must address the importance of maintenance. Issues that must be addressed include life of the lamp, durability of the luminaire, access to the luminaire due to both location and height of the light standard, and availability of replacement parts.

Refer to the current versions of the IESNA Lighting Handbook, the Recommended Practice 8 (RP-8-00) Roadway Lighting, and the AASHTO Lighting Guide for full descriptions on roadway lighting design using all methods.

3 Design Considerations

3.1 Visibility

Effective visibility in the nighttime environment depends on the control of six different factors: glare, luminance, uniformity, illuminance, contrast, and adaptation. One factor is not necessarily more important than another; rather all must be adequately addressed to produce high visibility. See Figure 1.

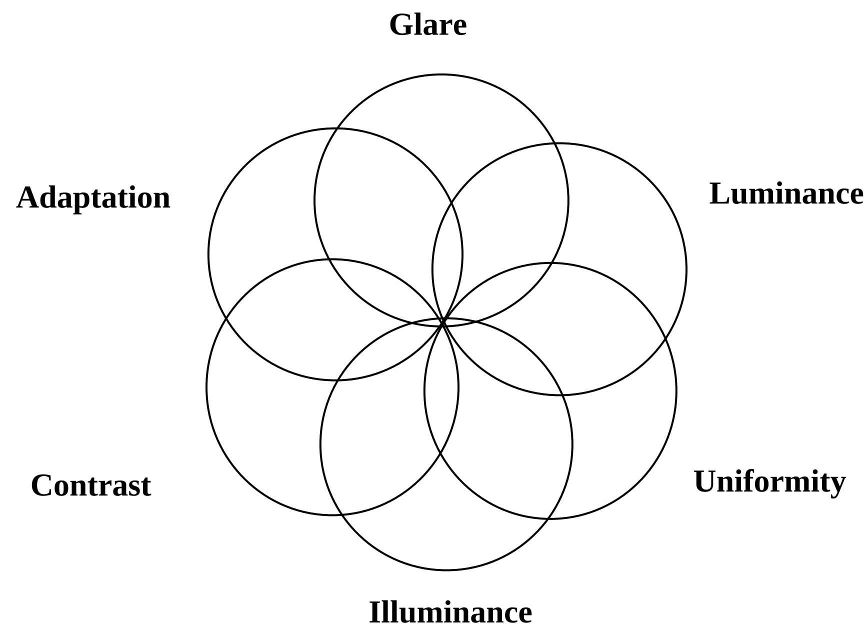


Figure 1. Diagram of the components of visibility.

Task visibility describes how size, brightness, and contrast of a particular activity affect the lighting required to view that activity. It should be noted that the ability to actually perform a task well includes other non-visual human factors such as skills and experience, independent of the task visibility.

Large tasks such as seeing vehicles generally require less brightness, contrast, and illuminance, to be performed. Small detailed tasks such as reading directional signs may require increased brightness, contrast, and illuminance. The luminance or brightness of a task increases the task visibility. Brighter tasks are easier to see, so long as it is not so much brighter than its surroundings that it becomes uncomfortable or a source of direct glare. As task contrast decreases, the light level required to see it will increase. An example of low task contrast may be viewing barrier indicating a lane shift detour. If the contrast is too low, it will be difficult to distinguish various components of the task, reducing visibility. The task of driving requires the detection of hazards and a clear view of the surrounding traffic and road conditions.

Way finding refers to the visual guidance provided by the lighting system and the visual elements illuminated. This guidance may be illuminated signage that directs motorists to various destinations, or lighted barrier in a construction zone or it may be more subtle aids such as continuity and hierarchy of lighting equipment that reinforces areas of similar use or traffic density. By using the same luminaires for areas of the same use, a consistent pattern is established that visually guides and orients pedestrians as well as motorists.

For example, the size and type of lighting equipment provides visual cues about the surroundings. Bollards and pedestrian poles often signify pedestrian walkways or plazas. Roadway light standards may alert pedestrians to intersections in the same way that pedestrian poles or bollards may alert motorists to crosswalks.

3.1.1 Glare

Direct glare is caused by excessive light entering the eye from a bright light source. The potential for direct glare exists anytime one can see a light source. With direct glare, the eye has a harder time seeing contrast and details. A system designed solely on lighting levels, tends to aim more light at higher viewing angles, thus producing more potential for glare.

Causes of direct glare include an exposed bright light source, for example a dropped-lens cobrahead or floodlight. Direct glare can be minimized with careful equipment selection as well as placement. Figure 2 illustrates two examples of exterior lighting that results in glare. Figure 3 shows how full cutoff luminaires can minimize this direct glare. In exterior applications, use fully shielded luminaires that directs light downwards towards the ground.

Figure 2. Examples of direct glare.

Figure 3. Minimized direct glare with IESNA full cutoff luminaires.

Indirect or reflected glare is caused by light reflecting off the pavement in such a manner that the contrast is washed out. Any light source can cause reflected glare depending on the viewing angle of the motorist. However, unshielded streetlights have an increased potential of reflected glare, especially on wet pavement, and cause it at more viewing angles. Reflected glare will wash out lines on the road, especially on wet pavement, and limit one's ability to see contrast. Like direct glare, indirect glare can be minimized with the type and layout of lighting equipment. Direct the light away from the observer with the use of low glare, fully shielded luminaires.

3.1.2 Luminance

Luminance is reflected light or the brightness of a surface or an object in an individual's field of view. It is measured in units of candela per square meter (cd/m^2). It is dependant on the viewing angle between the object or surface and the viewer's eye. This measure is important because, unlike illuminance, this quantity is actually seen.

In roadway lighting, pavement luminance refers to how bright the pavement appears to motorists. When the pavement is dark, it is harder to see pavement markings and objects on the road. Higher pavement luminance gives the motorist visual information on the roadway boundaries, conflict areas such as crosswalks and intersections. Concrete pavements reflect more light than asphalt pavements, so less light is required for concrete surfaces. Road side barriers or tunnel walls are ideal surfaces to light because their luminance helps motorists navigate through vertical barriers.

3.1.3 Uniformity

Lighting uniformity refers to the evenness of light. Our eyes are continually adapting to the brightest object in our field of view. Any object lighted to 1/10 the level of the immediate surroundings appears noticeably darker. As the uniformity ratio increases (poorer uniformity), object details become harder to see. For roadway lighting, good uniformity shows evenly lighted pavement. However, to meet small target visibility criteria, a non uniform roadway surface may be better. There should be a balance between uniform perception and detecting objects on the road. Also, emphasis is put on horizontal surface uniformity. In reality, vertical surfaces may require more lighting in order to improve guidance.

3.1.4 Illuminance

Illuminance refers to the light level, or amount of light falling on a surface. It is measured in footcandles (fc). Horizontal illuminance refers to the amount of light falling on a horizontal surface such as pavement. Vertical illuminance refers to the amount of light falling on a vertical surface such as signs and pedestrians. Traditionally, illuminance has been the sole basis of lighting design. However, we see brightness; we don't see lighting levels or footcandles.

There are three different types of visual responses: Photopic or our day vision , scotopic or our night vision, and mesopic or a combination of night and day vision. The majority of exterior lighting falls within the mesopic range.

In mesopic vision, our peripheral detection is greatly enhanced with shorter wavelength light (blue light) versus longer wavelength light (orange or red light). White light sources produce light in all wavelengths making it an ideal nighttime lighting source.

For all exterior lighting applications where peripheral vision is important such as detecting pedestrians and animals on the side of the road, white light as produced by a metal halide, fluorescent, or induction lamp is recommended.

3.1.5 Contrast

Contrast is the difference between two adjacent luminance values. High contrast is necessary for good visibility. An example of high contrast is freshly painted pavement markings on new asphalt. If the contrast becomes excessively high such as a overhead sign luminaire aimed towards oncoming traffic, the brighter can become a source of glare.

Surface or object contrast gives motorists the most information for guidance. When contrast is washed out or diminished like pavement markings on wet pavement or snow packed roads, then navigation becomes difficult. It is important to keep strong object contrast for all driving tasks.

3.1.6 Adaptation

Adaptation refers to the eye's ability to adjust between changes in luminance. Our eye will automatically adjust to the brightest object in our field of view. Glare from headlights or fixed lighting can affect one's ability to adapt to lower surface luminance. This is especially true as one ages. Another form of adaptation occurs when driving from a lighted area to a non-lighted section of roadway. In this case, the lighted area should slowly transition to darker by allowing adaptation time. Transition in and out of tunnels is critical during the day as well as at night.

3.2 Light Trespass / Light Pollution

Light trespass is often referred to as nuisance glare or the "light shining in my window" effect. It is usually caused by a glare source that is bright compared to the darker background and immediately adjacent to another property.

Uncontrolled light sources are usually the cause of light trespass. However, even a controlled, full cutoff luminaire may cause light trespass if not properly located. In cases where the location of a light standard cannot be changed, additional shielding may be necessary to prevent light trespass. Increasing the height of a light standard will also increase the potential for light trespass. As the luminaire is raised, its brightness can be seen from a greater area. Not only does light trespass cause neighbor annoyance, but it also increases light pollution.

To minimize light trespass, use only fully shielded or IESNA full cutoff luminaires for area lighting. In some cases, additional shielding may be required to shield light sources from residential neighborhoods. Or, at low mounting heights, reduce the lamp brightness to that of a 3200 lumen lamp (similar to a 55 watt induction lamp) or less. This is also in accordance with the Colorado Revised Statute (CRS 24-82-902) limiting light pollution for all State funded projects. In addition to limiting the lumen output, using coated lamps and installing lamp shielding will also reduce light trespass. Do not overlight areas because reflected light can also result in complaints and poor visibility by increasing visual adaptation. It is also very difficult to go from a brightly lighted area to a non-lighted area.

Figure 4. Fully shielded or IESNA full cutoff luminaires (left) are recommended. Do not use unshielded floodlights or wallpacks (right).

Light pollution or sky glow is caused by light aimed directly up into the sky and by light reflected off the ground or objects. Any addition of light will add to light pollution. However, it is the direct component (rather than reflected) that is the most significant cause of light pollution. Floodlights, wall packs, and other un-shielded luminaires are major contributors to sky glow. Overlighting, even with shielded luminaires, reflects unnecessary light back into the atmosphere and adds to the sky glow. Figure 5 shows two views of Denver and the results of uncontrolled light pollution.

Figure 5. City of Denver light pollution from Mt. Evans Observatory ©University of Denver – Astronomy Department.

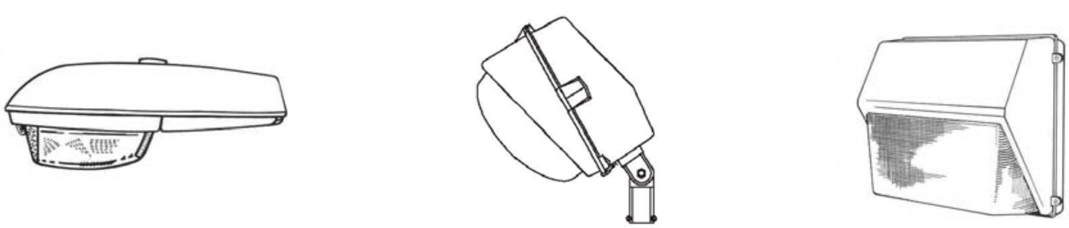


Figure 6. Unshielded and non-cutoff luminaires lead to light pollution.

To minimize light pollution, use fully shielded luminaires or IESNA full cutoff type for area and roadway lighting as illustrated in Figure 7. The use of full cutoff luminaires may reduce uniformity and therefore require greater light standard heights or spacing. Cutoff, semi-cutoff, and non-cutoff luminaires may be used at low mounting heights if the lumen output of the lamp is limited to 3200 lumens, conforming to the Colorado Revised Statute. This allows a 42 watt compact fluorescent, 50 watt metal halide, or 55 watt induction lamp. Such applications include pedestrian lighting, bollards, and low level bridge lighting. However, the majority of CDOT luminaires will use light sources greater than 3200 lumens and therefore require full cutoff characteristics. For a more detailed description of full-cutoff, and cutoff luminaires, see Table 2. Providing uniform, low glare lighting and not overlighting exterior areas will minimize light pollution. Also, the control of lighting with time clocks, photocells, and motion sensors provides lighting only when needed.

Figure 7. Examples of IESNA full cutoff luminaires.

3.3 Lighting Equipment

3.3.1 Light Sources

Lamp types and their suitable applications are illustrated in Table 1. Additionally, some lamp characteristics are also included. Lamps must be chosen based on the criteria that are most appropriate to the project.

Light Source	Pedestrian (10’-14’)	Roadway (20’-30’)	Roadway (30’-40’)	*Roadway (40’-70’)	Parking Areas	Tunnels/Underpass	Wall/Pedestrian Underpass	Steplights/Barrier /Post	Controls: Motion Sensors (Instant Start)	Controls: Dimming	Long Life / Low Maintenance
Metal Halide											
70 watt	●				●		●				
100 watt		●			●						
150 watt		●			●	●					
250 watt			●								
400 watt				●							
Induction											
55-70 watt	●						●		●		●
85-100 watt	●	●				●			●		●
150-165 watt		●	●			●			●		●
High Pressure Sodium (HPS)											
70 watt					●						
100 watt		●			●						
150 watt		●			●						
250 watt			●								
400 watt				●							
Fluorescent											
26 watt							●	●	●	●	
32 watt	●						●		●	●	
42 watt	●						●		●	●	
50+ watt		●							●	●	
Light Emitting Diode (LED)						●	●	●	●	●	●
* Mounting heights over 40’ should be used for special conditions only.											

Table 1. Lamp Applications.

3.3.1.1 Metal Halide

Metal Halide lamps (High Intensity Discharge) provide a small point source of white light. Metal halide lamp efficacies (lumens of light per watt of input electricity) and lamp life are increasing with pulse start technology. The disadvantages of the metal halide lamp are lumen depreciation over time and a long start up time. Additionally, these lamps also have a re-strike time. When a lamp is warm and then turned off, it must cool sufficiently before it can be re-ignited. This time delay is the re-strike time of the lamp. Even with these disadvantages, metal halide is a great source of white light, especially for exterior nighttime lighting, where it enhances peripheral vision.

Use electronic ballasts rated for roadway use for metal halide lamps 150 watts and below. These ballasts are more reliable and use less energy than magnetic ballasts. Currently they are only available for 150 watt lamps and lower. If higher wattage ballasts become commonly available they should be considered.

3.3.1.2 Induction Lamps

Induction lamps are essentially fluorescent lamps without electrodes. Therefore, they have very high efficacies and extremely long lives (70,000-100,000 hours). Induction lamps have many of the fluorescent lamp advantages such as superior color rendering, instant on/off switching, and long life.

Despite the high initial cost, these lamps offer significant cost benefits regarding low energy and maintenance costs. A typical relamping schedule may call for changing metal halide lamps after only 15,000 hours while induction lamps can be changed after 60,000 hours. The savings in lamp replacements and labor costs quickly pay for the higher installation cost. In some cases, the payback period may be as short as 5-7 years. Most importantly, the induction lamp is extremely reliable and efficient. When compared against higher wattage HPS lamps, the energy savings of the induction lamp reduces the payback period even more.

The ideal application for induction lamps is in areas where metal halide or high pressure sodium lamps are often used. Long life and instant on/off induction lamp characteristics make it very reliable and easy to control with motion sensors. The induction lamp is larger and requires suitable luminaries.

3.3.1.3 High Pressure Sodium (HPS)

High Pressure Sodium (HPS) lamps are typically used for many exterior applications. Although high pressure sodium lamps have long lives (20,000 hours) and appear to be efficacious, they have several disadvantages. The most important is the lack of short wavelength light such as blue and green light. As a result one's peripheral vision under nighttime exterior lighting conditions does not respond well to the color of high pressure sodium light. Therefore, HPS lamps render color poorly. White light can be two to twenty times more effective for peripheral vision detection than high pressure sodium. Because short wavelength light controls the pupil, high pressure sodium lamps cause objects to be out of focus or fuzzy. High pressure sodium lamps can be used where existing conditions and continuity of source type make it necessary.

3.3.1.4 Fluorescent

Compact fluorescent lamps are available in increasingly higher wattages. Lower wattage lamps such as 32 and 42 watts may be suitable for pedestrian scale poles and low mounting heights. Higher output lamps such as a 57 watt can be used with higher standards. As new compact fluorescent lamps become available, more luminaires will use them for roadway applications. Use low temperature ballasts and amalgam lamps for extreme conditions. These will decrease the warm-up time of the lamp in cold weather.

3.3.1.5 Light Emitting Diodes (LEDs)

Light Emitting Diodes (LEDs) will become increasingly important for exterior lighting. LEDs produce a directional narrow beam of light making it ideal for traffic signals, barrier lighting, and other directional light source applications. LED efficacies are increasing constantly, soon making LED luminaires an effective means for all types of lighting applications. Because LEDs are monochromatic, white light is difficult to produce unless different colors are combined. LEDs have extremely long lives (100,000 hours), consume very little energy, and are dimmable.

3.3.2 Luminaires

3.3.2.1 Pole Mounted Exterior Luminaires.

Pole mounted luminaires for exterior lighting come in a wide range of heights, but can generally be grouped in one of three categories: pedestrian scale luminaires on short light standards, area luminaires, and high mast luminaires.

3.3.2.2 Pedestrian Luminaires

Pedestrian poles light sidewalks, plazas, and other pedestrian areas. They should be mounted on 12 foot to 14 foot standards. These luminaires must be fully shielded or full cutoff unless the lamp output is under 3200 lumens. Their aesthetic character should be appropriate for the surrounding buildings and landscape.

