# CHAPTER 1

# INTRODUCTION

The purpose of this manual is to provide design guidelines and best practices, including criteria, policies, and procedures, for the light-emitting diode (LED) illumination systems in the State of Tennessee. The standards used in this manual are in conjunction with the Tennessee Department of Transportation (TDOT) *Standard Specifications for Road and Bridge Construction* and the TDOT Standard Drawings. This manual is in line with current best industry practices.

Based on the American Association of State Highway and Transportation Officials (AASHTO) *Roadway Lighting Design Guide*, illumination needs should be justified through warrants for both existing and proposed projects. Simply meeting warrants does not obligate TDOT to design and install the illumination systems. Other considerations may also be used to determine eligibility. This manual is intended for use by professional engineers and designers. Standard U.S. customary units (inch–foot–mile) are used in this standard.

## 1.1 Guideline Overview

The primary objective of roadway lighting is to enhance roadway safety. Properly designed roadway lighting should provide a level of visibility that enables motorists and pedestrians to quickly discern significant details of the roadway. Those details include the roadway alignment; the surrounding environment; obstacles on or near the roadway; and vehicles, people, or animals that are about to enter the roadway. In summary, lighting performs the following functions:

- Enables the driver to determine the geometry and condition of the roadway at extended distances
- Promotes safety at night by enhancing visibility so that drivers and pedestrians can comfortably make decisions
- Delineates the roadway and its surroundings and alerts motorists to potential obstructions and other hazards
- Assists the motorists in orienting themselves to the roadway's geometry
- Illuminates long underpasses and tunnels during the day to permit adequate visibility while entering, traveling through, and exiting such corridors
- Discourages crime at night or in other dark situations
- Enhances commercial and other activity zones to attract users

## 1.2 Engineering Requirements

The state requires the design and construction documents to be signed and sealed by a registered professional engineer who has experience in the area of roadway lighting and associated electrical systems. The expertise required for TDOT lighting designs includes the following factors:

- Lamp types and characteristics, including depreciation factors
- Fixture mechanical characteristics lens types
- Photometric performance of luminaires and factors impacting such performance
- Fixture mounting types
- Pole mechanical and electrical characteristics
- Breakaway device options and their appropriate use
- Clear zone criteria
- Pole types, mounting options, and loading considerations
- Foundation and support details
- Pavement reflection factors
- Mounting height and spacing options
- Light trespass and sky glow (light pollution) issues including laws and ordinances
- Lighting quality requirements, such as illuminance, luminance, veiling luminance, and visibility
- Lighting controls
- Electrical system requirements such as circuitry, voltage drop, and equipment sizing
- Maintenance considerations for individual components and the lighting system as a whole
- Energy and life cycle costs
- Coordination with master lighting plans

Designers for the lighting system should exercise engineering judgment when balancing all of the previously listed factors.

## 1.3 Funding Requirements

TDOT recognizes that under certain conditions, the installation of roadway lighting can improve the safety of a road or intersection. Consequently, TDOT includes roadway lighting in state highway projects when certain conditions are met:

- Interstate Highway System: TDOT will typically prepare plans to install new roadway lighting as part of the related interstate highway construction project when the following conditions are met:
  - Freeway lighting is determined to be warranted by the Traffic Design Office and as prescribed by the Illuminating Engineering Society (IES), the AASHTO Roadway Lighting Design Guide, and the FHWA Lighting Handbook and these references' latest revisions.
  - Roadway construction requires the replacement or relocation of the existing lighting, and the local governing agency agrees to maintain the installation.

- Interstate Interchange Lighting: Interchanges not under construction or not eligible for other funding may be approved and lighting installed, provided that the local governing agency submits a request for interchange lighting to the TDOT Commissioner in writing. The local governing agency must also submit funding to cover 50 percent of the costs for interchange lighting to TDOT when the project is programmed.
- Non-interstate Highways: TDOT generally does not replace or install new lighting on state routes and other non-interstate system highways. Installation or relocation of lighting on non-interstate system highways or related projects occurs only under the following specific circumstances:
  - Replacement of existing lighting impacted by construction on a state roadway project shall first be considered a utility relocation issue. The local agency shall be responsible for preparing relocation plans and submitting plans through the TDOT Utilities Office. The TDOT Regional Utilities Office will determine reimbursement eligibility. Relocation plans shall be completed by the local agency for review and approval by the TDOT Traffic Design Division.
  - Installation or relocation of roadway lighting in a state project occurs typically at the local agency's request. The TDOT Traffic Services Manager shall approve the installation or relocation of roadway lighting projects.
  - The local governing agency may request that relocation be installed under the state project as a non-participating item when the local agency working through the TDOT Utilities Office prepares relocation plans and submits funds to cover relocation costs prior to letting.
  - All requests for roadway lighting installations on non-interstate highways will be reviewed and approved by the TDOT Traffic Services Manager.
  - Installation and maintenance of roadway lighting along the state highways are the responsibilities of the local governing agencies. Those agencies desiring to install street lighting must submit street lighting photometric data to TDOT and obtain utility permits. For more information on obtaining utility permits, contact the regional utility offices.

# CHAPTER 2

# LIGHTING FUNDAMENTALS

This chapter describes the fundamental concepts and technical terminology related to roadway lighting and illumination. The purpose of this chapter is to facilitate readers with the relevant background information for understanding this manual.

## 2.1 Illumination

Per the Federal Highway Administration (FHWA), illumination describes the amount of light incident on a surface. It represents the general condition of being illuminated. Two main aspects of illumination are the quantity of illumination and the quality of illumination. According to IES-RP-8-14, the quantity of illumination includes metrics such as luminous intensity, illuminance, and luminance. On the other hand, the quality of illumination includes glare, uniformity of illuminance, and color rendition.

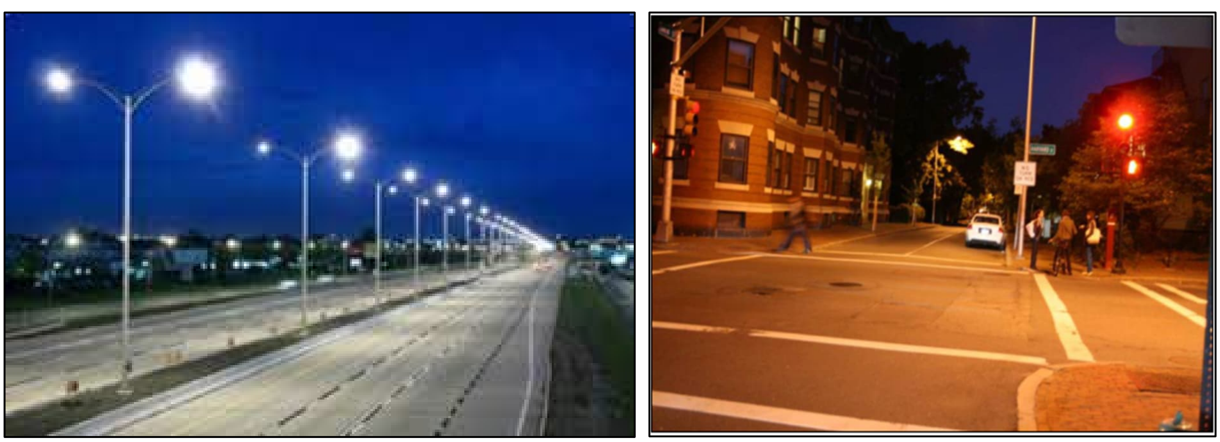
## 2.2 Lighting Metrics and Terminology

**Luminous Intensity:** Luminous intensity is the light-emitting power of a light source in a specific direction. Luminous intensity is measured in candela.

**Illuminance:** Illuminance is a measure of the amount of light falling onto a surface. The unit lux (lumens per square meter; SI unit) or foot-candle (lumens per square foot) is used to measure illuminance. There are two types of illuminances, horizontal illuminance and vertical illuminance, as shown on **Figure 2-1**. Horizontal illuminance is the amount of light that falls on the ground, while vertical illuminance shows how much light falls on a vertical surface. Vertical illuminance is used to help driver's see pedestrians or other hazards at night.

**Figure 2-1. Horizontal Illuminance (left) and Vertical Illuminance (right)**

*Source: FHWA Roadway Lighting Workshop (Street and Roadway Lighting Design)*



**Luminance:** Luminance refers to the amount of light emitted from a surface. Luminance is measured in candela per square meter. Luminance is the brightness of a surface and is a direct measure of what a driver sees on the illuminated roadway. The brightness of a light source compared with the roadway surface is called veiling luminance.

**Glare:** The IES defines glare as the sensation produced by luminances within the visual field that are sufficiently greater than the luminance to which the eyes are adapted to cause annoyance, discomfort, or loss in visual performance and visibility. Glare is caused when an object is so bright that it causes visual discomfort to the eyes of the observer. There are two types of glares: direct glare and indirect glare. The glare from a light source is termed direct glare, whereas the glare from a bright object is termed indirect glare. Glare can distract drivers, which can lead to safety issues. Glare that causes discomfort without necessarily causing visual impairment is termed discomfort glare. Glare resulting in reduced visual performance and visibility is called disability glare.

**Contrast:** Contrast indicates how clearly an object is visible compared with its background. Contrast can be positive or negative depending on the brightness levels of the object and the background, as shown on **Figure 2-2**. If the target object is brighter than its background, it is called positive contrast. Opposite to this, if the background is much brighter than the target object, it is called negative contrast. Normally, positive contrast is desirable.