3.3.2.3 Area Luminaires

Area luminaires light roads and parking lots. They should be mounted on 25 foot to 40 foot standards. These luminaires should use IESNA full cutoff optics to eliminate glare. They should have a neutral aesthetic quality so that the luminaire disappears into its surroundings.

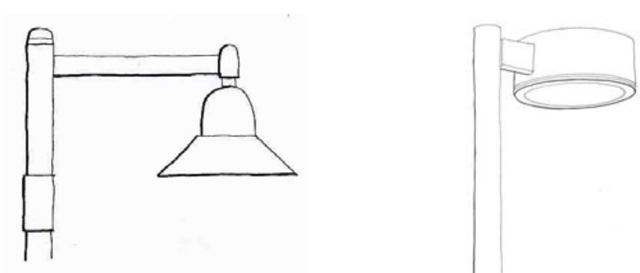


Figure 8. Pole mounted exterior luminaires.

3.3.2.4 Exterior Luminaire Classification.

The National Electrical Manufacturers Association (NEMA) classifies exterior luminaires by intensity distribution. Tables 2 and 3 describe the cutoff and distribution classification. One classification refers to the vertical candela distribution of light from an individual luminaire (Table 2) and the other refers to the illuminance pattern produced on the ground or horizontal surface (Table 3). Each successive classification provides more vertical illuminance, but also introduces more glare and stray uplight. Full cutoff luminaires are typically used for roadway and area lighting to minimize glare, light trespass, and light pollution. Semi-cutoff and non-cutoff should be used only at low mounting heights and with low output lamps (less than 3200 lumens).

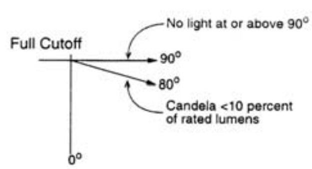
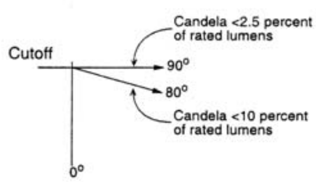
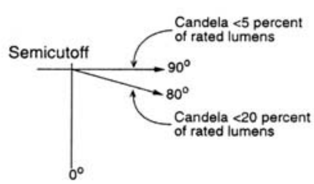
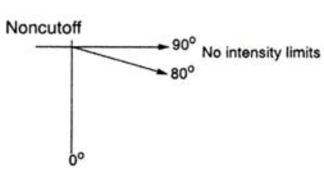
TYPE	DESCRIPTION	APPLICATIONS
Full Cutoff  	A luminaire light distribution where zero candela intensity occurs at an angle of 90° above nadir (straight down) and at all greater angles from nadir. Additionally, the candela per 1000 lumens does not numerically exceed 100 (10%) at a vertical angle of 80° above nadir. This applies to all lateral angles around the luminaire.	Use for roadway, parking, and other vehicular lighting applications. Minimizes glare and light pollution and light trespass.
Cutoff  	A luminaire light distribution where the candela per 1000 lamp lumens does not numerically exceed 25 (2.5%) at an angle of 90° above nadir, and 100 (10%) at a vertical angle of 80° above nadir. This applies to all lateral angles around the luminaire.	Use in applications where pedestrians are present. Provides more vertical illuminance than Full Cutoff luminaires. Lamp rating should be less than 3200 lumens.
Semicutoff  	A luminaire light distribution where the candela per 1000 lamp lumens does not numerically exceed 50 (5%) at an angle of 90° above nadir, and 200 (20%) at a vertical angle of 80° above nadir. This applies to all lateral angles around the luminaire.	Use in pedestrian areas. If using in residential areas, provide with houseside shields to minimize light trespass. Lamp rating should be less than 3200 lumens.
Noncutoff  	A luminaire light distribution where there is no candela limitation. The light source may be completely unshielded.	Use for decorative applications only. Lamp rating should be less than 3200 lumens.

Table 2. Exterior Luminaire Cutoff Classification.[1]

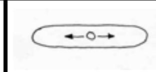
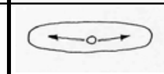
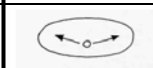
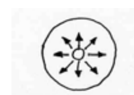
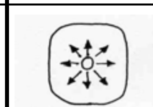
Type	Description	Plan View
Type I	Narrow, symmetric illuminance pattern.	
Type II	Slightly wider illuminance pattern than Type I.	
Type III	Wide illuminance pattern.	
Type IV	Widest illuminance pattern.	
Type V	Symmetrical circular illuminance pattern.	
Type VS	Symmetrical, nearly square illuminance pattern.	

Table 3. Exterior Luminaire Distribution Classification.

3.3.3 Light Standards

Light standard heights are determined by the width of the road, light trespass potential and the standard heights used by the utility or the responsible agency. Typically, the higher the standard, the fewer standards are required for uniform lighting. Yet, standards over 40 feet increases the light trespass potential. In using standards over 40 feet, the impact on residential neighborhoods and open space wildlife must be assessed. Streets within a municipality may benefit from lower light standards (30 feet or less) since the scale of the installation is more aesthetic with the town or city theme.

Round standards will be used since they reflect less light and have lower effective projected areas (EPA). Standards less than 20 feet should be straight while light standards 20 feet and greater should be tapered. Poles greater than 70 feet are rarely used and ared addressed under High Mast Applications. Square section standards should not be used.

All standards shall be galvanized in order to reduce maintenance. Exterior surfaces of galvanized standards may be painted if requested and approved.

Decorative light standards should only be specified if maintained by a municipality and is part of their standards.

Every standard shall have a handhole or a transformer base. Some light standards may have seasonal lighting receptacles with an in-use cover per the municipality's request.

3.3.4 Ballasts and Power Sources

3.3.4.1 General.

High Intensity Discharge (HID) lamp sources will flicker due to the changes in line voltage. This flicker effect may be noticeable in certain applications and can be effectively eliminated with the use of high frequency electronic ballasts[2].

Ambient air temperature affects the performance and output of fluorescent lamps. In exterior, low temperature applications (less than 50 degrees Fahrenheit), provide ballasts capable of low temperature lamp starts. Light output will be reduced until the lamp warms up to operating temperature. Mercury amalgams added to fluorescent lamps improve the lamp performance and provide for operation over a wide temperature range. These lamps typically take slightly longer to reach normal operating temperature and full light output.

The operating temperature of ballasts directly affects the life. The luminaire housing or ballast enclosure should provide for adequate dissipation of heat. When ballasts operate at excessive temperatures, the insulation degrades resulting in a shortened ballast life.

3.3.4.2 HID Electronic ballasts.

The use of electronic ballasts as opposed to older technology core and coil ballasts reduces the energy requirements of HID and fluorescent sources. The input wattage is minimized with electronic ballasts. They also have the benefits of reduced flicker, smaller size, less weight, and lower starting temperature. Electronic ballasts used for roadway lighting must be rated for at least 10,000ISC. Provide electronic metal halide ballasts for 150 watt lamps and lower. These ballasts are more reliable and use less energy than magnetic ballasts. Currently they are only available for 150 watt lamps and lower. If higher wattages become commonly available, they should be considered.

3.3.4.3 HID Magnetic Ballasts.

Provide magnetic ballasts for HID lamps that do not have electronic ballast options. These ballasts should have a high power factor (minimum of 90 percent).

3.3.4.4 Induction Generator.

Induction lamps require the support of both a high frequency generator and a power coupler. The overall operating system should include a five-year minimum manufacturer warranty.

3.3.4.5 Compact Fluorescent Electronic Ballasts.

Select ballasts for compact fluorescent lamps that operate with a high power factor (greater than 90 percent) and for low temperature use. Provide programmed start ballasts for compact fluorescent lamps that include end of life protection.

3.3.4.6 Light Emitting Diodes (LED) Power Supply.

LED power supplies convert an input voltage to low voltage DC output. One power supply module may operate multiple LED luminaires. Dimmable power supplies are available.

3.3.5 Lighting Control Centers (LCC) or Secondary Service Pedestals (SSP)

Lighting Control Centers (LCC) or Secondary Service Pedestals (SSP) are required in order to provide a location for lighting panel boards, photoelectric controls, contactors, maintenance receptacle, and a copy of the lighting plan and luminaire schedule. Each LCC and SSP must be grounded with an approved ground rod system. It must also be in an easily accessible location for maintenance and inspection.

3.4 Maintenance and Economics

3.4.1 Luminaire Maintenance

Maintenance must be considered in the design process. By selecting long-life sources, the frequency of re-lamping can be reduced. Evaluate the ability to perform future maintenance in the installed location. For example, lighting in tunnels and other difficult to access locations can be very hard to maintain. In cases of poor or limited access, evaluate lamp and luminaire life as part of the design.

Group re-lamping should be the principal method of periodically replacing lights in a given area. The group re-lamping frequency should be based on ensuring intended lighting levels are maintained above minimum levels. Spot re-lamping is not recommended in this regard because lighting levels will tend to eventually fall below intended levels. The group re-lamping interval should consider the lamp mortality curve (provided by the manufacturer for each type of lamp) that spot re-lamping does not become an excessive maintenance burden.

To improve the maintenance, the municipality or other responsible agents should be involved throughout the design process. This will ensure that the party responsible for maintenance and operation of the lighting system is aware of the design intent and requirements.

3.4.2 Inventory Minimization.

Lamp and ballast types should be consolidated across luminaire types to minimize the number of various components that need to be stocked by the maintenance team. In addition to lamp replacement, the next most likely element that must be replaced is the photocell. These should also be stocked and the number of types minimized.

3.4.3 Economic Evaluations.

To determine the economic feasibility of various design options, several methods may be used.

Simple Payback Period (SPP) is the most common and easiest to calculate. This value is equal to the initial investment (or increase in investment) divided by the annual savings.

This savings may be from reduced energy use or lower predicted maintenance costs. The result represents the number of years for the investment to be recouped. While it is easily understood, the simple payback does not take into account the time value of money or the value of the savings that may be realized during all of the years after the investment has been paid for.

A Life Cycle Cost (LCC) or Net Present Value (NPV) analysis considers inflation, a discount rate, and the total savings achieved by the investment over its expected life. Designers can use these values to compare a series of design alternatives. The option with the lowest life cycle cost represents the best economic decision.

A Rate of Return (ROR) analysis results in a percentage value. This value represents the equivalent interest rate that could be received on another investment. Like an LCC, the ROR of multiple designs can be compared. The alternative with the highest rate represents the best investment. Additionally, the ROR provides a value in a recognizable form, as it can be compared to interest rates available from a bank or other potential investments.

Table 4 illustrates an example of how these various values may be used. The initial luminaire cost may vary between two potential options: metal halide (option 1) and induction (option 2). In this example, option 2 is $200 more expensive than option 1. The next series of rows in the table calculates the energy use of each option over one year. The induction lamp costs slightly less to operate, but the difference is minimal. The annual energy payments for both are converted to a present value with the Uniform Series Present Worth factor (USPW). Maintenance costs are then calculated over the 20 year life of the induction lamp. In that time, the metal halide lamp must be replaced three times. The relacement cost at each of those times is converted to a present value using the Single Payment Present Worth factor (SPPW). The life cycle cost is then determined by adding the initial capital cost, the energy costs, and the replacement costs (all converted to present values). Considering energy savings only, the simple payback period is forty years – twice the life of the induction lamp. However, using the life cycle cost method to incorporate maintenance costs, the induction option saves $145 over the life of the luminaire. The third method shows that option 2 gives a rate of return of nearly 12% - a very good investment.

	Option 1 (Metal Halide Luminaire)	Option 2 (Induction Luminaire)	Notes
Initial Investment			
Luminaire Cost:	$500	$700	
Energy Use			
Input Watts:	185	165	
Energy Cost ($/kWh):	$0.07	$0.07	
Operating Hours /yr:	3,650	3,650	*=10 hrs/day * 365 days/yr*
Energy Cost /yr:	$47	$42	
Maintenance			
Replace at Y=	5	20	
Lamp + Labor Cost	$150	$0	
Present Worth=	$118	$0	*=SPPW * Cost*
Replace at Y=	10	20	
Lamp + Labor Cost	$150	$0	
Present Worth=	$92	$0	*=SPPW * Cost*
Replace at Y=	15	20	
Lamp + Labor Cost	$150	$0	
Present Worth=	$72	$0	*=SPPW * Cost*
Total Main. Cost=	$282	$0	*=SUM(present worth)*
Life Cycle Cost			
Initial Cost	$500	$700	*Capital Costs*
Uniform Payments	$589	$525	*Energy Costs*
Single Payments	$282	$0	*Maintenance Costs*
LCC=	**$1,371**	**$1,225**	
Life Cycle Savings=		$145	
SPP (yrs) =		**40**	
Additional Cost=		$200	
Energy Savings Only=		$5	
ROR=		**11.95%**	
discount rate (d):	5%		
project life in yrs (N):	20		
Uniform Series Present Worth (USPW):	12.462		*USPW=(1-(1+d)^-N)/d*
Single Payment Present Worth (SPPW): (varies with year of replacement)			*SPPW=(1+d)^(-Y)*

Table 4. Life Cycle Cost Example using a discount rate of 5% and a 20 year project life.

4 Design Guidelines

4.1 Master Planning

Lighting master plans allow for consistency of design, more control over the nighttime visual environment, and standardization of maintenance procedures. Additionally the effort put into a master plan can minimize design time of component projects later on.

Refer to the AASHTO Roadway Lighting Design Guide for a more in-depth discussion.

4.2 Design Methods

Three methods can be used to calculate the effectiveness of a roadway lighting design. Commercially available computer programs perform point-by-point calculations. These programs permit multiple luminaires and can take buildings and other obstacles into account. Most programs generate CAD-compatible site isolux plots and analytical statistics related to illuminance and uniformity. Luminance, veiling luminance, and small target visibility should also be calculated for roadway applications.

4.2.1 Luminance

Luminance is the preferred method for roadway lighting design and calculations. This method represents what motorists see and results in quality roadway lighting systems. This method also demands luminance uniformity and a veiling luminance analysis. Veiling luminance is a measure of disability glare. It compares the amount of light entering a motorist's eye to the brightness or luminance of the roadway surface. If too much light is entering one's eye, then light scatters providing a veil of light such that it is difficult to see objects on the road pavement. Luminaires that are not full cutoff have the greatest potential for disability glare.

To calculate the luminance values of a design, a computer program must be used. The program will need the type of roadway pavement that will be used. Then the user must define a grid of points. The program will then calculated the luminance of each point in the grid as it is seen from a distant observer. An average value of all of these points will also be calcuated so that it can be compared to the project criteria. It is important to understand that the calculated luminance is dependent on the direction from which the a point is being viewed. In some designs, it may therefore be necessary calculate the luminance in both directions of traffic flow.

4.2.2 Small Target Visibility (STV)

Small Target Visibility is another preferred method. STV, while not an AASHTO approved method of calculation, represent the lastest methodology to quantify the combined effect of all of the visibility factors. It not only assesses luminance and luminance ratio uniformity (as described above), but also addresses veiling luminance. The more luminance differences on a roadway, the greater the chance an object will be detected either with positive contrast or by silhouette. The combination of pavement brightness, disability glare and object detection is the best assurance of effective lighting.

Like luminance, a lighting computer program must be used to calculate STV. The process is much like the luminance method where a pavement type must be selected and a point grid defined. The STV calculation will produce a value of Visibility Level (VL). This value increases with improved visibility. The calculated value must be greater than or equal to the project criteria. As the driver moves along the road, objects may be illuminated (positive contrast), in silhouette (negative contrast), or in some combination of the two. A combination of positive and negative contrast can result in the objects disappearing from view. Figures 9, 10, and 11 illustrate these concepts.

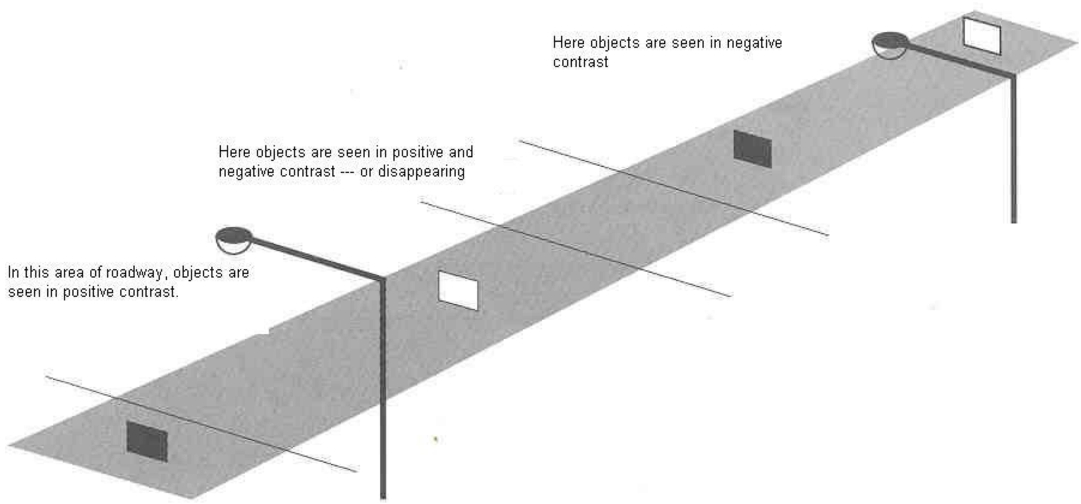


Figure 9. Objects along a roadway with positive, negative, and no contrast.[3]

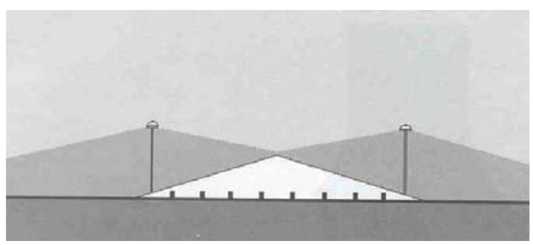


Figure 10. Light standards spaced close together and with non-full cutoff luminaires have poor STV.[4]

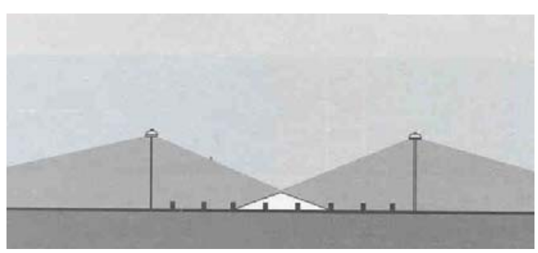


Figure 11. Light standards further apart and full cutoff luminaires have good STV.[5]

4.2.3 Illuminance

This method is not recommended because it does not address the brightnesses that are actually seen. The illuminance method specifies a minimum horizontal illuminance depending on pavement type and a minimum uniformity.

Illuminance is the oldest method of calculation. It was readily used because of the ease of calculation and measurement. Unfortunately, illuminance does not predict motorist visibility since it only calculates incident light and not roadway brightness. For other non-roadway applications such as walkways, bikepaths and signs, illuminance is currently the only design method.

4.3 Design Configurations

Three design configurations are typically used in roadway lighting: opposing, median, and staggered. Regardless of the configuration used, light standards should be placed in accessible locations. Ideally this location is behind the guardrail, out of a drainage area, and positioned with the luminaire over the shoulder of the road. These locations provide easy and safe access from the maintenance truck with minimal obstruction of traffic. Final locations must be checked with the traffic and maintenance teams.

4.3.1 Opposing

Opposite configurations refer to pairs of luminaires located on opposite sides of the roadway. When roadways are wide, opposite locations are ideal. This design not only provides the best uniformity, but also results in high small target visibility levels.

The pairs are then spaced along the roadway length. If the road is narrow (two lanes wide) the lighting criteria may be met by a design with poles on just one side of the roadway. If possible, locate the poles on the outside of curves. This minimizes the chance of them being hit in the event of an accident.

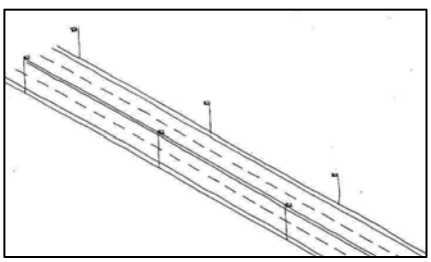


Figure 12. Opposing configuration

4.3.2 Median

In a median configuration, two luminaires are mounted on a single light standard located in the median of the roadway. This provides a reduced initial cost by eliminating half of the standards needed in an opposite or staggered configuration. Additionally it simplifies the power supply and layout. These advantages must be balanced with the fact that these standards may be more difficult to maintain and have a higher potential for light trespass. Even though they are not located on the property line, the distribution of the light may be less controlled. Median lighting has other visibility advantages such as guidance around curves, least amount of equipment for the greatest visibility, and has high small target visibility results.

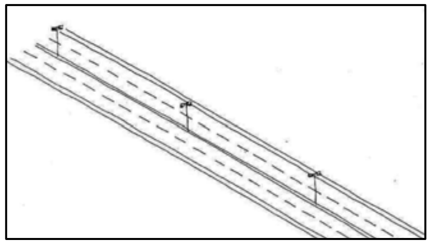


Figure 13. Median configuration

4.3.3 Staggered

Staggered configurations used to be the most common design layout. With the illuminance method, staggered arrangements use the least amount of light standards. Unfortunately, with small target visibility, the staggered arrangements produce the worst results. Therefore, such configurations should be avoided.

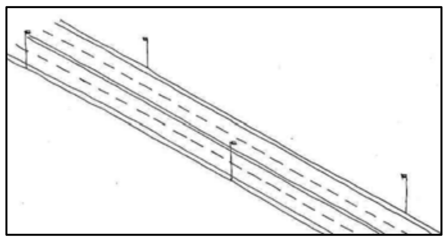


Figure 14. Staggered configuration

5 Roadway Applications

The following application pages begin with a summary of the warrants to determine if lighting is actually necessary. The criteria that should be met by the lighting design are summarized in a table format. In some cases the criteria is given as a range. Specific values must be obtained from the appropriate tables located in the Appendix. A list of the design intent and possible rules of thumb follow to give the designer a starting point for the design as well as an overall view of the design objectives. Any special considerations for that particular application are also listed. On the facing page, an example design is illustrated with a perspective view, a plan view, and a luminaire schedule. These are provided to show how the criteria were met for a given case. It cannot be taken as a standard. All designs must be treated individually.

The criteria and example assume a simple layout such as straight, horizontal stretches of roadway. For sharp curves, steep hills, or any special case consult the latest version of the IESNA Handbook, Recommended Practice RP-8 Roadway Lighting, or AASHTO Design Guide.

For some applications, an example calculation is also included. This is intended to illustrate the type of calculation results that were used to verify the design. For most designs, a typical section of the roadway is all that must be calculated. As with the lighting criteria, the extent and type of calculations will vary with type and complexity of the project.

5.1 Freeways

Warrants (from AASHTO):

- The freeway is in or near a city where the present average daily traffic is 30,000 or more.
- There are three or more successive interchanges with an average spacing of 1.55 miles or less and the adjacent area is substantially urban.
- For a length of 1.86 miles the freeway passes through an urban or suburban area in which one or more of the following conditions exist:
    - Local traffic operates on a lighted street grid, portions of which are visible from the freeway;
    - The freeway passes through lighted developments including residential, commercial, industrial and civic, colleges, parks and terminals;
    - Separate cross streets occur with an average spacing of 0.62 mile or less; and
    - The freeway cross-section elements are less wide than those found in rural areas
- Special freeway considerations are warranted when:
    - Continuous, complete or partial interchange lighting when the local government agency is willing to pay an appreciable percentage of or wholly finance the lighting installation.
    - Complete interchange lighting where there is continuous freeway lighting.
    - Lighting of crossroad ramp terminals when there are raised channelizing islands or when sight distance is poor.

Criteria:

Design Method	Luminance Range (cd/m^2)	Uniformity (avg:min)	Veiling Luminance Ratio (L_{vmax}/L_{avg})	Visibility Level	Illuminance Range (avg fc)
Luminance	0.4 – 0.6	3.5	0.3		
STV	0.3 – 0.5	6.0 (max:min)		2.6 – 3.8	
Illuminance		3.0	0.3		0.4 – 1.4

Design Intent / Rules of Thumb:

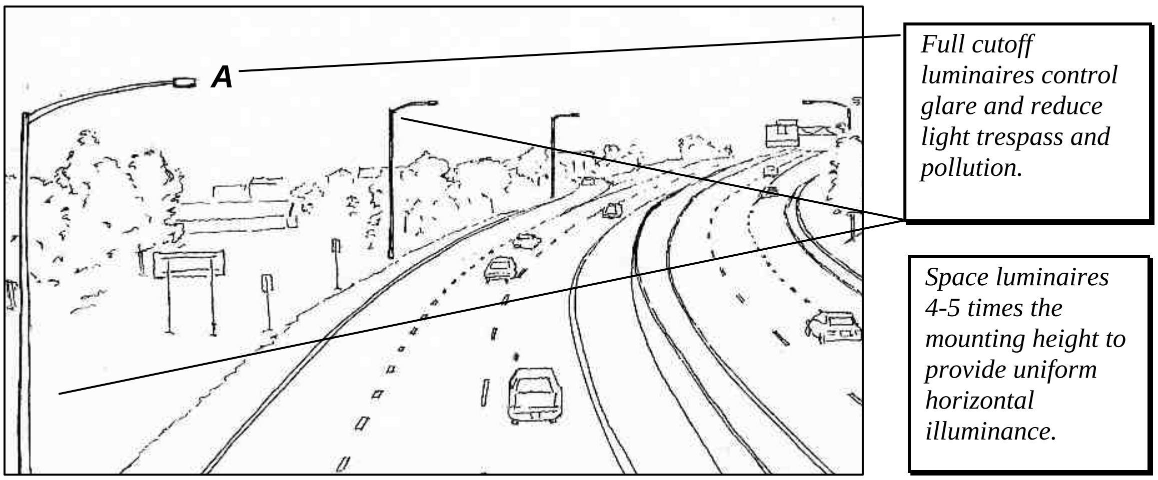
- Mounting height: 25 to 40 feet
- Light Source: 150 - 250 watt metal halide, 165 watt induction lamps or 250 HPS
- Luminaire: Full cutoff with Type III distribution
- Spacing to mounting height: When beginning a design, start with a 5:1 spacing to

mounting height ratio and modify accordingly to meet critical design issues.

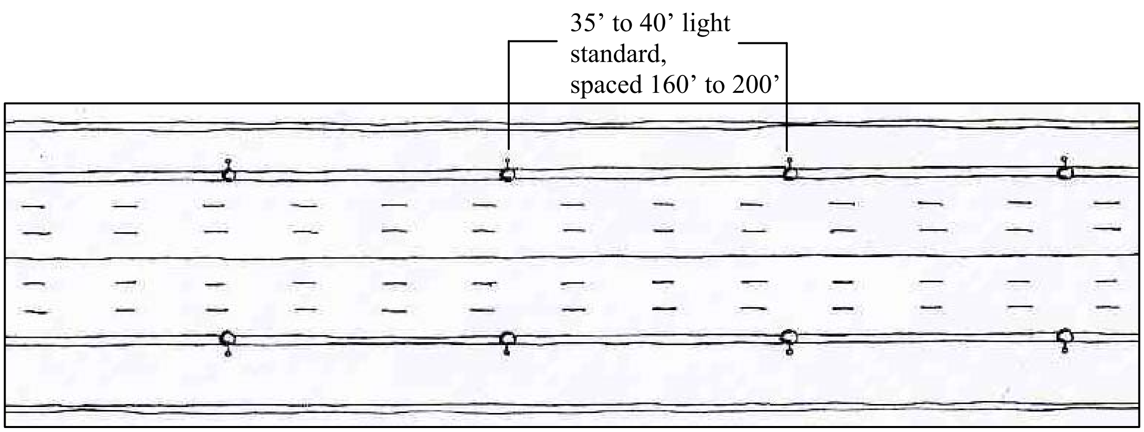
Special Considerations:

- Curves: tight curves may require closer spacing of standards and an increase in light level
- Hills: short steep hills may also require increased light levels

Freeways – Example Design



Perspective View



Plan View

Equipment Used in Example:

	LUMINAIRE	LAMP	CONTROLS
A	Pole mounted, full cutoff roadway luminaire with Type III distribution	250 watt metal halide coated lamp, 3500 K	Photocell on/off at LCC

Calculation:

The values shown below were produced with a commercially available lighting calculation program. The calculation assumed a flat, straight, section of roadway and used the average light output of the lamps to determine maintained (rather than initial) values.

	Luminance (cd/m^2)	Uniformity (avg:min)	Uniformity (max:min)	Veiling Luminance Ratio (Lv_{max}: L_{avg})	VL	Illuminance
Luminance	0.46	1.5		3.8		
STV	0.46		3.0	3.8	3.62	
Illuminance		2.0	4.3			0.78

5.2 Complete Interchanges

Warrants:

Complete interchange lighting is warranted if any of the following conditions exist:

- The total ramp average daily traffic exceeds 10,000 in urban areas, 8,000 in suburban areas and 5,000 in rural areas.
- The crossroad average daily traffic exceeds 10,000 in urban areas, 8,000 in suburban areas and 5,000 in rural areas.
- The location has substantial commercial or industrial development that is lighted, or the crossroad is lighted for at least 0.62 mile on each side of the interchange.
- The night to day accident rate is at least 1.5 times higher than the statewide average for similar unlighted interchanges.

Criteria:

Design Method	Luminance Range (cd/m^2)	Uniformity (avg:min)	Veiling Luminance Ratio (L_{vmax}/L_{avg})	Visibility Level	Illuminance Range (avg fc)
Luminance	0.4 – 0.6	3.5	0.3		
STV	0.3 – 0.5	6.0 (max:min)		2.6 – 3.8	
Illuminance		3.0	0.3		0.4 – 1.4

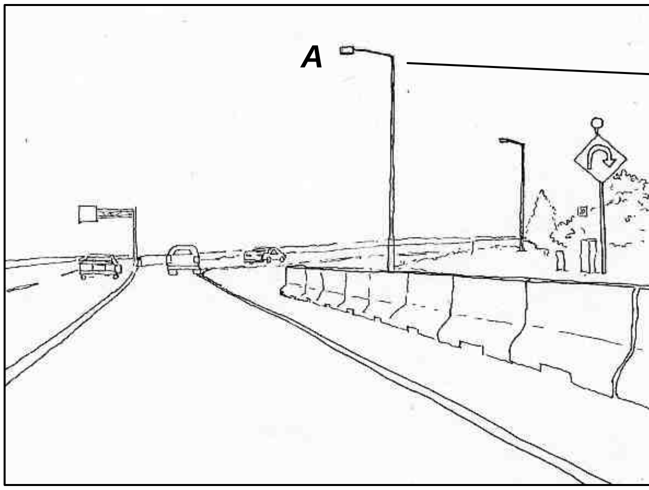
Design Intent / Rules of Thumb:

- Mounting height: 40 – 70 feet
- Light Source: 250 – 400 watt metal halide or dual 165 watt induction luminaires
- Luminaire: Full cutoff with Type III distribution
- Spacing to mounting height: When beginning a design, start with a 5:1 spacing to mounting height ratio and modify accordingly to meet critical design issues

Special Considerations:

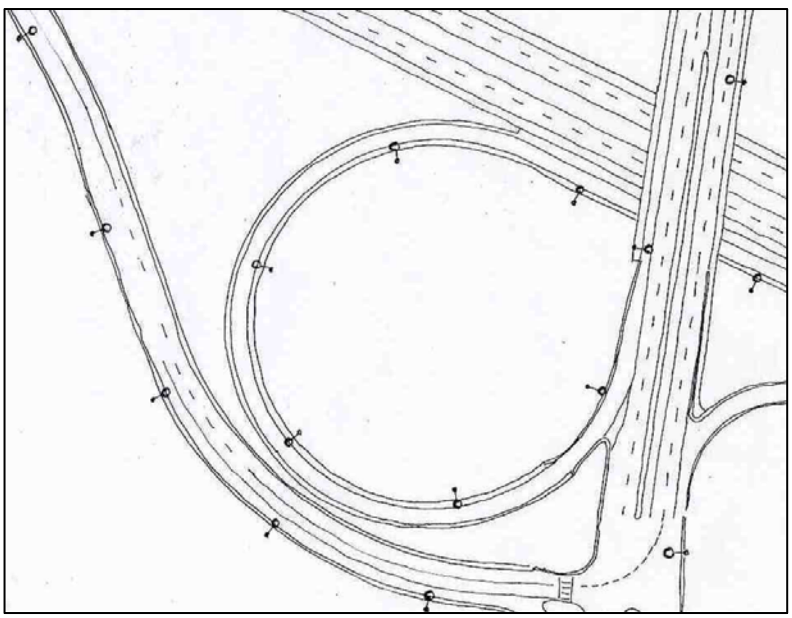
- Higher light standards present greater light trespass potential. All luminaires in view of residential properties must be completely shielded to avoid brightness in the neighborhoods.
- Median mounted standards work well in these situations especially with HOV lanes.
- High mast lighting (higher than 70 feet) must be approved by the Department because of the increase cost with lowering devices and new AASHTO standards for towers.

Complete Interchanges – Example Design



Standards follow the roadway through the interchange. When possible, they are located on the inside of curves.

Perspective View



Plan View

Equipment Used in Example:

	LUMINAIRE	LAMP	CONTROLS
A	Pole mounted, full cutoff roadway luminaires	250 - 400 watt metal halide	Photocell on/off at LCC

5.3 Partially Lighted Interchanges

Warrants:

Partial interchange lighting is warranted if any of the following conditions exist:

- The total ramp average daily traffic exceeds 5,000 in urban areas, 3,000 in suburban areas and 1,000 in rural areas.
- The average daily traffic on the through freeway lanes exceeds 25,000 in urban areas, 20,000 in suburban areas and 10,000 in rural areas.
- The nighttime to daytime accident rate is at least 1.25 times higher than the statewide average for similar unlighted interchanges.