**Figure 2-2. Positive Contrast (left) and Negative Contrast (right) with Respect to the Object**

*Source: FHWA Lighting Handbook*

**Light Trespass:** Light trespass refers to the light crossing into the surrounding neighborhood or area beyond the area it was intended to illuminate. Light trespass causes light pollution and can be a cause of nuisance to locals.

**Veiling Luminance Ratio:** The veiling luminance ratio is the ratio of maximum veiling luminance at the driver's eye to the average pavement luminance. The veiling luminance ratio provides information about the veiling effect of glare as a percentage of average overall luminance. This ratio is used by the IES and AASHTO as a measure of the amount of glare generated by roadway lighting.

**Visual Comfort Probability:** Per the IES visual comfort probability refers to the percentage of drivers who will find the lighting system and its environment comfortable with regard to visual glare.

**Uniformity Ratio:** Uniformity of illuminance measures the evenness of the light distribution over a target area. This ratio is typically the average level of illuminance to the minimum level of illuminance. Often the ratio of maximum level of illuminance to minimum level of illuminance is also calculated.

## 2.3 Characteristics of LED Light Sources

The characteristics of LED light sources as described in the FHWA Lighting Handbook are as follows:

**Efficacy:** A simple measure of the light output of the light source measured in lumens per watt. The higher the number the more efficient the light source. Where efficacy measures the efficiency of the lights output, it does not measure the efficiency of light delivery to the surface of the roadway.

**Unit Power Density (UPD):** Analyzes optimal luminaire performance and energy efficiency. UPD is the ratio of the rated luminaire watts to the amount of lighting delivered for a given area; thus, a lower UPD indicates better lighting.

**Correlated Color Temperature (CCT):** The CCT is a measure of the color appearance of a light source in degrees Kelvin. LEDs are available in various CCT values ranging from 2,700 K to 7,000 K with 2,700 K having a yellow tint and 7000K having a blue tint. In comparison, HPS lighting is 2,200K, Incandescent is 2,800, Metal Halide is 4,000K, Direct Sunlight is 4,800K, and blue sky is 10,000 K.

**Color Rendering Index (CRI):** The color appearance of an object under a light source, compared with the same object lighted under a reference standard light source, is described as the CRI. It is a measure of the ability of the light source to accurately reflect the true colors of the target objects. CRI is measured on a scale of 0 to 100, with a higher CRI value meaning better color rendering. The color shift or distortion is lesser with a higher CRI. LED light sources are known to have the best CRI in the range of 70 to 95, which is an excellent lighting condition for roadway lighting.

## 2.4 Lighting Sources: HID Lamps

This manual recommends and focuses on LED lighting.

## 2.5 Lighting Sources: LED Roadway Lighting

An LED is a solid-state semiconductor lighting source device. Early uses of LED included lamps for electronic devices and in traffic signals. Technological advancement has led to a wide range of applications in LED lighting for general purposes including roadway lighting.

### 2.5.1 LED Light Sources versus Other Light Sources

The following characteristics of LEDs make them unique compared with other lighting sources:

**Light generated by LED is directional:** The light generated by LED is directional unlike other lighting sources. Other types of lighting sources emit light 360 degrees, but LEDs emit light only up to 180 degrees. This results in higher energy efficiency because all the light is directed toward the intended illumination area. The need for additional accessories to redirect light is also minimized.

**LEDs consume less energy:** LEDs offer high lumen output with low energy consumption, leading to higher energy efficiency compared with other lighting sources. Per the *2022 Solid-State Lighting R&D Opportunities* by EERE, white LED packages now have an improved efficiency of more than 200 lumens per watt. With ongoing research and the continual upgrade of technologies, there is still room for further improvement in efficiency of LED lights.

**LED efficacy is less affected by temperature:** LED light sources work well in a wide range of temperatures without any significant degradation. LEDs are not as temperature sensitive as fluorescent light sources. However, LEDs work more efficiently in lower ambient temperatures.

**LEDs have a longer life:** The most distinguishing feature of LED light sources from other light sources is the longer life span that LEDs offer. Per the *2022 Solid-State Lighting R&D Opportunities* by EERE, outdoor LED lamps have a useful lifespan ($L_{70}$: Point in time when 70% of initial light is produced by the LED) of about 50,000 to 100,000 operating hours or more.

**LEDs have a lower carbon footprint:** LEDs have low carbon emissions compared with other lighting sources due to the small amounts of fossil fuels being burned. This makes LED light sources an environmentally safe alternative, allowing for improved air quality and added health benefits.

**LEDs use a small and bright point source of light:** An LED is a small and bright point source of light, which requires less space in the assembly. LEDs are adaptable to large number of lighting applications owing to their small size.

**LEDs can be dimmed and operate at low voltages:** LEDs have high dimming capabilities and can even operate at power less than their rated power. They can also operate at low voltages, making them even more suitable for roadway lighting applications. This is unlike other light sources, which cannot function properly at lower voltages and have lower dimming capabilities.

#### 2.5.1.1 Advantages of LED over HPS

**Higher energy efficacy:** LEDs have a high energy efficacy, of around 200 lumens per watt, whereas HPS light sources have a lower energy efficacy of about 140 lumens per watt.

**Longer lifespan:** The useful lifespan of LEDs is in the range of 50,000 to 100,000 hours, whereas that of HPS is about 24,000 hours.

**Less heat emissions:** LEDs emit much less heat compared with HPS lighting sources. Almost 15 percent of the energy is lost as heat emissions in HPS lighting.

**High color-rendering properties:** The CRI value of LED light sources varies between 65 and 95, and for HPS lighting, it varies between 20 and 30. This shows that LEDs are much better than HPS at reflecting the true color of the object that is illuminated.

**Higher color temperature:** LEDs are available in a wide range of color temperature values. The higher color temperature values produce cooler and bluish light, which offer better illumination than the yellowish and warm light of HPS due to lower color temperature values.

## 2.6 Luminaire

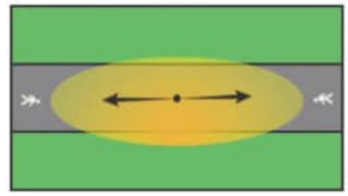
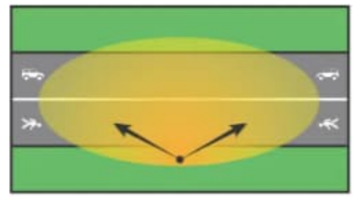
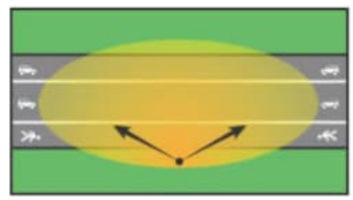
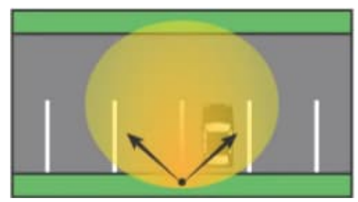
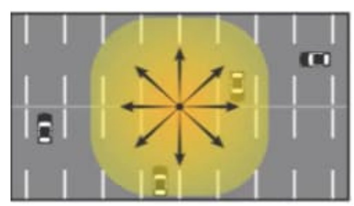
A luminaire, also known as a light fixture, may be defined as an assembly of a lighting source, light reflectors, housing, and so on that is used to direct light emitted from the lighting source.

### 2.6.1 Luminaire Classification System

The Illuminating Engineering Society (IES) developed a new method called the Luminaire Classification System (LCS). Per the *FHWA Lighting Handbook*, the LCS is for defining luminaire distribution and efficiency better. IES classifies outdoor luminaires based on the shape of the area illuminated by the luminaire. **Table 2-1** lists the IES classifications by intensity distribution for outdoor luminaires.