Criteria:

Design Method	Luminance Range (cd/m^2)	Uniformity (avg:min)	Veiling Luminance Ratio (L_{vmax}/L_{avg})	Visibility Level	Illuminance Range (avg fc)
Luminance	0.4 – 0.6	3.5	0.3		
STV	0.3 – 0.5	6.0 (max:min)		2.6 – 3.2	
Illuminance		3.0	0.3		0.4 – 0.9

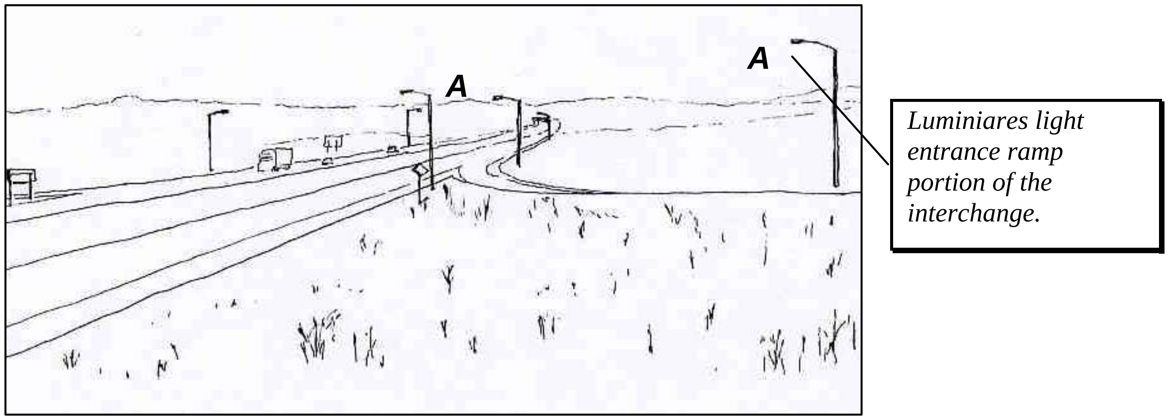
Design Intent / Rules of Thumb:

- Mounting height: 30 – 40 feet
- Light Source: 150 - 250 watt metal halide or 165 watt induction luminaires
- Luminaire: Full cutoff with Type III distribution
- Spacing to mounting height: When beginning a design, start with a 5:1 spacing to mounting height ratio and modify accordingly to meet critical design issues

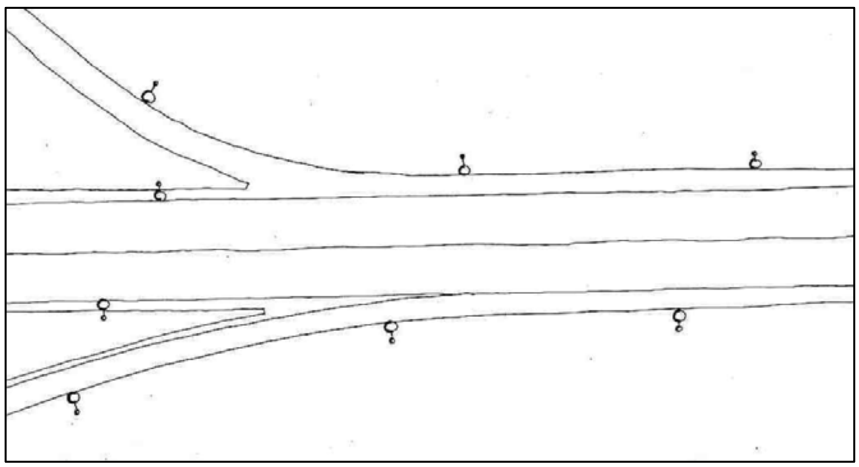
Special Considerations:

- Near residential neighborhoods, house side shields may be required to minimize light trespass.

Partially Lighted Interchanges – Example Design



Perspective View



Plan View

Equipment Used in Example:

	LUMINAIRE	LAMP	CONTROLS
A	Pole mounted, full cutoff roadway luminaire with Type III distribution	150watt metal halide or 165 watt induction	Photocell on/off at LCC

5.4 Municipal Streets

Warrants:

Lighting warrants for municipal streets are much less specific than those for freeways. Generally, lighting is warranted if any of the following conditions exist:

- The respective governmental agencies concur that lighting will contribute to the efficiency, safety and comfort of motorists and pedestrians.
- Streets where the ratio of nighttime to daytime accidents is high.
- Locations where severe or unusual weather or atmospheric conditions exist.
- Locations where the local governmental agency is willing to pay an appreciable percentage of or wholly finance the lighting installation.

Criteria:

Design Method	Luminance Range (cd/m^2)	Uniformity (avg:max)	Veiling Luminance Ratio (L_{vmax}/L_{avg})	Visibility Level	Illuminance Range (avg fc)
Luminance	0.3 – 0.8	3.0 – 6.0	0.4		
STV	0.3 – 0.6	6.0 – 10.0 (max:min)		1.6 – 3.8	
Illuminance		4.0 – 6.0	0.4		0.4-1.2

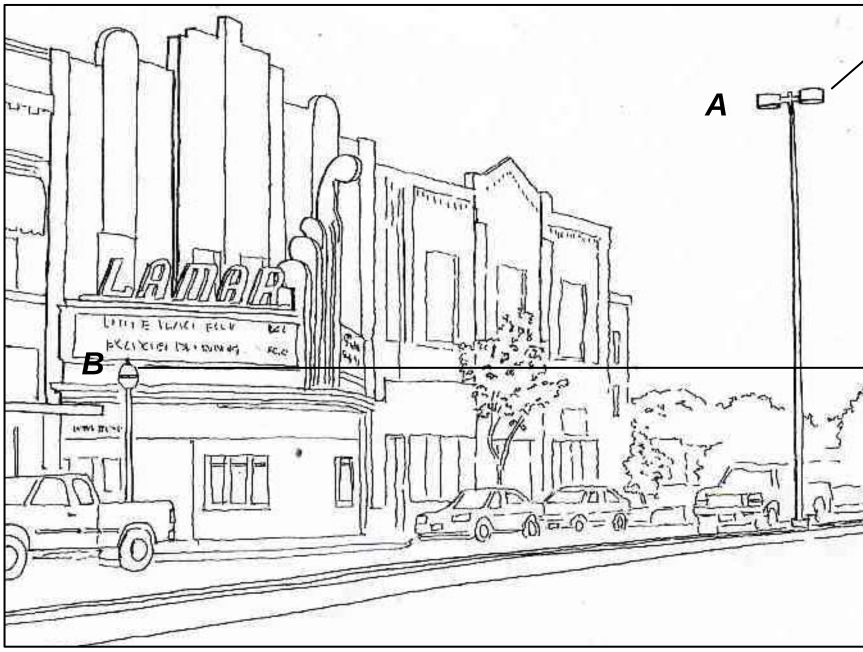
Design Intent / Rules of Thumb (for roadway lighting only, not including pedestrian lighting):

- Mounting height: 20 – 30 feet
- Light Source: 150 – 250 watt metal halide or HPS, or 165 watt induction lamps
- Luminaire: Full cutoff with Type III distribution
- Spacing to mounting height: When beginning a design, start with a 5:1 spacing to mounting height ratio and modify accordingly to meet design criteria

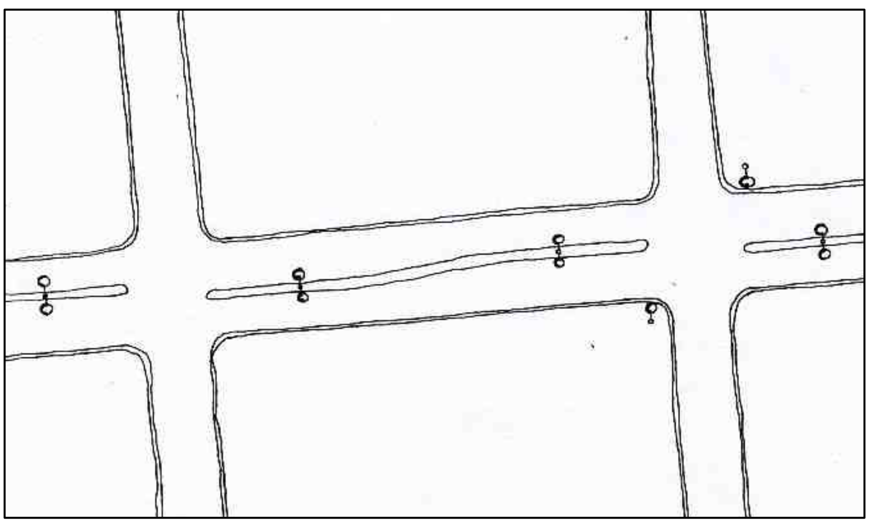
Special Considerations:

- Architectural style versus cobra heads may be important to the municipalities.
- Ask if accessories are required for light standard such as banner arms, signs, and seasonal lighting receptacles and then size accordingly.
- House-side shields may be required if located adjacent to residential neighborhoods.

Municipal Streets – Example Design



Perspective View



Plan View

Equipment Used in Example:

	LUMINAIRE	LAMP	CONTROLS
A	Pole mounted, full cutoff roadway luminaire with Type III distribution.	150 – 250 watt Metal halide or 165 induction lamp	Photocell on/off at LCC
B	Pole mounted, cutoff or semi cutoff pedestrian luminaire	50 watt Metal halide or 55 watt induction lamp	Photocell on/off at LCC

5.5 Rural Intersections

Warrants:

- Rural Intersection lighting is warranted by an unusually high nighttime to daytime accident rate ratio.
- The FHWA Roadway Lighting Handbook[1] suggests that lighting is warranted if the average annual number of nighttime accidents exceeds the average annual number of daytime accidents divided by three.
- Channelized intersections should also be lighted regardless of accident rates. Generally, only minimal lighting is required.

Criteria:

Design Method	Luminance Range (cd/m^2)	Uniformity (avg:min)	Veiling Luminance Ratio (L_{vmax}/L_{avg})	Visibility Level	Illuminance Range (avg fc)
Luminance	0.5	3.5	0.3		
STV	2.6	6.0 (max/min)		N/A	
Illuminance		4.0	0.3		0.4-0.9

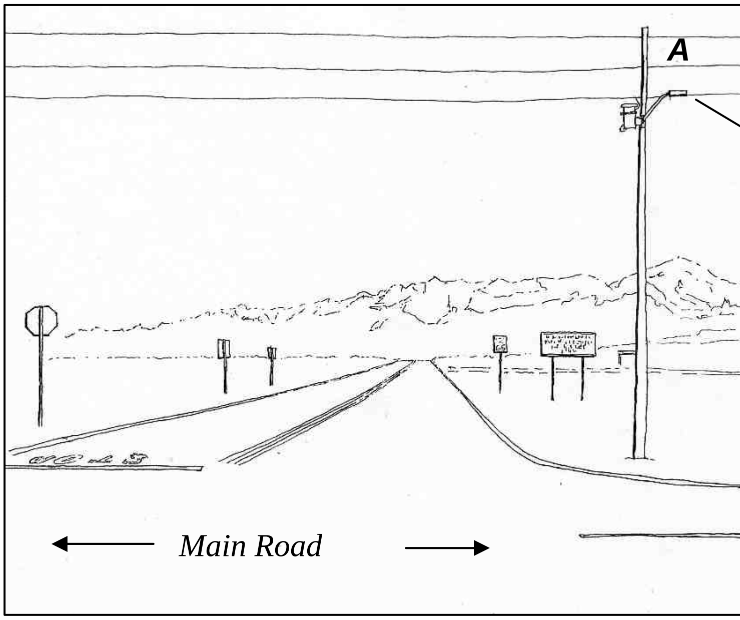
Design Intent / Rules of Thumb:

- Rural intersections should not be over lighted since only one or two light standards may be present.

Special Considerations:

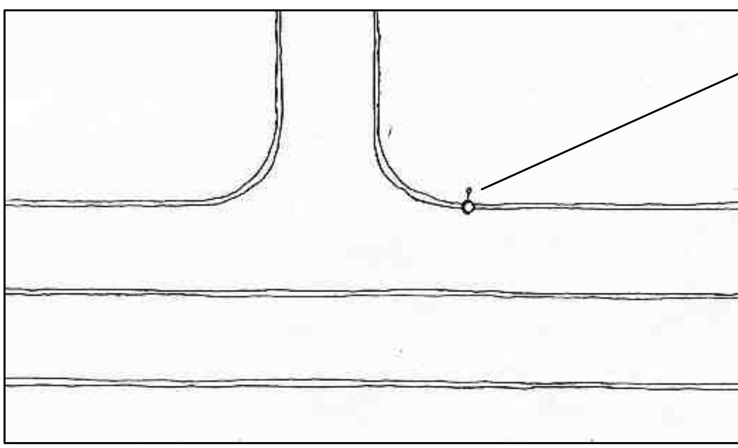
- Use lower wattage lamp for adaptation in and out of rural intersection.
- Use lower height light standards and luminaire shielding if adjacent to residential properties.

Rural Intersections – Example Design



Full cutoff luminaire lights oncoming traffic along main road.

Perspective View



Luminaire at this location lights a vehicle at the intersection as viewed from oncoming traffic main road.

Plan View

Equipment Used in Example:

	LUMINAIRE	LAMP	CONTROLS
A	Pole mounted, full cutoff roadway luminaire with Type III distribution	100 watt metal halide lamp	Photocell on/off at LCC

5.6 Highway Underpasses

Warrants:

- Vehicular underpasses on lighted roadways should be lighted to the same luminance or illuminance as the roadway.
- For short underpasses, it may be possible to judiciously locate the roadway luminaires such that sufficient light shines into the underpass.
- For longer underpasses, it will be necessary to install wall or ceiling mounted lighting fixtures.
- When the length to height ratio of an underpass exceeds approximately 10:1, it should be evaluated for the need for daylight illumination.

Criteria:

Design Method	Luminance Range (cd/m^2)	Uniformity (avg:min)	Veiling Luminance Ratio (L_{vmax}/L_{avg})	Visibility Level	Illuminance Range (avg fc)
Luminance	0.4 – 0.6	3.5	0.3		
STV	0.3 – 0.5	6.0 (max:min)		2.6 – 3.8	
Illuminance		3.0	0.3		0.4 – 1.4

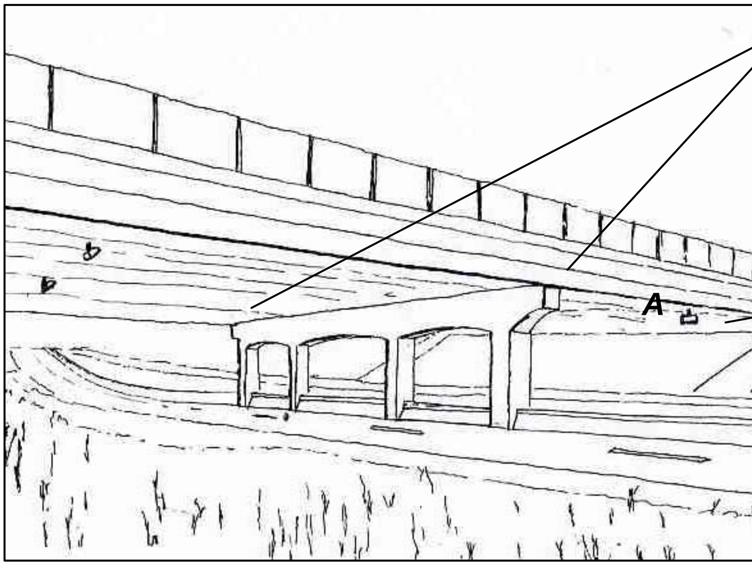
Design Intent / Rules of Thumb:

- Locate roadway light standards far enough away from underpass such that the underpass lighting is located at the typical luminaire spacing.
- All luminaires must have side shields in order to avoid glare for the motorists.

Special Considerations:

- Most underpasses do not require lighting if the light standards are adequately spaced and light the pavement beneath the underpass.
- Underpasses do not require lighting if the approach is not lighted.

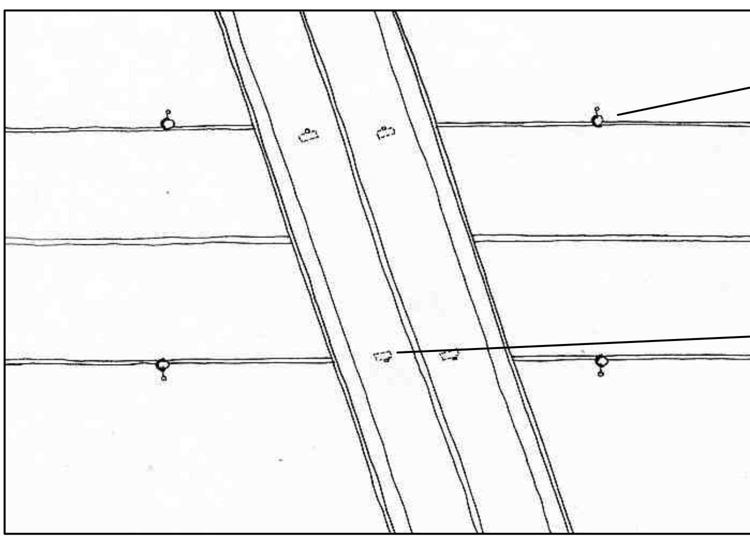
Highway Underpasses – Example Design



Depending on width of underpass, adjacent roadway lighting may be adequate to light below.

If necessary, add surface mounted floodlights to light roadway from the side.

Perspective View



By adjusting spacing of light standards, the roadway may be illuminated under the overpass.

Additional floodlights under the deck of the overpass can fill in for the pole mounted luminaires.

Plan View

Equipment Used in Example:

	LUMINAIRE	LAMP	CONTROLS
A	Surface mounted, shielded, floodlight luminaire	85 watt induction lamp	Photocell on/off at LCC

5.7 Tunnels

Warrants:

- The AASHTO Informational Guide for Roadway Lighting[2] defines a tunnel as short if its length from portal to portal is equal to or less than the wet pavement minimum stopping sight distance for the vehicle operating speeds of the tunnel roadway and approaches. Lighting is rarely warranted for short tunnels.
- Lighting is almost always warranted for long tunnels, and special consideration must be given to transitional lighting from the portal to the tunnel interior. The FHWA Tunnel Lighting Design Procedures[7] identifies up to five separate tunnel zones with different illumination requirements.
- The approach zone is the area outside the portal. Its length is approximately one safe stopping sight distance for the design speed.
- The threshold zone extends from the portal into the tunnel for a distance of either two to four seconds travel time or one safe stopping sight distance at the design speed. This is the most critical zone for the lighting system design.
- The transition zone extends from the threshold zone for a distance of either two to four seconds travel time or one safe stopping sight distance at the design speed.
- The interior zone extends from the transition zone to the exit zone.
- The exit zone extends from the interior zone to the exit portal. Its length should be either two seconds travel time or one safe stopping sight distance at the design speed

Criteria:

Design Criteria for Tunnels have both daytime and nighttime criteria. Refer to IESNA RP-22-96 or current version of "Recommended Practice for Tunnel Lighting" for complete design criteria. Factors influencing lighting design criteria include tunnel entrance zone, interior dimensions and surface reflectances, tunnel approach scenes and geometry, tunnel zones (threshold, transition and interior) and maintenance.

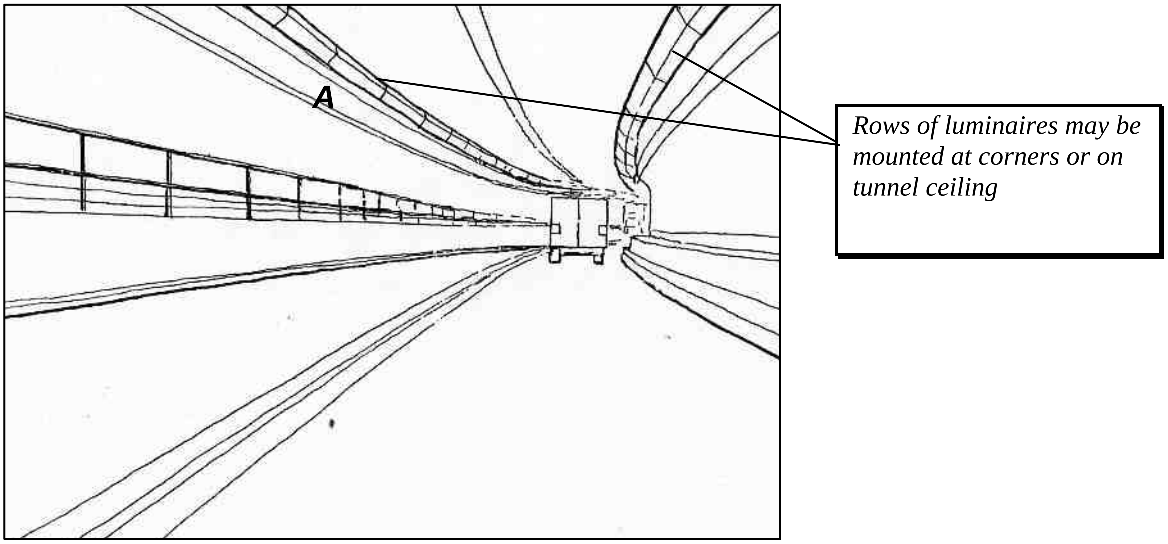
Design Intent / Rules of Thumb:

- Design tunnel lighting for daytime threshold and transition zones for motorist adaptation from sunlight to interior tunnel.
- Select tunnel approach scene from the Commission Internationale de l'Eclairage (CIE) scenes 1-8.
- Determine threshold, transition, and interior zones pavement luminance and uniformity according to IESNA RP-22-96.
- Daytime transition lighting must be turned off at nighttime.
- Design for nighttime pavement luminance values of 2.5 cd/m^2 minimum.
- Calculate flicker effect when placing equipment.

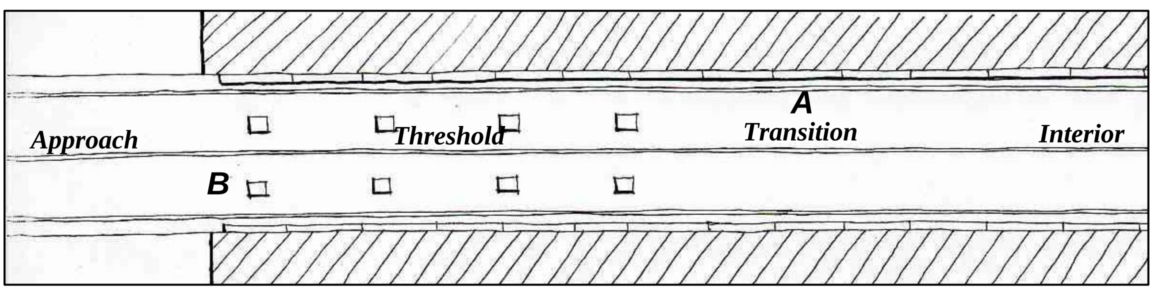
Special Considerations:

- It is recommended that tunnel lighting be designed by an illumination engineer.
- Luminaire maintenance and relamping is especially difficult in tunnels.

Tunnels – Example Design



Perspective View



Plan View

Equipment Used in Example:

	LUMINAIRE	LAMP	CONTROLS
A	Surface mounted lensed luminare	165 watt Induction, 150 watt Metal Halide, LED, or fluorescent	Depending on length of tunnel, luminaires may always need to be on.
B	Surface mounted lensed luminare for transition lighting	165 watt induction	Turn off transition lighting at night.

5.8 Bridges and Viaducts

Warrants:

- Bridges and viaducts should be lighted to the same luminance or illuminance values as the approach roadway.
- Lighting the approaches to bridges and viaducts on otherwise unlighted highways can have significant safety benefits if the bridge or viaduct is less wide than the approach roadway.
- Lighting is generally warranted for sidewalks on bridges and viaducts with significant pedestrian traffic.

Criteria:

Design Method	Luminance Range (cd/m^2)	Uniformity (avg:max)	Veiling Lumiance Ratio (L_{vmax}/L_{avg})	Visibility Level	Illuminance Range (avg fc)
Luminance	0.3 – 0.8	3.0 – 6.0	0.4		
STV	0.3 – 0.6	6.0 – 10.0 (max:min)		1.6 – 3.8	
Illuminance		4.0 – 6.0	0.4		0.4-1.2

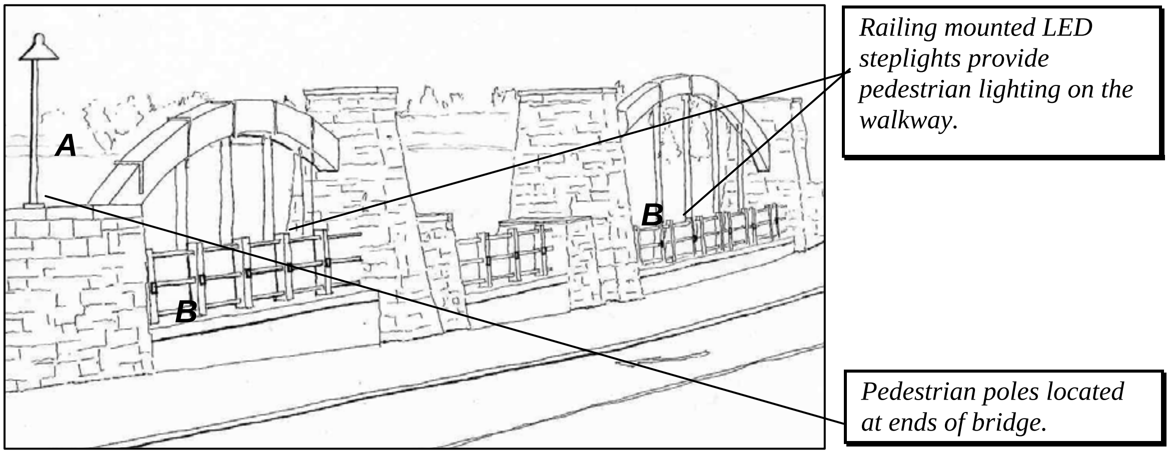
Design Intent / Rules of Thumb:

- Avoid placing standards on bridges that are 150 feet or less in length.
- If pole mounted luminaires are on bridges, use full cutoff luminaires to minimize motorist glare.
- Use railing mounted LED step lights for pedestrian walkways.

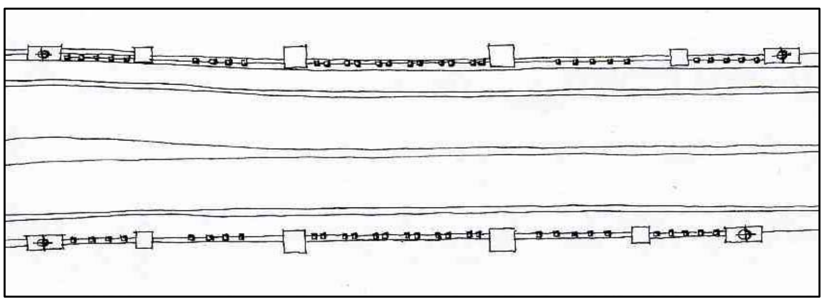
Special Considerations:

- When bridges cross waterways, minimize or eliminate light falling on the water for maximum environmental sensitivity
- Light standards on bridges are hard to maintain and should be avoided if possible.
- Pedestrian walkways can be lighted with step lights versus pole mounted pedestrian lights.

Bridges and Viaducts – Example Design



Perspective View



Plan View

Equipment Used in Example:

	LUMINAIRE	LAMP	CONTROLS
A	Pole mounted, fully shielded or full cutoff roadway or pedestrian luminaire with Type III distribution	150 watt metal halide or 165 watt induction for roadway; 55 watt induction for pedestrian luminaire	Photocell on/off at LCC
B	Recess mounted steplight in bridge railing	White LED	Photocell on/off at LCC

5.9 Roundabouts

Warrants:

- Lighting is warranted for all roundabouts.

Criteria:

Illuminance	Uniformity (avg:min)
1.3 – 2 X level of the approach	3:1

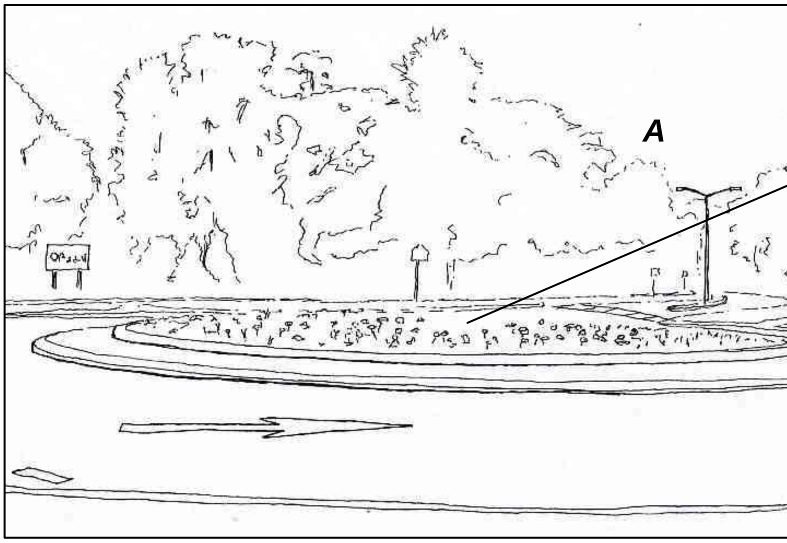
Design Intent / Rules of Thumb:

- Light standards should not be located in the center of the roundabout.
- Locate light standards on the approach side of each entry such that the maximum amount of light falls on vehicles entering the roundabout

Special Considerations:

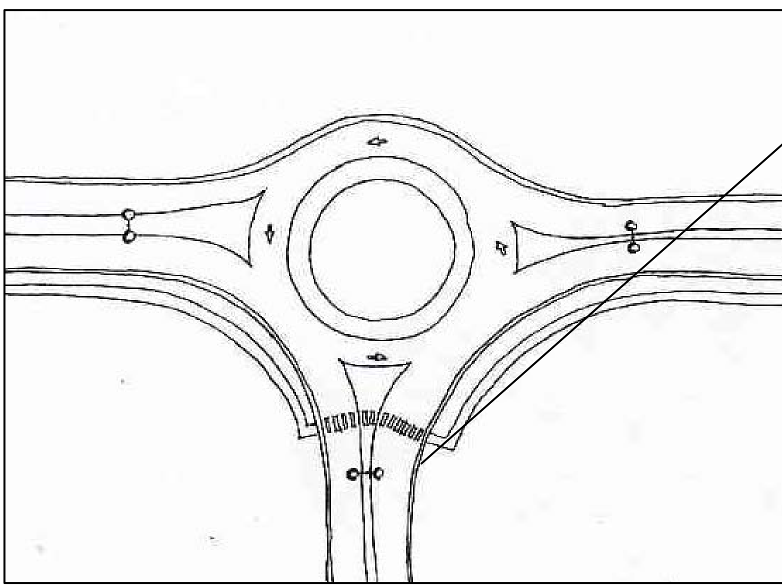
- Lighted features in the center of the roundabout may increase the ambient brightness. Care must be given to not cause glare for any of the motorists.

Roundabouts – Example Design



Keep center of roundabout free of light standards, high landscape, or other obstructions.

Perspective View



Locate light standards at the entrances to the roundabout. If crosswalks are present, position standard between pedestrian and oncoming traffic.

Plan View

Equipment Used in Example:

	LUMINAIRE	LAMP	CONTROLS
A	Pole mounted, full cutoff, dual head roadway luminaire	165 watt induction lamp	Photocell on/off at LCC

5.10 Bicycle Paths

Warrants:

- Bicycle paths are classified in Engineering Society of North America RP-8-00 as either Type A or Type B. Type A is a designated bicycle lane along the paved surface of a roadway and is usually separated from motor vehicle traffic by pavement markings or curbs. Type B is a bicycle trail that usually has a separate alignment from the roadway and on which motor vehicles are prohibited.
- Lighting is warranted on Type A bicycle paths located along arterial streets where lighting is warranted based upon motor vehicle volume. Luminance and illuminance levels that are appropriate for bicycle paths are the same as those that are recommended for roadway luminance and illuminance. Special consideration should be given to providing adequate lighting at high turning movement intersections where there could be automobile-bicycle conflicts.
- Note that these levels are higher than those recommended for roadways because most bicycles are not equipped with headlights. Illumination of Type B bicycle paths is generally warranted when the path carries a significant volume of bicycle traffic during hours of darkness.

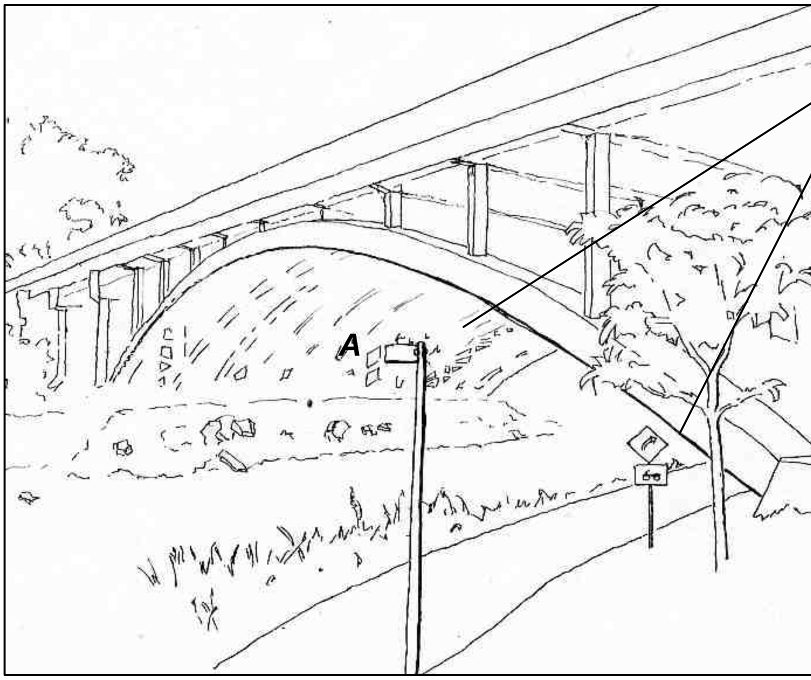
Criteria:

Design Method	Luminance Range (cd/m^2)	Uniformity (avg:min)	Veiling Luminance Ratio (L_{vmax}/L_{avg})	Visibility Level	Illuminance Range (avg fc)
Luminance	N/A				
STV	N/A			N/A	
Illuminance (Mixed vehicle and pedestrian)		4.0			2.0
Illuminance (Pedestrian only)		4.0			1.0
Illuminance (Walkways/ Bikeways)		4.0			0.5

Design Intent / Rules of Thumb:

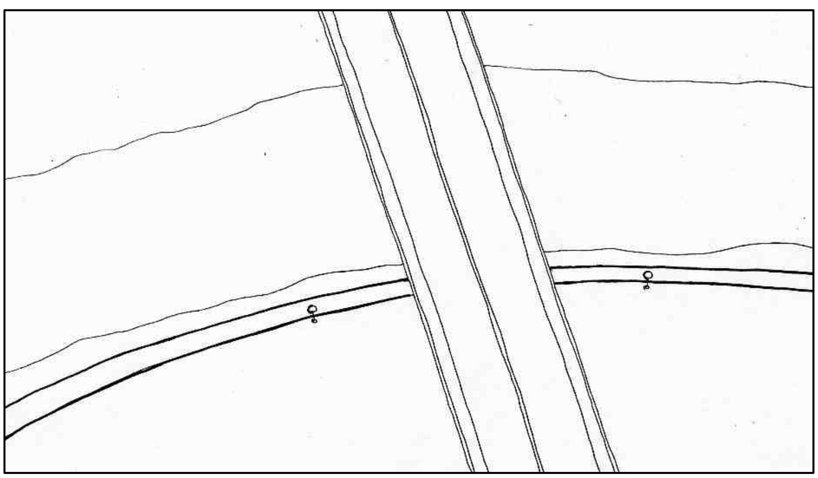
- Provide lighting at intersections or hazardous areas of the path.
- Use luminaires that minimize glare for the bicyclist and also avoid light trespass onto neighboring properties. This may require the use of internal house-side shields as well as full cutoff distribution.