**Table 2-1. IES Classification for Light Distribution**

*Source: IES Lighting Handbook 10th ed.*

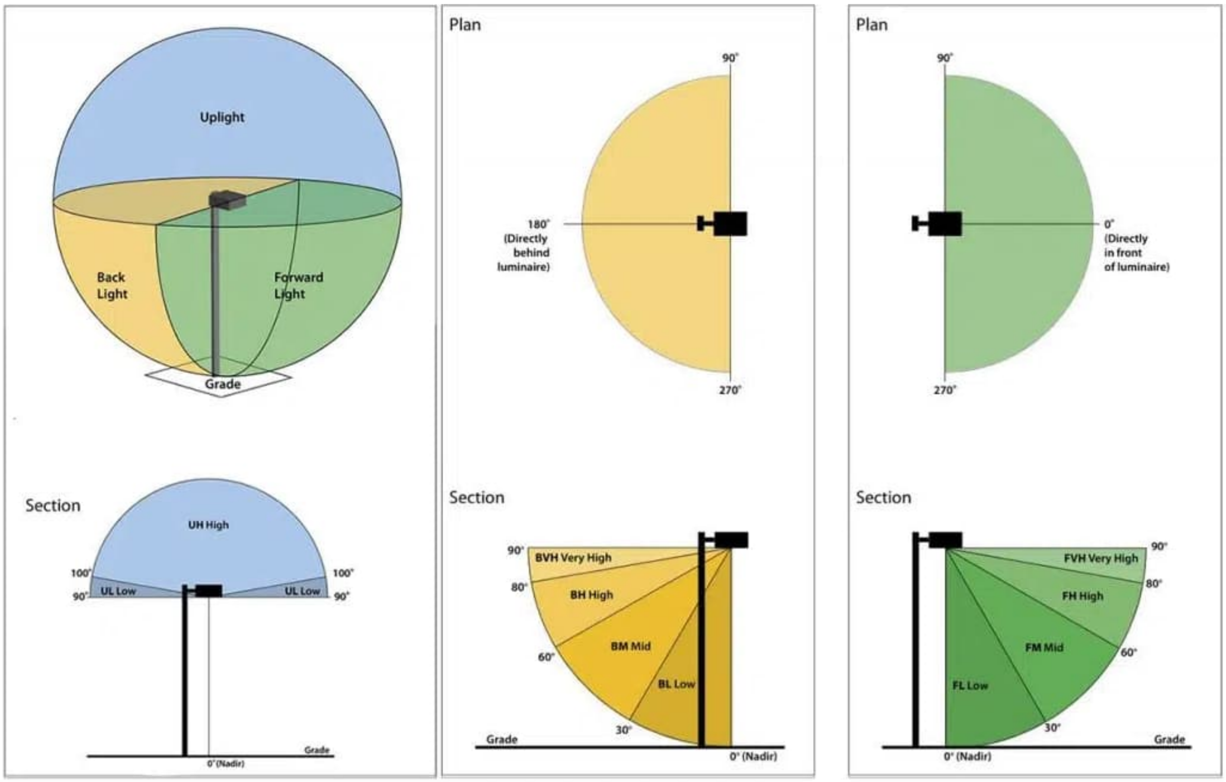
| Type | Description | Application | Plan View |
|---|---|---|---|
| Type I | Narrow, symmetric illuminance pattern | Walkway<br>Path<br>Roadway |  |
| Type II | Slightly wider, more asymmetric illuminance pattern | Walkways<br>Roadways<br>Bike paths |  |
| Type III | Wide, asymmetric illuminance pattern | Roadway (highways)<br>Parking |  |
| Type IV | Asymmetric, forward throw illuminance pattern | Wall mount or pole mount perimeter applications |  |
| Type V | Symmetrical circular illuminance pattern | Parking<br>Area lighting |  |

### 2.6.2 Backlight, Uplight, and Glare (BUG) Rating System

The Backlight, Uplight, and Glare (BUG) rating system quantifies the amount of trespass light produced by a light fixture. Backlight (B) is the light directed behind the fixture, uplight (U) is the light directed upward above the horizontal plane and glare (G) is the light emitted from the luminaire at high angles. Per the IES *Lighting Handbook*, IES uses the output luminaire lumens in the backlight, uplight, and glare solid angles (**Figure 2-3**) for the luminaire classification. The BUG ratings range from 0 to 5; where 0 is the best case and 5 is the worst case.

**Figure 2-3. IES BUG Rating System Solid Angles**

*Source: IES Lighting Handbook, 10th ed.*




BUG ratings are classified into zones based on the *Model Lighting Ordinance* by IES and the International Dark-Sky Association. Lighting zones are categorized into the following five groups:

- **LZ0**: No ambient lighting – Areas such as "wilderness areas, parks and preserves, and undeveloped rural areas"
- **LZ1**: Low ambient lighting – Areas such as "rural and low-density residential areas"
- **LZ2**: Moderate ambient lighting – Areas such as "light commercial business districts and high density or mixed-use residential districts"
- **LZ3**: Moderately high ambient lighting – Areas such as "large cities' business district[s]"
- **LZ4**: High ambient lighting – Special case areas such as "high intensity business or industrial zone districts"

For all zones, roadway lighting should consider the following BUG ratings:

- **B:** The lowest back light rating possible will achieve sidewalk lighting levels and surround levels, which should take priority in the design.
- **U:** Up-light rating would be U0 is recommended to reduce the potential of skyglow.
- **G:** The design should minimize the glare rating with a maximum G of 3.

## 2.7 Luminaire Efficiency

According to IES-RP-8-14, luminaire efficiency may be defined as the percentage of lamp lumens produced that actually exit the fixture. It is the percentage of luminous flux emitted by the luminaire compared with the luminous flux emitted by the lamp or light source. In general, the higher the efficiency of the luminaire, the more visual discomfort to the eyes. Thus, a trade-off is required between luminaire efficiency and visual comfort to select the best luminaire to suit the site conditions.

## 2.8 Luminaire Maintenance

Maintenance is an important element of roadway lighting because it ensures the proper functioning and long life of a lighting system. All important components of the lighting system, such as lamps, luminaires, and other components like support structures and electrical components, require maintenance to provide the level of service they were designed for. As described in the AASHTO *Roadway Lighting Design Guide*, the various categories of lighting system maintenance include luminaire maintenance, support structure maintenance, electrical distribution and control maintenance, and external factors. The extent and frequency of maintenance should be considered while designing the lighting system.

### 2.8.1 Luminaire Maintenance Factors

The maintenance factors related specifically to the luminaire are termed luminaire maintenance factors. The various luminaire maintenance factors mentioned in the AASHTO *Roadway Lighting Design Guide* are as follows:

**Luminaire Dirt Depreciation (LDD):** Luminaire dirt depreciation (LDD) refers to the deterioration of the optical materials like luminaire lens, the reduction in the output lumens, and the change in the distribution characteristics on the roadway that are caused by the general accumulation of dirt on the surface of the lamp and luminaire. The rate of LDD depends on various factors like the mounting height, roadway offset, and so on.

**Lamp Lumen Depreciation (LLD):** Lamp lumen depreciation (LLD) refers to the gradual loss and decrease in the lumen output of the lamp due to the normal in-service aging of the light source. LLD depends on the type of light source.

**Equipment Factor (EF):** Equipment factors (EFs) account for luminaire losses resulting from all other factors like manufacturing tolerances, voltage drops, ballast/driver factor, etc.

**Light Loss Factor (LLF):** The light loss factor (LLF) is the product of the previous three loss factors: LDD, LLD, and EF. LLF accounts for the factors resulting in depreciation of the light output from the luminaire compared with the initial light output, at a certain point in time in the future. The LLF value to be used for LED calculations generally ranges between 0.80-0.90.

# CHAPTER 3

# LIGHTING APPLICATIONS

## 3.1 Overview

Lighting applications may vary according to the type of facility they may serve. This section describes the various lighting applications that can be implemented. The applications are defined along with the warrants that justify their implementation. The warrants stated are intended to establish a basis and do not obligate the agency to provide lighting. Warrants may be considered in conjunction with other factors like safety, funding availability, and engineering judgment to decide whether lighting should be installed on a project.

Lighting facilitates the safe and orderly flow of traffic by illuminating certain permanent features or conditions that are unusual, necessitate extra caution and awareness when negotiating, and, if illuminated, may be more easily understood and so compensated for by the motorist.

The different applications of lighting and their warrants have been adopted from Table 3-5a of the 2018 AASHTO *Roadway Lighting Design Guide.*

## 3.2 Lighting on Freeways

According to the Manual on Uniform Traffic Control Devices (MUTCD; FHWA 2009), freeways are divided highways with complete control of access. They are designed for high-speed vehicular and free-flow traffic. Lighting on freeways can be distinguished as continuous freeway lighting, complete interchange lighting, and partial interchange lighting.

### 3.2.1 Continuous Freeway Lighting

A continuous freeway lighting system provides uniform lighting on all main lanes, direct connections, and interchanges within the section. Frontage roads are not normally continuously lighted; however, this may be warranted upon engineering judgment.

The warranting conditions in the AASHTO *Roadway Lighting Design Guide* for continuous freeway lighting are described in **Table 3-1.**

**Table 3-1. Warranting Conditions for Continuous Freeway Lighting**

| Case | Warranting Conditions |
|---|---|
| CFL-1 | Sections in and near cities where the current average daily traffic (ADT) is 30,000 or greater. |
| CFL-2 | Sections where three or more successive interchanges are located with an average spacing of 1.5 miles or less, and adjacent areas outside the right-of-way are substantially urban in character. |
| CFL-3 | Sections of two miles or more passing through a substantially developed suburban or urban area in which one or more of the following conditions exist: |

| Case | Warranting Conditions |
|---|---|
| | Local traffic operates on a complete street grid having some form of street lighting, parts of which are visible from the freeway.<br>The freeway passes through a series of developments—such as residential, commercial, industrial, and civic areas, colleges, parks, terminals, etc. that include lighted roads, streets, parking areas, yards, etc.—that are lighted.<br>Separate cross streets, both with and without connecting ramps, occur with an average spacing of 0.5 miles or less, some of which are lighted as part of the local street system.<br>The freeway cross section elements, such as median and borders, are substantially reduced in width below desirable sections used in relatively open country. |
| CFL-4 | Sections where the ratio of nighttime to daytime crash rate is at least 2.0 times the statewide average for all unlighted similar sections, and a study indicates that lighting may be expected to result in a significant reduction in the night crash rate. Where crash data are not available, rate comparison may be used a general guideline for crash severity. |
| CFL-5 | Where the Local Agency finds sufficient benefit in the forms of convenience, safety, policing, community promotion or public relations; and the local maintaining agency agrees to pay an appreciable percentage of, or wholly finance, the installation, maintenance and operation of the lighting facilities. |

Note: CFL = continuous freeway lighting

#### 3.2.1.1 Design Criteria

Lighting levels will be considered as meeting the criteria if the three values (minimum, average, and uniformity) are taken collectively and not individually. The average luminance values for freeways are given in **Table 3-2** and the average illuminance values are given in **Table 3-3**.

**Table 3-2. Luminance Design Criteria for Continuous Freeway Lighting**

| Roadway Facility Classification | Area Classification (Pedestrian Conflict Areas) | Average Luminance $L_{avg}$ (cd/m$^2$) (Min) | Uniformity Ratio ($L_{avg}/L_{min}$) (Maximum allowed) (max) | Uniformity Ratio ($L_{max}/L_{min}$) (Maximum allowed) (max) | Veiling Luminance Ratio $LV_{max}/L_{avg}$ |
|---|---|---|---|---|---|
| Freeway Class A | No Conflict | 0.6 | 3.5 | 6.0 | 0.3 |
| Freeway Class B | No Conflict | 0.4 | 3.5 | 6.0 | |

Notes: Freeway Class A: Roadways with greater visual complexity and highway traffic volumes

Freeway Class B: All other divided roadways with full control of access

Lavg: Average luminance

LVmax: Maximum veiling luminance

**Table 3-3. Illuminance Design Criteria for Continuous Freeway Lighting**

| Roadway Facility Classification | Area Classification (Pedestrian Conflict Areas) | Average Maintained Horizontal Illuminance ($E_h$) Foot-candle (lux) | | | Uniformity Ratio (Avg/Min.) (max) | Veiling Luminance Ratio $LV_{max}/L_{avg}$ |
|---|---|---|---|---|---|---|
| | | Pavement Classification | | | | |
| | | R1 (Ave) | R2 and R3 (Ave) | R4 (Ave) | | |
| Freeway | Class A | 0.6 (6) | 0.9 (9) | 0.8 (8) | 3:1 to 4:1 | 0.3 |
| | Class B | 0.4 (4) | 0.6 (6) | 0.5 (5) | | |

Note: Class A: Roadways with greater visual complexity and highway traffic volumes
Class B: All other divided roadways with full control of access
Pavement classification types (R1, R2, R3) are defined in Section 4.7.

- Mounting height is typically 30 to 70 feet. Mid-mast light standards (40 to 70 feet) are typically included in large roadway projects and are typically installed on the median.
- It is recommended to begin light distribution design with Type II or Type III without any uplight (U0). Other distributions may be considered depending on the roadway design and light standard location.
- It is recommended to design the spacing with the spacing-to-mounting-height ratio 6:1. The ratio may be modified to meet lighting criteria or address other critical design issues.
- Illuminance calculations can be used to design curves and short, steep hills. The typical section of roadway should meet the same illuminance value as a straight section of roadway. With lighting calculation software, the straight roadway illuminance value can be calculated at the same time as the roadway luminance value. Refer to the acceptable design criteria values corresponding to the facility type being analyzed.
- Curves typically require closer spacing of standards. Short, steep hills may require closer spacing of standards. Some viaducts and flyovers may require alternative lighting solutions that limit the use of light standards.

#### 3.2.1.2 Design Examples

**Figure 3-1. Typical Freeway Design, Plan View**

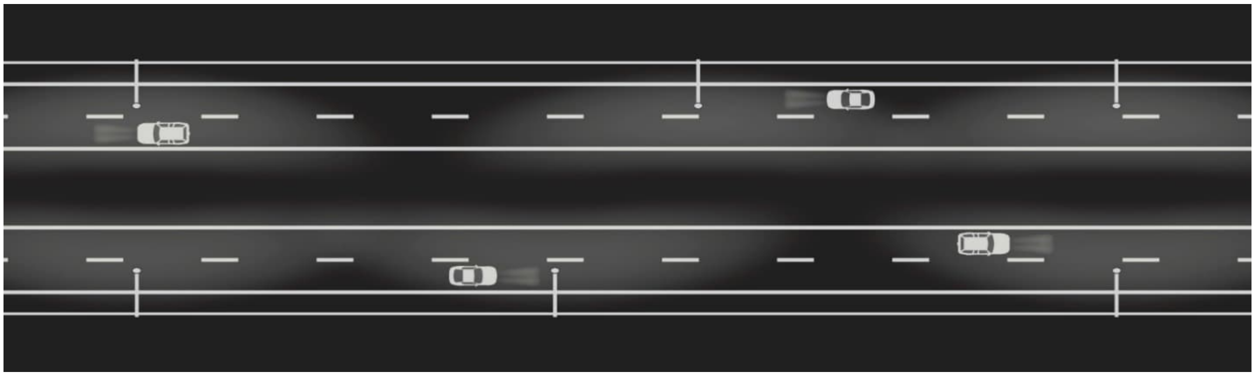


**Figure 3-2. Alternative Flyover, Plan View**

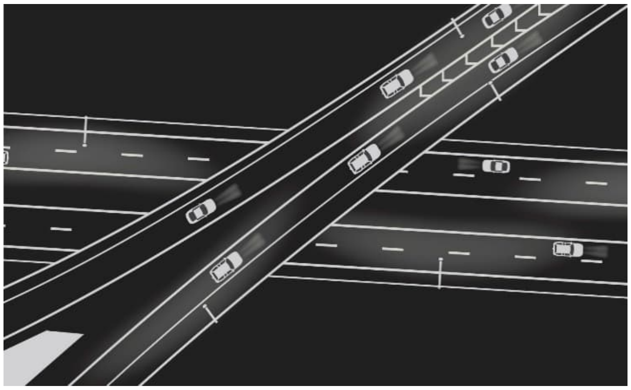


**Figure 3-3. Alternative Flyover, Isometric View**

Figures above all show lighting with mast arms. This is typical in locations where sidewalk or pedestrian activity occurs along the roadway or is preferred by the local entity. Freeway lighting typically uses offset lighting in place of mast arm lighting.

### 3.2.2 Complete Interchange Lighting

A complete interchange lighting system provides relative uniform lighting within the limits of interchange including main lanes, direct connections, ramp terminals, underpasses, and frontage roads or crossroad intersections.

The warranting conditions for complete interchange lighting in the AASHTO *Roadway Lighting Design Guide* are described in **Table 3-4**.

**Table 3-4. Warranting Conditions for Complete Interchange Lighting**

| Case | Warranting Conditions |
|---|---|
| CIL-1 | Where the total current ADT ramp traffic entering and leaving the freeway within the interchange areas exceeds 10,000 for urban conditions, 8,000 for suburban conditions, or 5,000 for rural conditions. |
| CIL-2 | Where the current ADT on the crossroad exceeds 10,000 for urban conditions, 8,000 for suburban conditions, or 5,000 for rural conditions. |
| CIL-3 | Where existing substantial commercial or industrial development that is lighted during hours of darkness is located in the immediate vicinity of the interchange, or where the crossroad approach legs are lighted for 0.5 miles or more on each side of the interchange. |
| CIL-4 | Where the ratio of nighttime to daytime crash rate within the interchange area is at least 1.5 times the statewide average for all the unlighted similar sections, and a study indicates that lighting may be expected to result in a significant reduction in the night crash rate. Where crash data are not available, rate comparison may be used as a general guideline for crash severity. |
| CIL-5 | Where the Local Agency finds sufficient benefit in the forms of convenience, safety, policing, community promotion or public relations; and the local maintaining agency agrees to pay an appreciable percentage of, or wholly finance, the installation, maintenance and operation of the lighting facilities. |
| CIL-6 | A complete interchange lighting should be considered at interchanges where continuous freeway lighting is provided. |

Note: CIL = complete interchange lighting

### 3.2.2.1 Design Criteria

Lighting levels will be considered as meeting the criteria if the three values (minimum, average, and uniformity) are taken collectively and not individually. The average luminance values for complete interchange lightings are given in **Table 3-5**.

**Table 3-5. Design Criteria for Complete Interchange Lighting**

| Roadway Facility Classification | Average Luminance ($cd/m^2$) | Uniformity Ratio ($L_{avg}/L_{min}$) (max) | Maximum Luminance Ratio $LV_{max}/L_{avg}$ |
|---|---|---|---|
| Freeway A | 0.6 | 3.5:1 | 0.3 |
| Freeway B | 0.4 | 3.5:1 | |

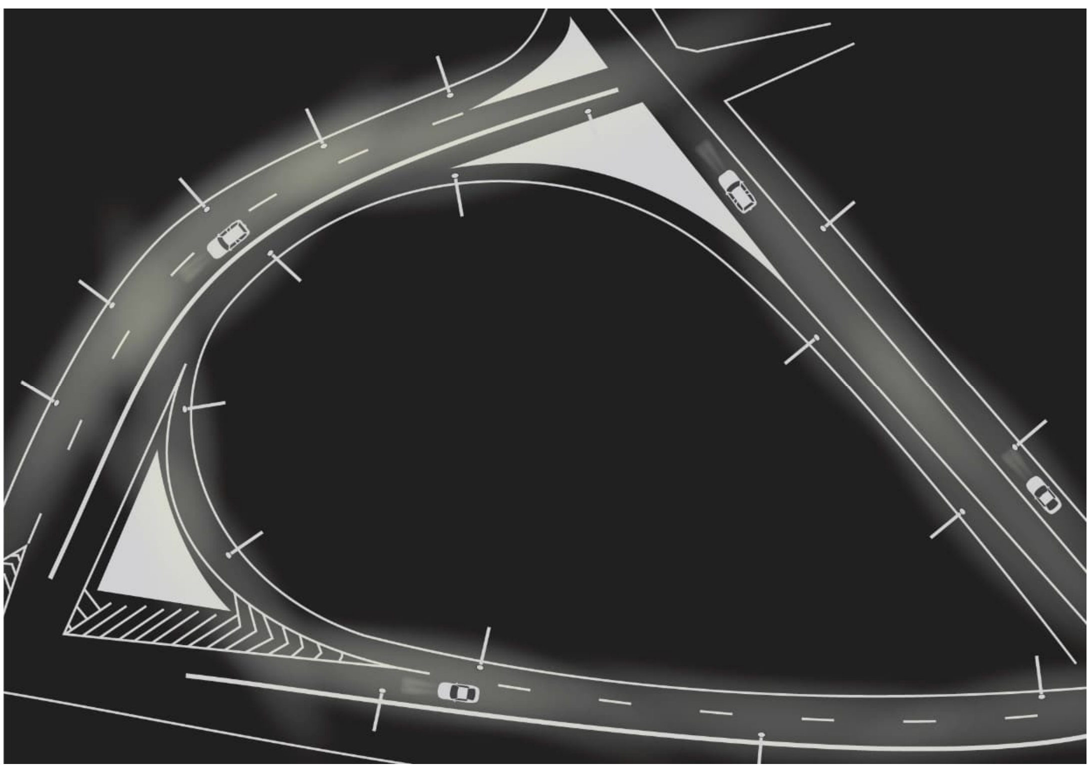
Notes: Freeway A: A highway with visual complexity and high traffic volumes
Freeway B: all other highways
cd/m2 = candela per square meter
avg = average lux
Lavg = average luminance
LVmax = maximum veiling luminance
min = minimum lux