Bicycle Paths – Example Design



Locate pedestrian scale luminaires at intersections or other hazardous points along trail.

Perspective View



Plan View

Equipment Used in Example:

	LUMINAIRE	LAMP	CONTROLS
A	Pole mounted, fully shielded or full cutoff pedestrian luminaire	55 or 85 watt induction	Photocell on/off at LCC

5.11 Pedestrian Walkways

Warrants:

- Pedestrian walkways include both sidewalks that are within the highway right of way and separate walkways including pedestrian overpasses, pedestrian underpasses and crossings near centers of long blocks.
- Sidewalk lighting strictly for pedestrian use would seldom be warranted. Sidewalk illumination is usually spill over from luminaires intended for roadway lighting. Consideration should be given to adequate sidewalk illumination when a roadway lighting system is designed. For example, opposed luminaire arrangements provide better sidewalk lighting than median mounted systems.
- Lighting is warranted for pedestrian paths independent from a highway for safety considerations.

Criteria:

Design Method	Luminance Range (cd/m^2)	Uniformity (avg:min)	Veiling Luminance Ratio (L_{vmax}/L_{avg})	Visibility Level	Illuminance Range (avg fc)
Luminance	N/A				
STV	N/A			N/A	
Illuminance (Mixed vehicle and pedestrian)		4.0			2.0
Illuminance (pedestrian only)		4.0			1.0
Illuminance (Walkways/ Bikeways)		4.0			0.5

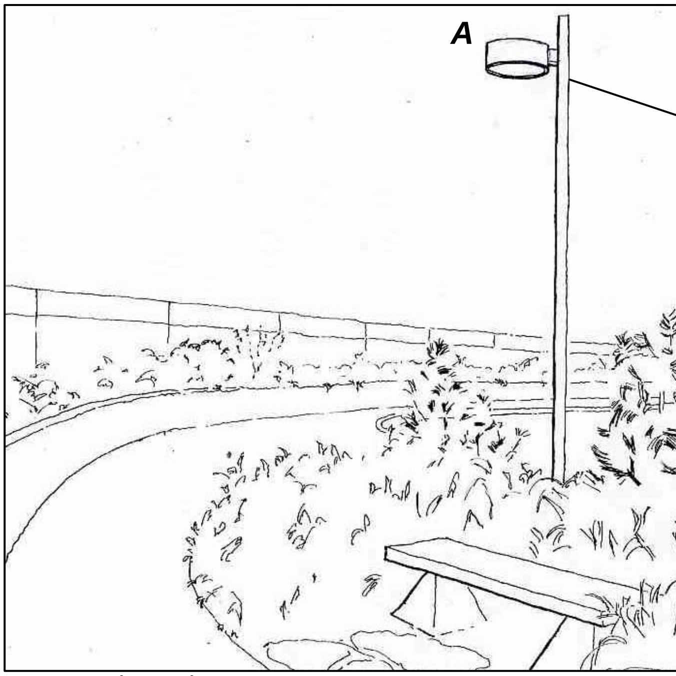
Design Intent / Rules of Thumb:

- Mounting height: 12 – 14 feet
- Light Source: 55 - 85 watt induction luminaires
- Luminaire: Full cutoff with Type III distribution
- Spacing to mounting height: When beginning a design, start with a 5:1 spacing to mounting height ratio and modify accordingly to meet critical design issues

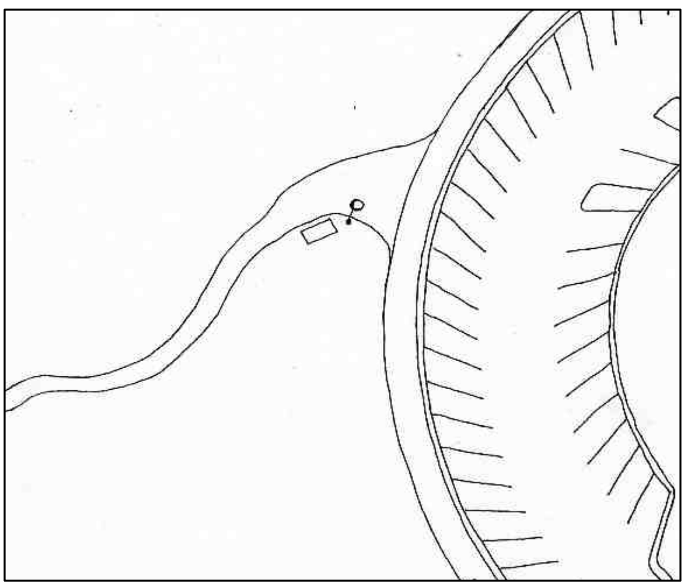
Special Considerations:

- Pedestrian walkways adjacent to residential properties will have to be shielded to avoid light trespass.
- Light conflict zones such as path intersections and abrupt grade changes if continuous lighting is not warranted.

Pedestrian Walkways – Example Design



Perspective View



Plan View

Equipment Used in Example:

	LUMINAIRE	LAMP	CONTROLS
A	Pole mounted, fully shielded or full cutoff pedestrian luminaire	50 watt metal halide, 55 watt induction, or 26 watt compact fluorescent	Photocell on/off at LCC

5.12 Crosswalks

Warrants:

- Lighting is warranted for all crosswalks.

Criteria:

Design Method	Luminance Range (cd/m^2)	Uniformity (avg:max)	Veiling Luminance Ratio (L_{vmax}/L_{avg})	Visibility Level	Illuminance Range (avg fc)
Luminance	0.3 – 0.8	3.0 – 6.0	0.4		
STV	0.3 – 0.6	6.0 – 10.0 (max:min)		1.6 – 3.8	
Illuminance		4.0 – 6.0	0.4		0.4-1.2

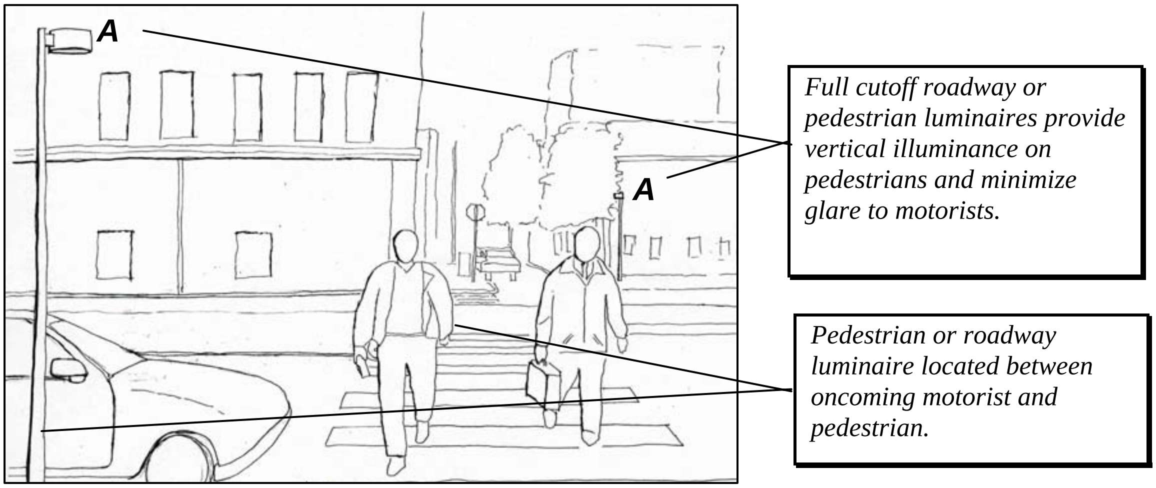
Design Intent / Rules of Thumb:

- Locate luminaires to provide vertical illuminance on pedestrians in the crosswalk. They should be located between the pedestrian and an oncoming motorist.

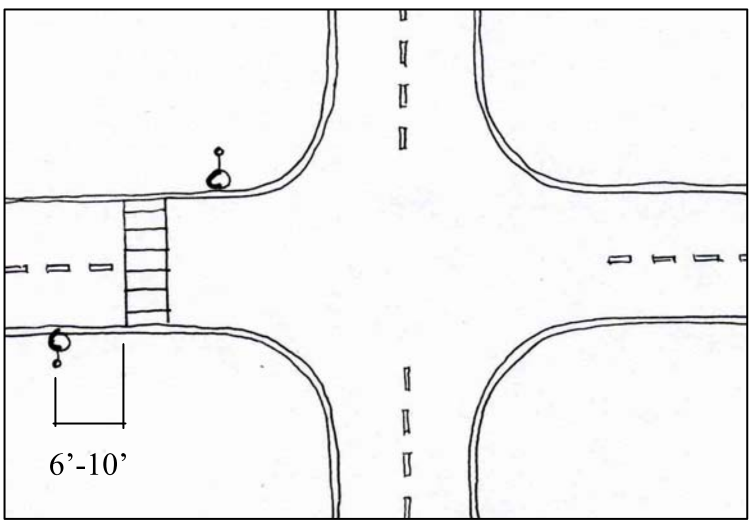
Special Considerations:

- At signalized intersections, luminaires on signal poles will light the pedestrian crosswalks.

Crosswalks – Example Design



Perspective View



Plan View

Equipment Used in Example:

	LUMINAIRE	LAMP	CONTROLS
A	Pole mounted, full cutoff roadway or pedestrian luminaire	165 watt induction lamp.	Photocell on/off at LCC

5.13 Park-n-Ride Facilities

Warrants (from AASHTO):

- Lighting is warranted for all park-n-ride facilities.
- Recommended luminance and illuminance levels shown in the table below for safety rest areas are appropriate for park-n-ride facilities.
- Bus or light rail loading areas, information centers and rest room facilities would qualify as major activity areas.

Criteria:

	Luminance (cd/m^2)	Uniformity	Illuminance (avg fc)
Entrance and Exit	0.4		0.6
Interior Roadways	0.4		0.6
Parking Areas		3:1 – 4 :1	1.0
Major Activity Areas		3:1 – 4 :1	1.0
Minor Activity Areas		6:1	0.5
Main Lanes	per roadway criteria	per roadway criteria	per roadway criteria

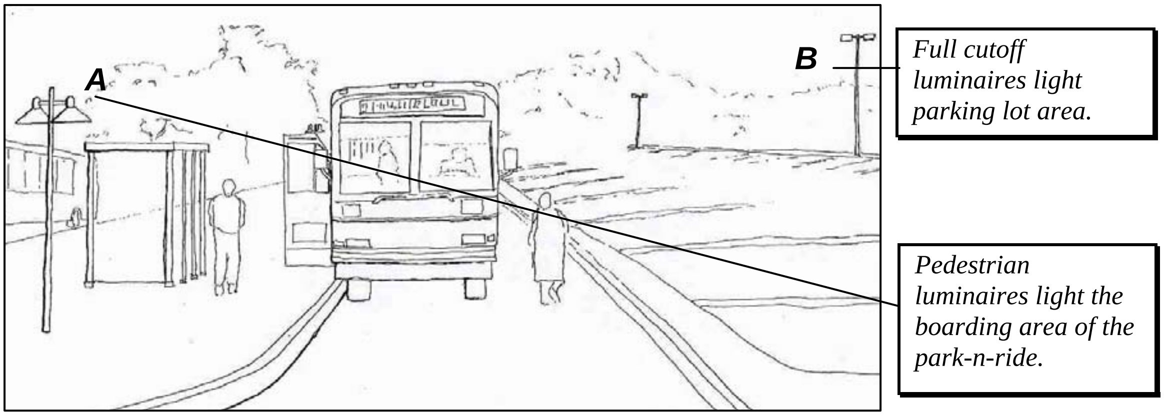
Design Intent / Rules of Thumb:

- Mounting height: 20 – 25 feet for parking lots and 12 -14 feet for pedestrian areas
- Light Source: 85 -165 watt induction luminaires for parking lot; 55 watt induction luminaires for sidewalks
- Luminaire: Full cutoff with Type III distribution
- Spacing to mounting height: When beginning a design, start with a 4:1 spacing to mounting height ratio and modify accordingly to meet critical design issues

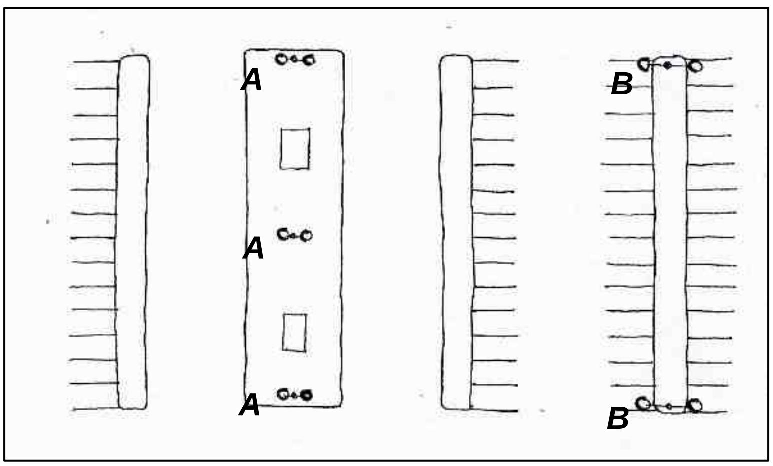
Special Considerations:

- Review local transportation authority for specific criteria.

Park-n-Ride Facilities – Example Design



Perspective View



Plan View

Equipment Used in Example:

	LUMINAIRE	LAMP	CONTROLS
A	Pole mounted, pedestrian luminaire	55 watt induction	Photocell on/off at LCC
B	Pole mounted, parking lot luminaire	165 watt induction	Photocell on/off at LCC

5.14 Rest Areas / Visitor Centers

Warrants:

- Lighting is warranted for any rest area offering complete rest facilities.
- Rest areas located along interstate highways frequently receive heavy usage during evening hours, and motorists will tend to avoid them if they are not adequately lighted to ensure safe use.

Criteria:

	Luminance (cd/m^2)	Uniformity	Illuminance (avg fc)
Entrance and Exit	0.4		0.6
Interior Roadways	0.4		0.6
Parking Areas		3:1 – 4 :1	1.0
Major Activity Areas		3:1 – 4 :1	1.0
Minor Activity Areas		6:1	0.5
Main Lanes	per roadway criteria	per roadway criteria	per roadway criteria

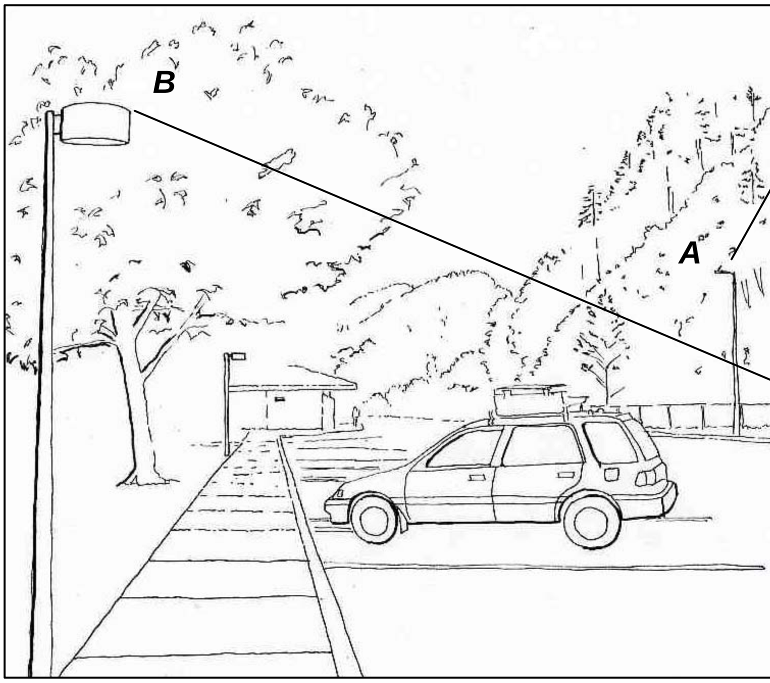
Design Intent / Rules of Thumb:

- Light areas of high nighttime use and those areas that might feel unsafe to users.
- Keep in mind that not lighting an area can deter nighttime use.
- Mounting height: 20 – 25 feet for parking lots and 12 -14 feet for sidewalks
- Light Source: 85 -165 watt induction luminaires for parking lot; 55 watt induction luminaires for sidewalks
- Luminaire: Full cutoff with Type III distribution
- Spacing to mounting height: When beginning a design, start with a 4:1 spacing to mounting height ratio and modify accordingly to meet critical design issues.

Special Considerations:

- If the rest area is near the main roadway, the roadway should be lighted adequately to minimize excessive contrast and veiling glare from the rest area.