- Mounting height is typically 30 to 70 feet. Mid-mast light standards (40 feet to 70 feet) are typically included in large roadway projects and are typically installed on the median.
- It is recommended to begin light distribution design with Type III without any uplight (U0).
- It is recommended to design the spacing with the spacing-to-mounting-height ratio 5:1. The ratio may be modified to meet lighting criteria or address other critical design issues.
- Light standards should follow the roadway through the interchange.
- When possible, a light standard should be placed adjacent to the gore area at off-ramps. Per IES locating light poles within the clear zone at a gore area is not desirable.
- Lights should be located on the insides of curves to minimize potential strikes from vehicles.
- Light standards present near residential neighborhoods have greater light trespass potential. Low backlight ratings (B0 through B2) and low glare ratings (G0 through G2) should be considered to minimize light trespass.

#### 3.2.2.2 Design Examples

An example of high-mast interchange lighting is provided in **Appendix A – Figure A-1.** TDOT does not design, use, recommend, or approve partial interchange lighting.

**Figure 3-4. Continuous Interchange, Plan View**



## 3.3 Lighting on Streets and Highways

Urban streets and highways other than freeways have high traffic volumes of both vehicles and pedestrians along with at-grade intersections, turning movements, signalization, and varying geometry. Installation of roadway lighting at these locations is recommended for safety, efficiency, and comfort for motorists, pedestrians, and other modal transportation users. TDOT recommends lighting on state routes next to the interstate system if these state routes are being widened.

The AASHTO *Roadway Lighting Design Guide* does not explicitly formulate warrants for these lighting conditions; however, AASHTO does state general guidelines where such lighting types may be considered. Urban and rural conditions, traffic volumes (both vehicular and pedestrian), intersections, turning movements, signalization, channelization, and varying geometry are factors that should be considered when determining the lighting needs of streets and highways other than freeways.

### 3.3.1 TDOT Requirements

- TDOT provides lighting for interstate highways and bridges. New lighting installations on the state highway system will be reviewed by TDOT using breakaway, nonbreakaway, and utility distribution poles (joint usage).
- Consider installing lighting to provide adequate levels of illumination; minimize the amount of glare; and reduce the number of poles required.
- Street lighting plans submitted to the TDOT Traffic Design Office for approval must provide photometric calculations using AGI32 software only and the type of lighting equipment to be installed. Poles that will be used for streetlights must be shown on the lighting design. In order to reduce the time involved to review and approve lighting designs, the agency or their designee should contact TDOT to discuss and resolve problems or concerns prior to the lighting plan submittal. If questions arise in the interpretations of the rules and regulations regarding roadway lighting, the TDOT Traffic Services Manager will make the final administrative and engineering determinations.

### 3.3.2 General Design Considerations on Street Lighting

- The recommended mounting height for existing utility poles is 45 feet. Where electrical distribution or communication lines exist, mounting heights less than 45 feet may be approved in order to use existing utility poles to the fullest extent; however, the effectiveness of a satisfactory lighting job should not be jeopardized just to use existing utility poles.
- In the relocation of utility poles on state highway right-of-way, every effort shall be taken to relocate these poles to provide for their use for roadway lighting. This will provide an economical system, allowing utility poles to be used for street lighting as well as electrical distribution. It will also reduce the number of fixed objects most frequently involved in motor vehicle accidents.
- Pole setback from the edge of the pavement shall be 20 feet minimum, or at the right-of-way line if located less than 20 feet from the edge of pavement. In urban areas,

poles shall be located as near to the right-of-way line as possible, but in no case shall they be less than 2 feet from the face of the curb. In case of sidewalks, it is desirable to place the poles outside of the sidewalk, preferably at the backside of the sidewalk.

- Poles shall not be set in the median of the roadway, except where a 20-foot minimum setback can be obtained on both sides of the divided roadway, or where protected by an existing guardrail for other safety considerations.
- Street lighting installed in depressed medians may be considered on a case-by-case basis, because this type of installation is a variance to TDOT's street lighting policies. Light standards may be installed in depressed medians that have a minimum width of 48 feet provided minimum clear zone requirements are met. The light standards are to be located 4 feet on either side of the drainage ditch. Light standards may be installed in depressed medians behind existing or proposed guardrail or barriers.
- Mast arm length shall be no greater than 6 feet, except as approved by the TDOT Traffic Services Manager.
- Concrete pole bases should be flushed but shall not extend over 4 inches above ground level. In parking lots, concrete bases shall be 3 feet above ground level for protection.
- Lighting standard mountings shall be of an approved AASHTO breakaway type. Consider non-breakaway mountings in highly developed areas with high pedestrian activity, where there is imminent danger of an impacted support striking a pedestrian, private property, or other traffic. Where sidewalk, curb, and gutter are present, non-breakaway poles shall be used in the installation.
- All poles must be installed a minimum of 4 feet behind the face of the guardrail. Poles to be located behind existing guardrails, rock bluffs, embankments, or ditches are not required to be of the breakaway type. The breakaway poles that are used for street lighting installation must meet AASHTO's breakaway requirements.
- Non-breakaway poles recommended specifically for street lighting installations must be located outside the clear zone. If the right-of-way is limited and sidewalk, curb, and gutter are not provided along highways, then poles equipped with AASHTO-approved breakaway bases must be installed.
- Non-breakaway poles may be used where joint use of utility poles for roadway lighting and electrical distribution is practical and the effectiveness of a satisfactory lighting job would not be jeopardized. Joint use of utility poles is an economical system, which reduces the number of fixed objects along the roadway. Mounting heights less than 45 feet may be approved in order to use existing poles to the fullest extent; however, the effectiveness of a satisfactory lighting job should not be jeopardized just to use existing poles. All installation must meet the minimum requirements set by the National Electrical Safety Code. The design engineer should coordinate with the local utility company to determine the mounting height.
- Offset lighting may be used in a lighting system required to be located 20 feet or greater from the edge of the highway. Offset lighting may be considered if the design parameters cannot be met due to geometric constraints.

- Rapid changes in levels of illumination may be compensated for by using transition lighting or adaptation lighting. When transition lighting is provided, the roadway sector requiring transition lighting should be illuminated so as to allow the motorist's eyes to adjust to a different level of illumination. Equation 1 is a practical formula for calculating the required roadway length for transition lighting.

*Equation 1. Roadway Length for Transition Lighting*

$$L = S \times C \times T$$

Where:

L = length of transition lighting

S = speed along roadway section in miles per hour (mph) (design speed)

C = 1.47 (converts mph to feet per second)

T = 15 seconds (recommended exposure time to allow motorist's eyes to adjust to a different level of illumination)

### 3.3.3 Methodologies

- Luminance is the design criterion for street lighting. The recommended values are defined in **Table 3-6** below. IES 8-21 recommends that illuminance calculations also be performed for the resultant design in order to provide the value that can be used for field validation of the performance. The illuminance design criterion values are shown in **Table 3-7**.

**Table 3-6. Luminance Design Values for Streets**

| Street Classification | Pedestrian Activity Classification | Average Luminance Lavg cd/m$^2$ | Average Uniformity Ratio $L_{avg}/L_{min}$ | Maximum Uniformity Ratio $L_{max}/L_{min}$ | Maximum Veiling Ratio $LV_{max}/L_{avg}$ |
|---|---|---|---|---|---|
| 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 |
| Minor | 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 |

Note: Pedestrian Activity Classifications are defined in Section 3.3.6.1.

**Table 3-7. Illuminance Design Values for Streets**

| Street Classification | Pedestrian Activity Classification | Average Maintained Horizontal Illuminance ($E_h$) Foot-candle (lux) — Pavement Classification: R1 (Ave) | R2 and R3 (Ave) | R4 (Ave) | Uniformity Ratio (Avg/Min.) (max) | Veiling Luminance Ratio $LV_{max}/L_{avg}$ |
|---|---|---|---|---|---|---|
| Major Arterial | High | 1.1 (11) | 1.6 (16) | 1.4 (14) | 3:1 | 0.3 |
| | Medium | 0.8 (8) | 1.2 (12) | 1.0 (10) | 3:1 | 0.3 |
| | Low | 0.6 (6) | 0.8(8) | 0.8 (8) | 3:1 | 0.3 |
| Minor Arterial | High | 0.9 (9) | 1.4 (14) | 1.0 (10) | 4:1 | 0.4 |
| | Medium | 0.8 (8) | 1.0 (10) | 0.9 (9) | 4:1 | 0.4 |
| | Low | 0.5 (5) | 0.7 (7) | 0.7 (7) | 4:1 | 0.4 |
| Collector | High | 0.8 (8) | 1.1 (11) | 0.9 (9) | 4:1 | 0.4 |
| | Medium | 0.6 (6) | 0.8 (8) | 0.8 (8) | 4:1 | 0.4 |
| | Low | 0.4 (4) | 0.6 (6) | 0.5 (5) | 4:1 | 0.4 |
| Local | High | 0.6 (6) | 0.8 (8) | 0.8 (8) | 6:1 | 0.4 |
| | Medium | 0.5 (5) | 0.7 (7) | 0.6(6) | 6:1 | 0.4 |
| | Low | 0.3 (3) | 0.4 (4) | 0.4 (4) | 6.1 | 0.4 |
| Alleys | High | 0.4 (4) | 0.6 (6) | 0.5 (5) | 6:1 | 0.4 |
| | Medium | 0.3 (3) | 0.4 (4) | 0.4 (4) | 6:1 | 0.4 |
| | Low | 0.2 (2) | 0.3 (3) | 0.3 (3) | 6:1 | 0.4 |

The different lighting applications on streets and highways are discussed in the following sections.

### 3.3.4 Intersection Lighting

Lighting at intersections is to alert the driver to an approaching intersection and is justified because it enhances visibility and safety.

- Identification of conflict points at an intersection and placing luminaires on or near these conflict points should be considered.
- Lighting is recommended at signalized intersections if requested by municipality and approved by TDOT.
- Care must be provided to reduce the number of poles at an intersection; a signal pole shaft with a luminaire mast arm or offset luminaire shall be used at these locations if a light pole—existing or proposed—is within a distance of 30 feet or less from the signal poles.
- The level of illumination of a signalized intersection should be dictated by the area classification.
- Crash data and an engineering study shall determine the additional light poles.

The warranting conditions for general intersection lighting are described in **Table 3-8**. The warranting conditions for rural intersection lighting are described in **Table 3-9**.

**Table 3-8. Warranting Conditions for Intersection Lighting**

| Case | Warranting Conditions |
|---|---|
| IL-1 | Where facilities have raised medians. |
| IL-2 | Where major arterials are located in urban areas. |
| IL-3 | Within the fringe of corporate limits which are suburban or rural in character provided they meet the above criteria, and the Local Agency assumes all ownership responsibility, installation, operational and maintenance costs. |
| IL-4 | Where there are high vehicle-to-vehicle interactions (e.g., sections with numerous driveways, significant commercial or residential development, high percentage of trucks). |
| IL-5 | Where the driver is required to pass through a roadway section with complex geometry. |
| IL-6 | Where the night-to-day ratio of crash rates is higher than the statewide average for similar locations, and a study indicates that lighting may be expected to significantly reduce the night crash rate. The number of nighttime crashes also should be evaluated. |
| IL-7 | Where the Local Agency finds sufficient benefit in the forms of convenience, safety, policing, community promotion or public relations; and the local maintaining agency agrees to wholly finance the installation, maintenance and operation of the lighting facilities. |

**Table 3-9. Warranting Conditions for Rural Intersection Lighting**

| Case | Warranting Conditions |
|---|---|
| RIL-1 | There are 2.4 or more crashes per million vehicles in each of three consecutive years. |
| RIL-2 | There are 2.0 or more crashes per million vehicles per year and 4.0 or more crashes per year in each of three consecutive years. |
| RIL-3 | There are 3.0 or more crashes per million vehicles per year and 7.0 or more crashes per year in each of two consecutive years. |
| RIL-4 | The intersection is signalized and there have been, in the past year, 5.0 or more reported nighttime crashes and a day to-night crash ratio of less than 2.0. |
| RIL-5 | Substantial nighttime pedestrian volume exists. |
| RIL-6 | Less than desirable alignment exists on any of the intersection approaches. |
| RIL-7 | The intersection is an unusual type requiring complex turning maneuvers. |
| RIL-8 | Commercial development exists in the vicinity which causes high nighttime traffic peaks. |
| RIL-9 | Distracting illumination exists from adjacent land development. |
| RIL-10 | There exists recurrent fog or industrial smog in the area. |

### 3.3.5 Roundabout Lighting

Per TDOT Traffic Operations Memorandum No. 2202, lighting shall be provided for roundabouts. For a roundabout to operate satisfactorily, a driver must be able to perceive the general layout and operation of the roundabout in time to make the appropriate maneuvers; therefore, adequate lighting shall be provided at all roundabouts.

- The overall illumination of the roundabout should be approximately equal to the sum of the illumination levels of the intersecting roadways.

- Good illumination design should provide adequate lighting levels on all approaches, conflict areas, roundabout exits, pedestrian crossings, bicycle merging areas, and adjacent electrical services.
- Continuity of illumination must be provided between illuminated areas and the roundabout. An unlit roundabout with one or more illuminated approaches is dangerous because a driver approaching on an unlit approach will be attracted to the illuminated areas and may not see the roundabout.
- It is preferable to light the roundabout from the outside in toward the center. This improves visibility of the circulating vehicles to vehicles approaching the roundabout. Ground-level lighting within the central island that shines upward toward objects in the central island can improve their visibility. Care must be given to not increase the ambient light to cause glare for any motorists.

#### 3.3.5.1 Design Criteria

The illuminance values for roundabouts are given in **Table 3-10**.

**Table 3-10. Design Criteria for Roundabout Lighting**

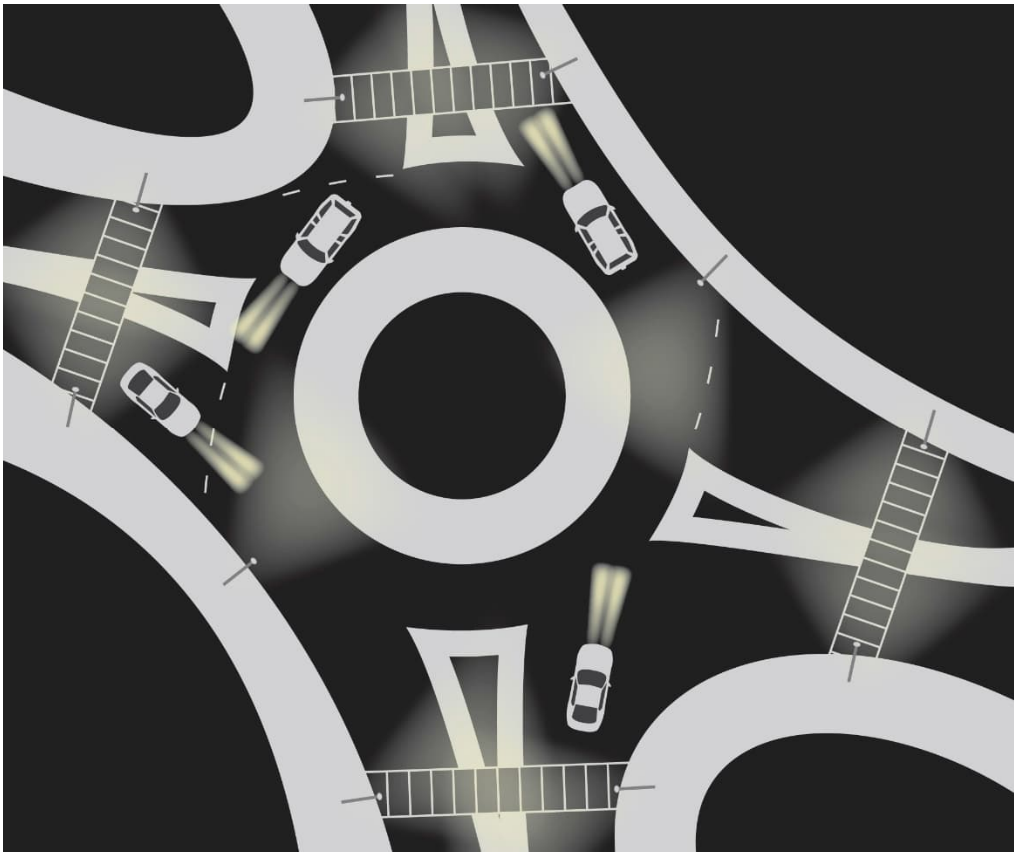
| Functional Classification | Pedestrian Activity Classification | | | Uniformity (avg:min) |
|---|---|---|---|---|
| | High | Medium | Low | |
| Major/Major | 34/3.2 | 26/2.4 | 18/1.7 | 3:1 |
| Major/Collector | 29/2.7 | 22/2.0 | 15/1.4 | 3:1 |
| Major/Local | 26/2.4 | 20/1.9 | 13/1.2 | 3:1 |
| Collector/Collector | 24/2.2 | 18/1.7 | 12/1.1 | 4:1 |
| Collector/Local | 21/2.0 | 16.1.5 | 10/0.9 | 4:1 |
| Local/Local | 18/1.7 | 14/1.3 | 8/0.7 | 6:1 |

Note: Pedestrian Activity Classifications are defined in Section 3.3.6.1.

- Light standards should be located at least 4 feet (6 feet is preferred) away from the front edge of the curb to minimize the chance of the pole being struck by a vehicle.
- Approach lighting should be considered for a minimum of 400 feet in front of the roundabout.
- 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 vertical light falls on vehicles entering the roundabout and on crosswalks when present.