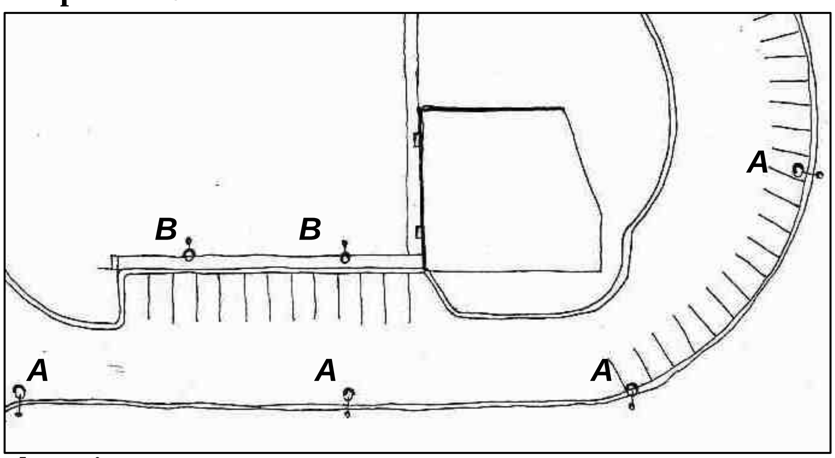
Rest Areas / Visitors Center – Example Design



Roadway luminaires light the parking and interior road through the rest area.

Pedestrian lighting illuminates the pathway to major activity areas such as restrooms.

Perspective View



Plan View

Equipment Used in Example:

	LUMINAIRE	LAMP	CONTROLS
A	Pole mounted, full cutoff roadway luminaire.	150 watt metal halide lamp or 165 watt induction	Photocell on/off
B	Pole mounted pedestrian scale luminare	50 watt metal halide, 55 watt induction, or 26 watt compact fluorescent lamp	Photocell on/off

5.15 Chain-up Areas

Warrants:

- All Chain-up areas require lighting.

Criteria:

Design Method	Luminance Range (cd/m^2)	Uniformity (avg:max)	Veiling Lumiance Ratio (L_{vmax}/L_{avg})	Visibility Level	Illuminance Range (avg fc)
Luminance	0.3 – 0.8	3.0 – 6.0	0.4		
STV	0.3 – 0.6	6.0 – 10.0 (max:min)		1.6 – 3.8	
Illuminance		4.0 – 6.0	0.4		0.4-1.2

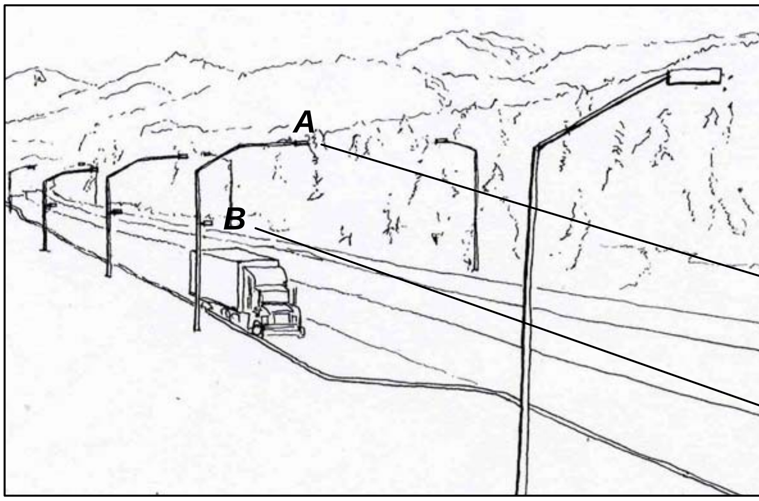
Design Intent / Rules of Thumb:

- Increase the luminance and lighting uniformity at chain-up areas. This improves visibility for the motorist who is fixing chains to a vehicle as well as for other motorists passing the area.
- Mounting height: 30 – 40 feet for extended (higher) luminare and 16 – 20 feet for lower luminaire
- Light Source: 165 watt induction luminaires
- Luminaire: Full cutoff with Type III distribution
- Spacing to mounting height: When beginning a design, start with a 4:1 spacing to mounting height ratio and modify accordingly to meet critical design issues

Special Considerations:

- Add two luminaires per pole; one for each side of the truck.
- Chain up lighting should only be activated during chain law activation.

Chain-up Areas – Example Design

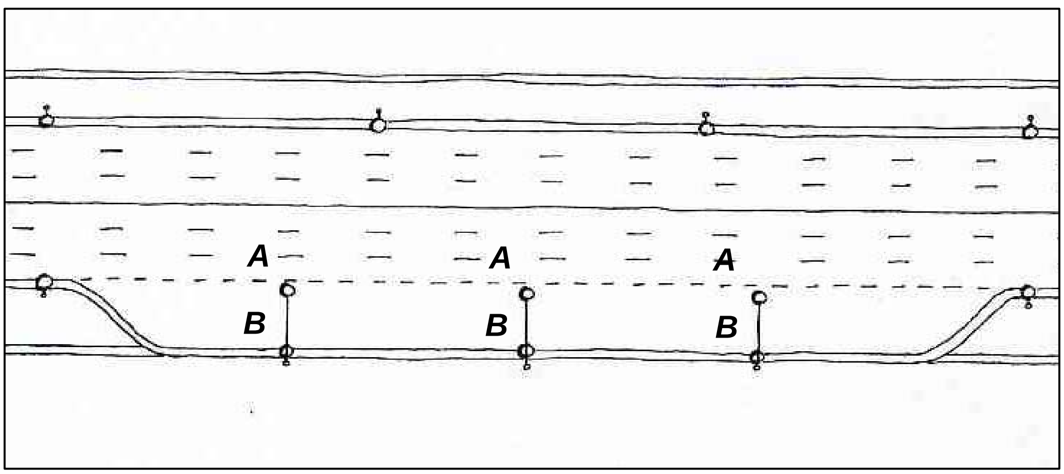


Closer spacing of luminaires increases both luminance and uniformity along roadway.

Higher luminaire extends over vehicle and lights the driver's side.

Lower luminaire is mounted immediately next to light standard and lights the passenger's side.

Perspective View



Plan View

Equipment Used in Example:

	LUMINAIRE	LAMP	CONTROLS
A	Pole mounted, full cutoff roadway luminaire	165 watt induction	Activated during chain up requirements at night.
B	Pole mounted, full cutoff roadway luminaire	85 watt induction	Activated during chain up requirements at night.

5.16 Temporary Lighting

Warrants: from Manual of Uniform Traffic Control Devices (MUTCD)

- Any nighttime work requires lighting of the work area, equipment crossings, and flagger stations.

Criteria:

	Illuminance (fc)
General Work Area	5
High Precision Tasks	20

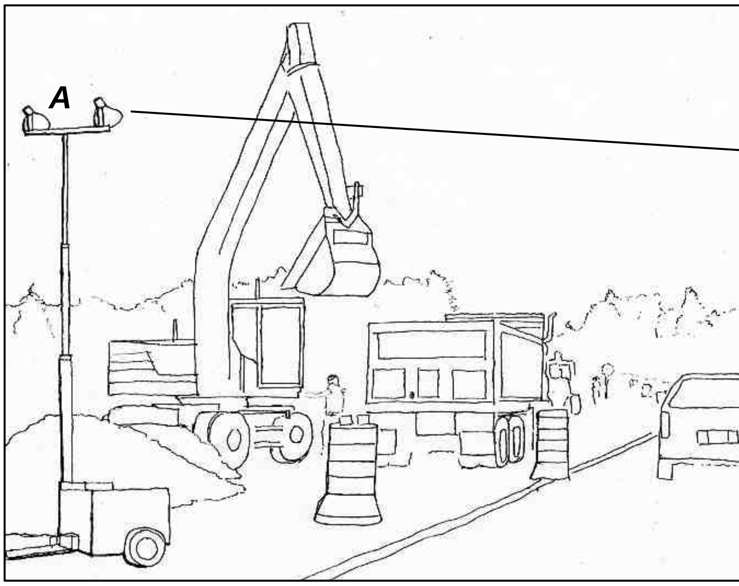
Design Intent / Rules of Thumb:

- Minimize glare to motorists, roadway works, and flaggers.

Special Considerations:

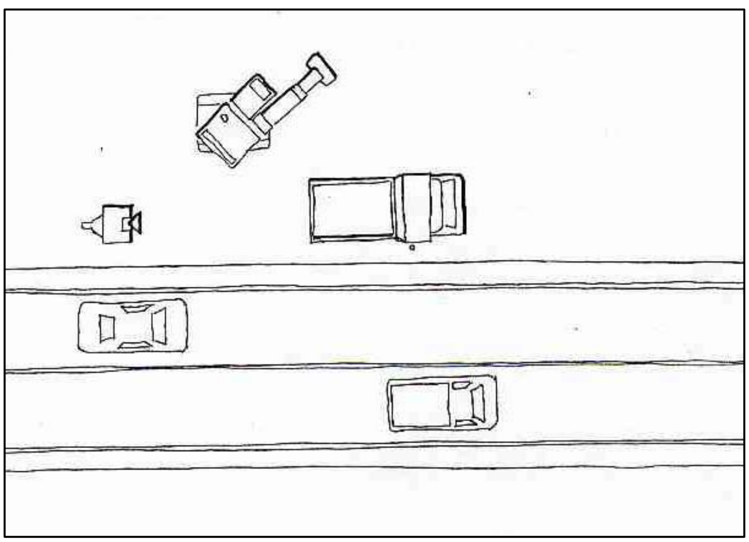
- Drive through work areas in both directions to evaluate the level of glare at the time of initial light setup and periodically during the work.

Temporary Lighting– Example Design



When possible, aim temporary lighting in direction of traffic flow.

Perspective View



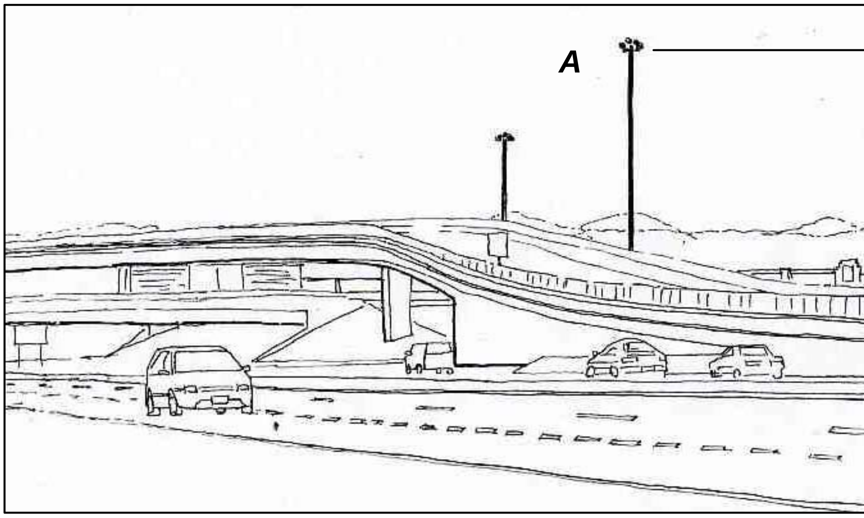
Plan View

Equipment Used in Example:

	LUMINAIRE	LAMP	CONTROLS
A	Pole mounted portable luminaire on adjustable pole; external glare shielding	Quartz halogen or metal halide	Manual on/off

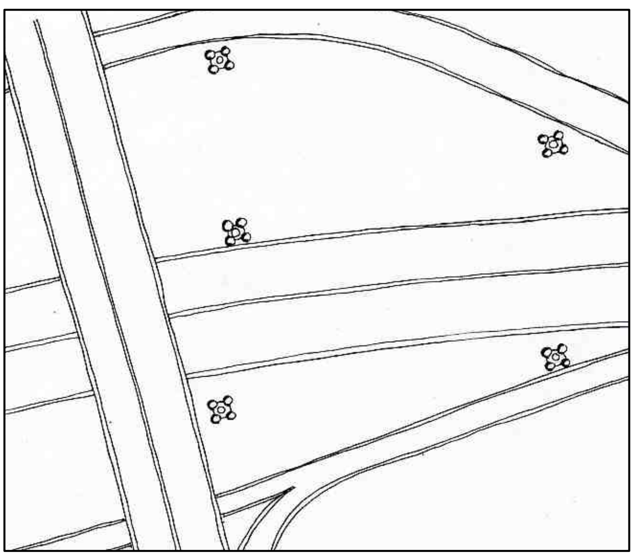
6 High Mast Applications

In some extreme cases, high mast lighting may be the best design solution. Due to their height, they have significant potential to cause light trespass and should only be used for large, complex interchanges. High mast luminaires should use IESNA full cutoff optics to eliminate glare as much as possible. For high mast lighting, illuminance is the only method for design. Towers over 70 feet high will be multi-sided segmented standards.



For complex interchanges, high mast lighting may be appropriate to light the entire area.

Perspective View



Plan View

Equipment Used in Example:

	LUMINAIRE	LAMP	CONTROLS
A	Pole mounted, full cutoff roadway or high mast luminaires	250 - 400 watt metal halide	Photocell on/off at LCC

7 Glossary

Following are general definitions of some factors considered in lighting design.

Ballast – A ballast is a device used to provide lamp voltage, current and waveform for starting and operating fluorescent, metal halide and high pressure sodium lamps.

Disability Glare - Also frequently called veiling luminance, it is a luminance superimposed on the retinal image that reduces its contrast. It is this veiling effect produced by bright sources or areas in the visual field that results in decreased visual performance and visibility.

Discomfort Glare - Glare that produces discomfort, but does not necessarily diminish visual performance.

Efficacy – Efficacy is the lumen output of the lamp divided by the total lamp power input expressed in lumens/watt. It is a measure on how energy efficient lamp sources are compared to alternative lamps.

Full cutoff - Refers to luminaires that do not emit light above a horizontal plane. These types of luminaires produce a minimal amount of disability glare and discomfort glare.

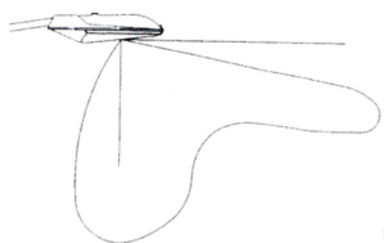


Figure 15. Vertical distribution diagram of a full cutoff luminaire.

Illuminance (footcandle) - The incident light falling on a surface such as roadway pavement. The source of light may include the roadway luminaires, automobile headlights and other nearby lighting equipment. Total illuminance at a point is a combination of all light sources that contribute.

Initial Illuminance (footcandle) - The average level of horizontal illuminance on the pavement area of a traveled way at the time the lighting system is installed, when lamps are new (after 100 hours) and luminaires are clean; units in footcandles (fc).

Light Loss Factor - A depreciation factor that describes the drop in light output over the life of the system. Factors that determine the light loss factor are lamp lumen depreciation (obtained from lamp catalogs), luminaire dirt depreciation and voltage regulation. Roadway lighting systems should be designed for the amount of light that will be generated near the end of the life expectancy of a luminaire and the amount of dirt depreciation that can be expected depending upon environmental conditions. Refer to Illuminating Engineering Society of North America RP-8 for Light Loss Factor calculation examples.

Luminaire - A complete lighting device consisting of lamp, ballast, reflector, refractor, housing and such support as is integral with the housing. The pole, posts, and bracket or mast arm are not considered to be part of the luminaire. Most outdoor luminaires can be divided into three basic types of luminaires: roadway lighting, floodlighting, and pedestrian. The various types of luminaires are determined by individual distribution characteristics, general construction, and size. To clearly specify the type of luminaire distribution for roadway and floodlighting applications, the Illuminating Engineering Society of North America has established five classifications.

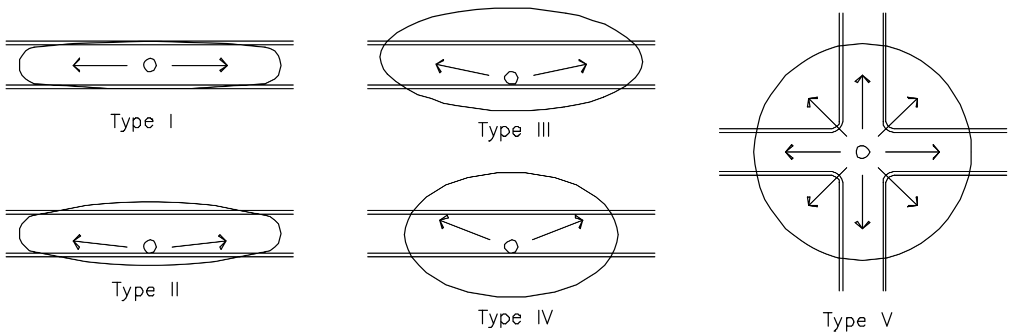


Figure 16. Horizontal distribution diagrams of Type I through V reflector distributions.[6]

Luminance (candelas per square meter) - The luminous intensity of any surface in a given direction per unit of projected area of the surface as viewed from that direction; i.e., the apparent brightness of a surface. Refer to figure 20.

Luminous Flux (lumen) - A unit of measure of the quantity of light. One lumen is the amount of light that falls on an area of one square meter, every point of which is one meter from a source of one candela. A light source of one candela emits a total of 12.57 lumens. Light sources are rated in terms of luminous flux.