#### 3.3.5.2 Design Examples

**Figure 3-5. Roundabout, Plan View**



### 3.3.6 Pedestrian Facility Lighting

Lighting provided for active modes of transportation depends on the type and features of the facility. Lighting of sidewalks and shoulders should be considered to improve the safety of pedestrians. When pedestrian areas fall within the jurisdictional boundary of a municipality, the governing municipality is responsible for the lighting.

Lighting is recommended at conflict points in pedestrian or bicycle pathways with adjacent electrical service, stairs and access ramps, pedestrian underpasses, and conflict points along pathways with anticipated pedestrian traffic during darkness hours.

#### 3.3.6.1 Design Criteria

The pedestrian categories are as follows: High pedestrian activity: More than 100 pedestrians during the highest nightly average one-hour volume period; Medium pedestrian activity: Between 11 and 99 pedestrians during the highest nightly average one-hour volume period; Low pedestrian activity: 10 or fewer pedestrians during the highest nightly average one-hour volume period. The illuminance design values for sidewalks and walkways are given in **Table 3-11**.

**Table 3-11. Lighting Design Criteria for Pedestrian Facility**

| Street Classification | Pedestrian Activity Classification | Average Maintained Horizontal Illuminance ($E_h$) Foot-candle (lux) — Pavement Classification: R1 (Ave) | R2 and R3 (Ave) | R4 (Ave) | Uniformity Ratio (Avg/Min.) | Veiling Luminance Ratio $LV_{max}/L_{avg}$ |
|---|---|---|---|---|---|---|
| Sidewalks | High | 0.9 (9) | 1.3 (13) | 1.2 (12) | 3:1 | 0.4 |
| | Medium | 0.6 (6) | 0.8 (8) | 0.8 (8) | 4:1 | 0.4 |
| | Low | 0.3 (3) | 0.4 (4) | 0.4 (4) | 6:1 | 0.4 |
| Walkways | All | 1.4 (14) | 2.0 (20) | 1.8 (18) | 3:1 | 0.4 |

- Pedestrian luminaire mounting height is typically 10 to 15 feet. A mounting height of 12 feet is the most common.
- It is recommended to design the spacing with the spacing-to-mounting-height ratio 5:1. The ratio may be modified to meet lighting criteria other critical design issues.
- Pedestrian underpasses are typically lighted with a wall or ceiling mounted luminaire spaced 15 feet to 30 feet on center. Approach lighting (pedestrian light standards, bollards, step lights, or wall-mounted lights) should be considered when the grade drastically changes before the entrance to a pedestrian underpass.
- Pedestrian luminaires adjacent to residential properties should be shielded to minimize light trespass and glare. Maximum values of B1-U1-G1 BUG ratings are recommended.
- The lighting design area of a roadway lighting should include the full width of the sidewalk or the shoulder width when a sidewalk is not present. To illuminate a separate pedestrian facility, separate pedestrian-level light poles may be required following continuous lighting conditions. For a shared-use path on a bridge that does not have roadway lighting, an approved lighting would be recommended.
- Careful attention should be paid to vertical illumination levels. Vertical illuminance is important for identifying approaching pedestrians' intent to enhance the sense of safety.
- When the pedestrian underpass is lighted, the lights should remain on during daytime hours to provide some adaptation from daylight to the darker interior.

### 3.3.6.2 Design Examples

**Figure 3-6. Pedestrian Bridge, Isometric View**

**Figure 3-7. Pedestrian Walkway, Isometric View**

**Figure 3-8. Pedestrian Sidewalk, Isometric View**

### 3.3.7 Crosswalk Lighting

An appropriate lighting design will allow motorists to see pedestrians on the crosswalks. Crossings at intersections should be considered as a part of the intersection to receive adequate lighting. Crosswalk lighting design is required for all mid-block pedestrian crossings. AASHTO recommends a positive contrast (i.e., lighting the approach side of the pedestrian in the crosswalk) where it would be advantageous. Vehicle headlights help increase the contrast, which inherently improves and increases the visibility of pedestrians in the crosswalk. FHWA recommends overhead lighting placed in advance of the crosswalk, illuminating pedestrians from the sides, and not creating overhead shadows on pedestrians crossing the road.

#### 3.3.7.1 Design Criteria

When setting up the crosswalk calculation, the horizontal calculation grid should span the entire crosswalk, plus 5 feet within the walkway/approach, at ground level. The vertical calculation grid should be located 5 feet above finished grade, facing the direction of oncoming traffic. The vertical calculation grid will span all lanes of traffic traveling in a single direction. Refer to the acceptable design criteria values corresponding to the facility type where lighting application is being installed.

#### 3.3.7.2 Design Examples

**Figure 3-9. Crosswalk Isometric View**

**Figure 3-10. Crosswalk Plan View**

### 3.3.8 Bridge Lighting

Bridge lighting should be considered as lighting that is provided on a roadway. It may be desirable to provide fixed source lighting in urban and suburban areas. If there is no lighting on the adjacent roadway, bridge lighting may be omitted, but if the span of the bridge is long such that it calls for lighting, then lighting should be provided irrespective of the adjacent roadway lighting conditions. Refer to the acceptable design criteria values corresponding to the facility type where lighting application is being installed.

It is desirable to install bridge lighting units at abutments or pier locations of bridges to minimize the effects of vibration. All street lighting designs submitted for luminaires to be mounted on bridges must be approved by the TDOT Structures Division.

When TDOT's bridge projects are in the early phase of development, the local agencies should contact the TDOT Structures Division so that proposed changes needed to support future lighting can be incorporated into the designs for new bridges.

#### 3.3.8.1 Guidance on Provision of Bridge Structure Lighting

Use the following guidance as shown in **Table 3-12** to determine whether a bridge structure should have roadway lighting included in the design process:

**Table 3-12. Provision Guidance**

| Proposed Bridge Length | Structural Lighting (714-01) | |
|---|---|---|
| | Urban Area | Rural Area |
| <250 Feet | **Local Agency Request** | **Local Agency Request** |
| 250 Feet to 500 Feet | **Engineering Study Needed** | **Local Agency Request** |
| >500 Feet | **Required** | **Local Agency Request** |

Other bridge structure guidance to follow include:

- New bridges with the inclusion of pedestrian walkways or greenways should have structural lighting.
- Underpass lighting shall be used for bridge structures 60 feet minimum width and 80 feet minimum length. Underpass lighting under existing bridge structures shall have 1-inch RGS conduit unless otherwise approved in writing from the TDOT Traffic Services Manager.

### 3.3.9 Other Roadway Lighting Design Criteria

- Per TDOT Traffic Operations Memorandum No. 2022, all roundabouts and mid-block pedestrian crossing shall include lighting design.
- TDOT only uses steel and aluminum poles. The use of concrete poles shall be approved in writing from the TDOT Traffic Services Manager.
- TDOT standards/specifications shall be used if there is a conflict, perceived or not, between TDOT standards/specifications and local utility standards/specifications.

### 3.3.10 Typical Interchange Lighting Design Process Guidance

- Assuming a diamond interchange layout, begin by assigning eight (8) high mast poles for the interchange (2 per quadrant). Make sure that the high mast poles are located outside the clear zone and not located in wetlands, ditches, and other drainage areas.
- Use offset lights with a maximum spacing of 250 feet to cover the lighting for the acceleration and deceleration lanes (or entrance and exit ramp). Refer to Figure 3-2 in the AASHTO *Roadway Lighting Design Guide*.
- Use the AGi32 software to adjust final position and number of high mast poles including the number of luminaires per ring.
- If a bridge includes structural lighting, then use the light poles on the bridge instead of using high mast poles for the lighting design.
- Follow additional guidance specified in the TDOT Roadway Lighting Standard Drawings.

### 3.3.11 Underpass Lighting

Because of their typical configuration and length-to-height ratio, underpasses generally have good daylight penetration and do not require supplemental daytime lighting. When the length-to-height ratio of the underpass exceeds approximately 10:1, it usually is necessary to analyze specific geometry and roadway conditions, including vehicular and pedestrian activity, to determine the need for supplemental daytime lighting. TDOT recommends analyzing the need to provide underpass lighting on all highways that are continuously lighted.