Luminous Intensity (candela) - The candela is the basic unit of light quantity. The candela is historically related to the light emitted by a candle flame and was once known as candlepower. The candela can be thought of as the number of photons per second emitted by the light source. (A photon is a subatomic particle with zero mass that carries the energy of light and all other forms of electromagnetic energy.)

Maintained Illuminance (fc) - The average level of horizontal illuminance on the roadway pavement when the illuminating source is at its lowest output and when the luminaires are in their dirtiest condition; expressed in footcandles for the pavement area. This is calculated by multiplying the initial illuminance by a light loss factor and a dirt depreciation factor.

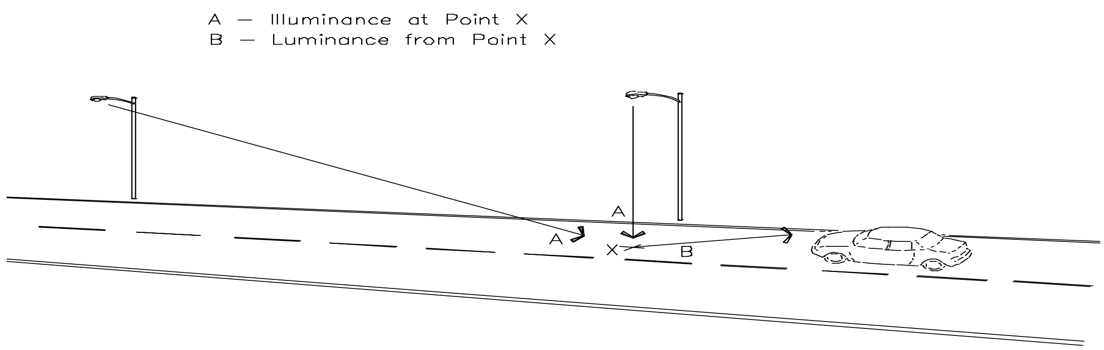


Figure 17. Various surface luminances as seen by the motorist.

Mesopic – Mesopic vision is fully adapted to a lighted environment nighttime vision such as what one may experience with roadway lighting. The range of adaptation is between 3 and 0.001 cd/m^2.

Nadir – Nadir is the lowest point on a sphere, or pointing straight down.

Non-cutoff - Refers to luminaires that produce uncontrolled light. These luminaires should not be used on major highways since they produce uncontrolled glare. Roadway lighting luminaires of this type are usually reproductions of Victorian-era gaslights, and they may be used for decorative purposes if they are not equipped with high-wattage bulbs. They are most commonly used in historic districts.

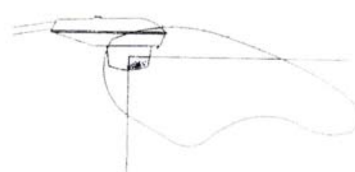


Figure 18. Vertical distribution diagram of a non-cutoff luminaire.

Photopic – Photopic vision is our day vision. It is generally associated with adaptation to a luminance of at least 3 cd/m^2.

Scotopic – Scotopic vision is our night vision when lighting is not present. It is generally associated with adaptation to a luminance of below 0.001 cd/m^2.

Semi-cutoff - Refers to luminaires that produce some amount of uncontrolled light above a horizontal plane. These luminaires can contribute to glare and their use should be minimized on major roadways.

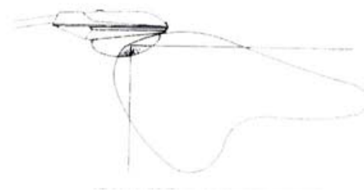


Figure 19. Vertical distribution diagram of a semi-cutoff luminaire.

Small Target Visibility (STV)– The calculated prediction of a driver to see a small target (18 inches flat target perpendicular to the roadway surface at a fixed distance of 83 meters) on the different roadway surfaces under specific lighting conditions. Listed below are factors that affect STV from IESNA RP-8-00.

Table B1: Common Lighting Systems Changes and The Effects Produced

System Change	Effect on Pavement Luminance	Effect on Small Target Visibility
Increase lamp output *	• Proportional increase • No change in uniformity	Small increase in average
Reduce spacing **	• Increase average • Improve Uniformity	Decrease average
Increase mounting height **	• Decrease average • Improve Uniformity	Decrease average
Increase overhang **	• Increase average • Uniformity change unpredictable	Slight decrease
Change from Staggered to Opposite ***	• No change in average • Improve Uniformity	Large increase
Change from Staggered to Center Mounting ***	• Small change in average • Degrade Uniformity	Large increase

* Assumes no change in luminaire distribution.
** Assumes no change in lamp output or distribution.
*** Assumes spacing is doubled with no change in lamp or luminaire.

Table 5. Common lighting system changes and the effects produced.[7]

Uniformity Ratio - Maximum uniformity ratios are used to judge the evenness of the light on the road surface. The ideal roadway lighting system would have high uniformity, yielding uniformity ratios of 1:1. This is not a realizable goal, however, and uniformity is generally the limiting factor in the design of roadway lighting systems. The most significant uniformity ratios are average to minimum and maximum to minimum.

Veiling Luminance Ratio - Describes how bright the light source is compared to the roadway surface. It is important in roadway lighting since source brightness can inhibit one's ability to see details on the pavement. Refer to Figure 21.

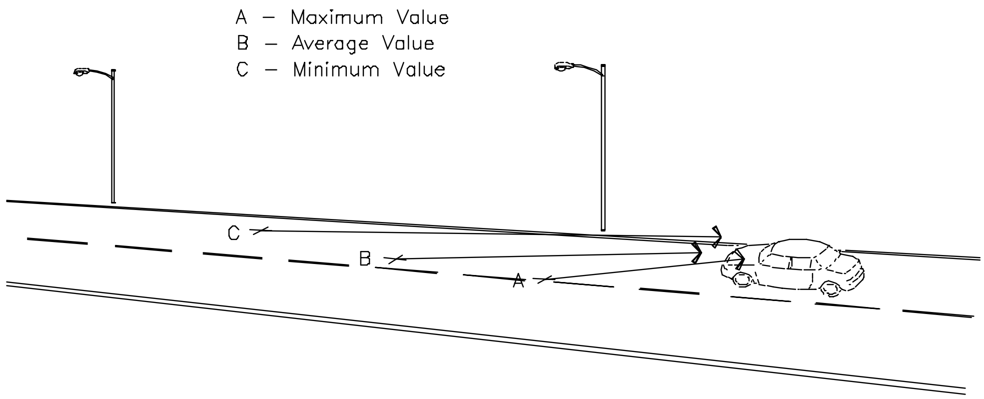


Figure 20. Roadway luminance as seen by a motorist.

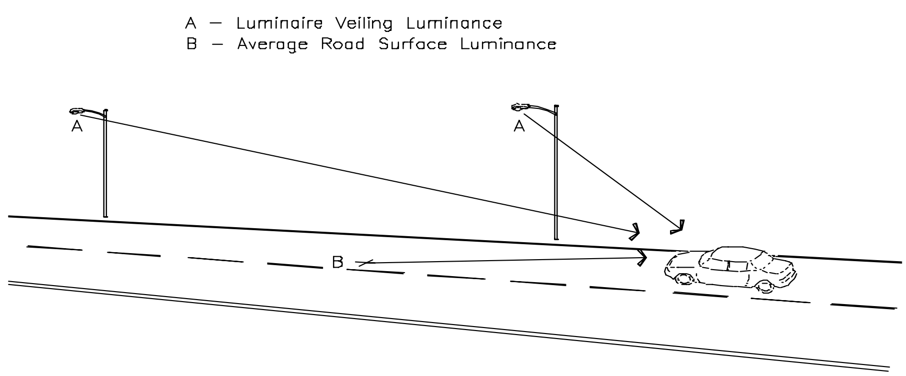


Figure 21. Veiling luminance as seen by a motorist.

8 Appendix – IESNA RP-8-00 Criteria

The following tables from the IESNA RP-8-00 Roadway Lighting have been reprinted here with permission.

Class	Q_o	Description	Mode of Reflectance
R1	0.10	Portland cement concrete road surface. Asphalt road surface with a minimum of 12 percent of the aggregates composed of artificial brightener (e.g., Synopal) aggregates (e.g., labradorite, quartzite).	Mostly Diffuse
R2	0.07	Asphalt road surface with an aggregate composed of a minimum 60 percent gravel [size greater than 1 cm (0.4 in.)]. Asphalt road surface with 10 to 15 percent artificial brightener in aggregate mix. (Not normally used in North America.)	Mixed (diffuse and specular)
R3	0.07	Asphalt road surface (regular and carpet seal) with dark aggregates (e.g., trap rock, blast furnace slag); rough texture after some months of use (typical highways).	Slightly Specular
R4	0.08	Asphalt road surface with very smooth texture.	Mostly Specular

Table A-1. Road Surface Classifications

Road and Pedestrian Conflict Area		Pavement Classification (Minimum Manintained Average Values)			Uniformity Ratio	Veiling Luminance Ratio
Road	Pedestrian Conflict Area	R1 lux/fc	R2 & R3 lux/fc	R4 lux/fc	E_{avg}/E_{min}	L_{vmax}/L_{avg}
Freeway Class A		6.0/0.6	9.0/0.9	8.0/0.8	3.0	0.3
Freeway Class B		4.0/0.4	6.0/0.6	5.0/0.5	3.0	0.3
Expressway	High	10.0/1.0	14.0/1.4	13.0/1.3	3.0	0.3
	Medium	8.0/0.8	12.0/1.2	10.0/1.0	3.0	0.3
	Low	6.0/0.6	9.0/0.9	8.0/0.8	3.0	0.3
Major	High	12.0/1.2	17.0/1.7	15.0/1.5	3.0	0.3
	Medium	9.0/0.9	13.0/1.3	11.0/1.1	3.0	0.3
	Low	6.0/0.6	9.0/0.9	8.0/0.8	3.0	0.3
Collector	High	8.0/0.8	12.0/1.2	10.0/1.0	4.0	0.4
	Medium	6.0/0.6	9.0/0.9	8.0/0.8	4.0	0.4
	Low	4.0/0.4	6.0/0.6	5.0/0.5	4.0	0.4
Local	High	6.0/0.6	9.0/0.9	8.0/0.8	6.0	0.4
	Medium	5.0/0.5	7.0/0.7	6.0/0.6	6.0	0.4
	Low	3.0/0.3	4.0/0.4	4.0/0.4	6.0	0.4

Table A-2. Illuminance Method – Recommended Values

Road and Pedestrian Conflict Area		Average Luminance	Uniformity Ratio	Uniformity Ratio	Veiling Luminance Ratio
Road	Pedestrian Conflict Area	L_{avg} (cd/m^2)	L_{avg}/L_{min} (Maximum Allowed)	L_{max}/L_{min} (Maximum Allowed)	L_{Vmax}/L_{avg} (Maximum Allowed)
Freeway Class A		0.6	3.5	6.0	0.3
Freeway Class B		0.4	3.5	6.0	0.3
Expressway	High	1.0	3.0	5.0	0.3
	Medium	0.8	3.0	5.0	0.3
	Low	0.6	3.5	6.0	0.3
Major	High	1.2	3.0	5.0	0.3
	Medium	0.9	3.0	5.0	0.3
	Low	0.6	3.5	6.0	0.3
Collector	High	0.8	3.0	5.0	0.4
	Medium	0.6	3.5	6.0	0.4
	Low	0.4	4.0	8.0	0.4
Local	High	0.6	6.0	10.0	0.4
	Medium	0.5	6.0	10.0	0.4
	Low	0.3	6.0	10.0	0.4

Table A-3. Luminance Method – Recommended Values

Road and Pedestrian Conflict Area		STV Criteria	Luminance Criteria		
Road	Pedestrian Conflict Area	Weighting Average VL	L_{avg} cd/m^2 Median <7.3 m	L_{avg}* cd/m^2 Median ≥7.3 m	Uniformity Ratio L_{max}/L_{min} (Maximum Allowed)
Freeway "A"		3.2	0.5	0.4	6.0
Freeway "B"		2.6	0.4	0.3	6.0
Expressway		3.8	0.5	0.4	6.0
Major	High	4.9	1.0	0.8	6.0
	Medium	4.0	0.8	0.7	6.0
	Low	3.2	0.6	0.6	6.0
Collector	High	3.8	0.6	0.5	6.0
	Medium	3.2	0.5	0.4	6.0
	Low	2.7	0.4	0.4	6.0
Local	High	2.7	0.5	0.4	10.0
	Medium	2.2	0.4	0.3	10.0
	Low	1.6	0.3	0.3	10.0

Table based on a 60 year old driver with normal vision, an 18 cm x 18 cm (7.1 in. x 7.1 in.) 50 percent reflective target, and a 0.2 second fixation time.

* *This column also applies to freeways and expressways where the alignment at the two roadways is independent of each other, or where there is a median barrier sufficient to block the direct view of oncoming headlights or a one way street.*

Table A-4. Small Target Visibility – Recommended Values

Maintained Illuminance Values for Walkways/Bikeways			
	E_H lux/fc	E_{Vmin} lux/fc	E_{avg}/E_{min} *
Mixed Vehicle and Pedestrian**	20.0/2.0	10.0/1.0	4.0
Pedestrian Only	10.0/1.0	5.0/0.5	4.0

* Horizontal only

Mixed vehicle and pedestrian refers to those areas where the pedestrians are immediately adjacent to vehicular traffic without barriers or separation. Does not apply to mid-block crossings. (See **Section 3.5.1.4.)

E_H = average horizontal illuminance at walkway/bikeway
E_{Vmin} = minimum vertical illuminance at 1.5 m (4.9 ft.) above walkway/bikeway measured in both directions parallel to the main pedestrian flow

Table A-5. Recommended Values for High Pedestrian Conflict Areas

Maintained Illuminance Values for Walkways/Bikeways			
	E_H lux/fc	E_{Vmin} lux/fc	E_{avg}/E_{min} *
Pedestrian Areas	5.0/0.5	2.0/0.2	4.0

* Horizontal only

E_H = average horizontal illuminance at walkway/bikeway
E_{Vmin} = minimum vertical illuminance at 1.5 m (4.9 ft.) above walkway/bikeway measured in both directions parallel to the main pedestrian flow

Table A-6. Recommended Values for Medium Pedestrian Conflict Areas

Maintained Illuminance Values for Walkways/Bikeways			
	E_H lux/fc	E_{Vmin} lux/fc	E_{avg}/E_{min} *
Rural/Semi-Rural Areas	2.0/0.2	0.6/0.06	10.0
Low Density Residential	3.0/0.3	0.8/0.08	6.0
Medium Density Residential	4.0/0.4	1.0/0.1	4.0

* Horizontal only

E_H = average horizontal illuminance at walkway/bikeway
E_{Vmin} = minimum vertical illuminance at 1.5 m (4.9 ft.) above walkway/bikeway measured in both directions parallel to the main pedestrian flow

Table A-7. Recommended Values for Low Pedestrian Conflict Areas

Maintained Illuminance Values for Walkways/Bikeways			
	E_H lux/fc	E_{Vmin} lux/fc	E_{avg}/E_{min} *
Day	100.0/10.0	50.0/5.0	3.0
Night	40.0/4.0	20.0/2.0	3.0

* Horizontal only

E_H = average horizontal illumination at walkway/bikeway
E_{Vmin} = minimum vertical illumination at 1.5 m (4.9 ft.) above walkway/bikeway measured in both directions parallel to the main pedestrian flow

Table A-8. Recommended Values for the Pedestrian Portion of Pedestrian Vehicular Underpasses and Exclusive Pedestrian Underpasses

Illuminance for Intersections				
Functional Classification	**Average Maintained Illumination at Pavement by Pedestrian Area Classification** lux/fc			E_{avg}/E_{min}
	High	Medium	Low	
Major/Major	34.0/3.4	26.0/2.6	18.0/1.8	3.0
Major/Collector	29.0/2.9	22.0/2.2	15.0/1.5	3.0
Major/Local	26.0/2.6	20.0/2.0	13.0/1.3	3.0
Collector/Collector	24.0/2.4	18.0/1.8	12.0/1.2	4.0
Collector/Local	21.0/2.1	16.0/1.6	10.0/1.0	4.0
Local/Local	18.0/1.8	14.0/1.4	8.0/0.8	6.0

Table A-9. Recommended Illuminance for the Intersection of Continuously Lighted Urban Streets.

9 Endnotes

1. *The IESNA Lighting Handbook, Ninth Edition*, Chapter 7, "Luminaires", p. 7-8. The Illuminating Engineering Society of North America, New York, 2000.
2. *The IESNA Lighting Handbook*, *Ninth Edition,* Chapter 6, "Light Sources", p. 6-50. The Illuminating Engineering Society of North America, New York, 2000.
3. *IESNA Recommended Practice 8-00 Roadway Lighting*. p 30, Figure B1. The Illuminating Engineering Society of North America, New York, 1999. Used with permission.
4. *IESNA Recommended Practice 8-00 Roadway Lighting*. p 31, Figure B2. The Illuminating Engineering Society of North America, New York, 1999. Used with permission.
5. *IESNA Recommended Practice 8-00 Roadway Lighting*. p 31, Figure B3. The Illuminating Engineering Society of North America, New York, 1999. Used with permission.
6. *The IESNA Lighting Handbook, Ninth Edition*, Chapter 22, "Roadway Lighting", p. 22-7. The Illuminating Engineering Society of North America, New York, 2000. Used with permission.
7. *IESNA Recommended Practice 8-00 Roadway Lighting*. p 29, Table B1. The Illuminating Engineering Society of North America, New York, 1999. Used with permission.