#### 3.3.11.1 Design Examples

**Figure 3-11. Highway Underpass, Isometric View**

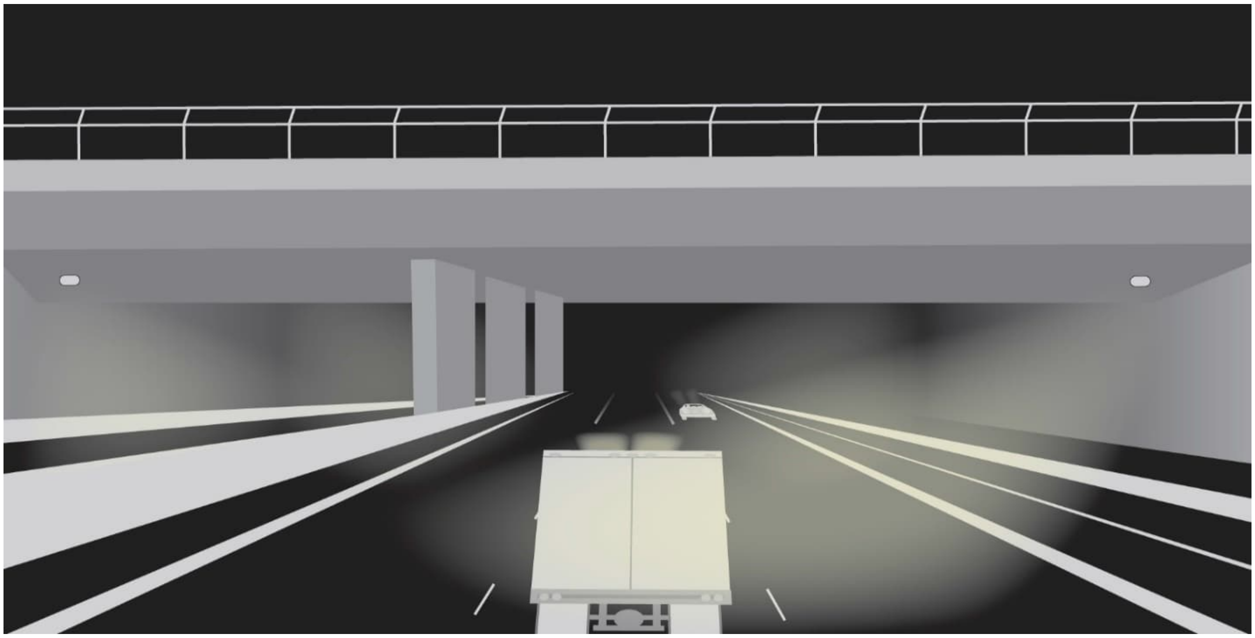
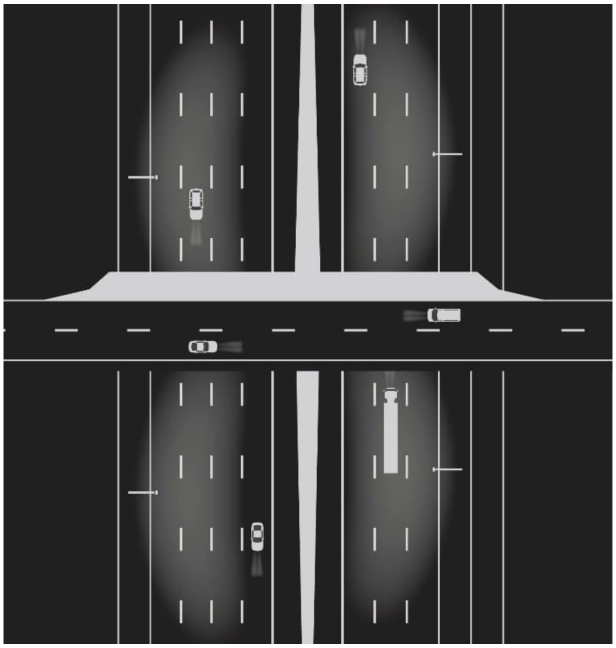


**Figure 3-12. Highway Underpass, Plan View**



### 3.3.12 Tunnels

A tunnel is defined as a structure over a roadway that restricts the normal daytime illumination of a roadway section such that the driver's visibility is substantially diminished. Daytime tunnel lighting is justified when driver visibility requirements are not satisfied without the use of a lighting system to supplement natural sunlight.

Visibility requirements vary considerably with portal-to-portal tunnel length; tunnel portal design; geometry of the tunnel; vehicular and pedestrian traffic characteristics; treatment of pavement, portal, interior, and environmental reflective surfaces; climate and orientation of the tunnel; and visibility objectives to provide for safe and efficient tunnel operation.

Tunnel structures greater than 80 feet in length reduce motorists' ability to adapt to lower light levels during the daytime within the structure. For this reason, daytime and nighttime lighting should be considered for any tunnel greater than 80 feet in length. Daytime and nighttime lighting is required for any tunnel greater than 410 feet in length.

Refer to ANSI/IES RP-8-21, Chapter 14: Tunnel Lighting (IES 2021), for information on how to design the lighting system for tunnels greater than 80 feet in length.

Tunnel lighting system upgrade is to be confirmed by the TDOT Project Manager. Recommendations for existing lighting system upgrades include the following:

- Minor upgrades do not need to follow these guidelines.
- Major upgrades may need to follow these guidelines.
- Replacement of existing lighting systems should follow these guidelines.

#### 3.3.12.1 Design Criteria

Tunnels have both daytime and nighttime lighting criteria; refer to ANSI/IES RP-8-22, Chapter 14: Tunnel Lighting, for complete design criteria. Apply the Lseq method to determine the appropriate pavement luminance. Refer to the acceptable design criteria values corresponding to the facility type where lighting application is being installed.

Factors influencing lighting design criteria include the following:

- Bidirectional (undivided) or divided tunnel traffic direction.
- AASHTO stopping sight distance varies by speed and roadway grade.
- Threshold zone lighting criteria depend on the tunnel portal solar orientation and surrounding geometry, tunnel length, traffic volume, wall reflectance, daylight penetration, and visibility of the portal.
- The ratio between the average illuminances of the pavement and wall should not exceed 2.5:1.
- The luminaire shall be tested per, and meet, the following requirements shown in **Table 3-13**.
- Refer to National Fire Protection Association (NFPA) 502 for emergency lighting considerations.

**Table 3-13. Tunnel Luminaire Requirements**

| | |
|---|---|
| Correlated color temperature (CCT) | 4,000 K within the tunnel |
| Salt spray test per ASTM B117 | 1,000 hours, minimum |
| Vibration rating per ANSI C136.31 | 3G |
| IP rating per IEC 60598 | IP66 |
| Ambient operation temperature | -40°C to +40°C |
| Photometric testing | IES LM-79 and IES LM-80 |

Notes: °C = degree(s) Celsius
IP = ingress protection

The tunnel preliminary design documents should include an evaluation of the existing conditions of the tunnel elements associated with the tunnel systems (luminaires, conduit, electrical wiring, lighting control system, etc.).

Onsite tunnel measurements should be taken per IES LM-71-14 (IES 2015), *Photometric Measurement of Tunnel Lighting Installations*.

Tunnel Maintenance and Operations should be consulted about the following:

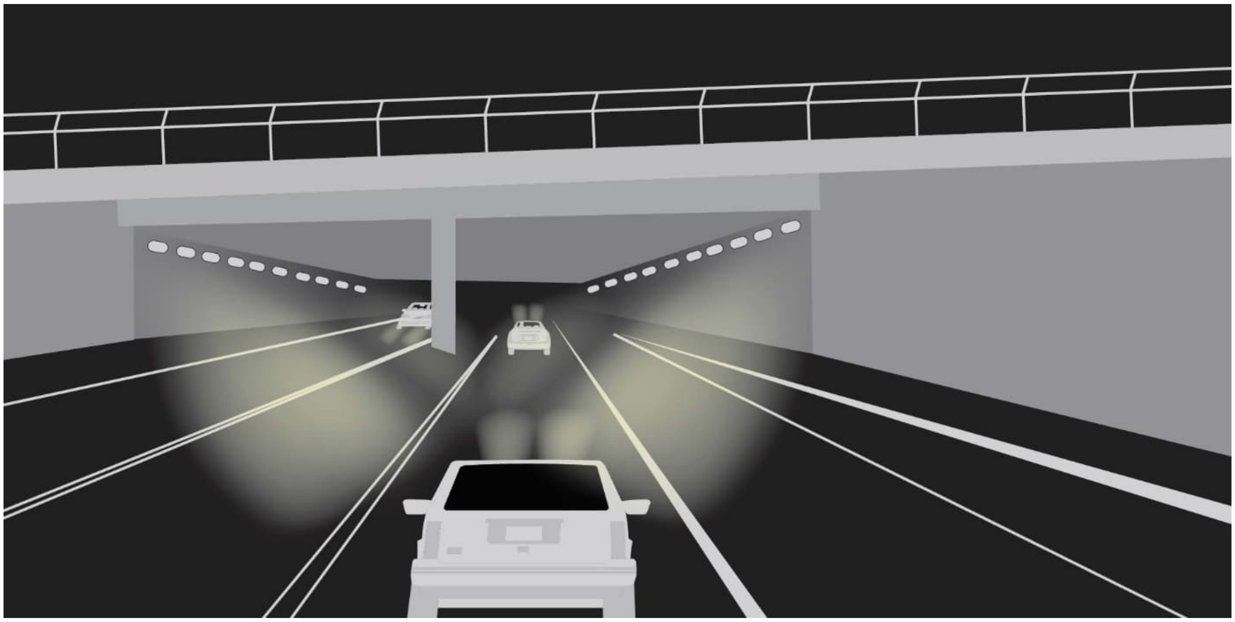
- The tunnel cleaning schedule
- The existing lighting system utility costs
- Desires for adding assets to the inventory

Avoid flicker and luminaire frequency between the range of 4 hertz (Hz) to 11 Hz per the frequency analysis based on the luminaire spacing and design speed.

The tunnel pavement and wall lighting levels should be calculated using AGi32. Refer to the *FHWA Lighting Handbook* for additional information on tunnel lighting systems.

#### 3.3.12.2 Design Examples

**Figure 3-13. Tunnel, Isometric View**



## 3.4 Other Lighting Applications

The following categories are areas where TDOT may install lighting on a limited and case-by-case basis.

### 3.4.1 Rest Areas

For lighting at rest areas, there is typically no involvement by TDOT in the design (unless requested by the responsible state agency), installation, or maintenance. The following general guidelines are noted:

- Lighting is typically provided at rest areas that offer complete rest facilities (e.g., comfort station, information kiosk, picnic areas).
- Illuminate all areas within the facility that have pedestrian activities (e.g., parking areas, immediate area of building).
- Provide lighting at rest area ramps, gore areas, and other decision points.
- Light areas of high nighttime use to improve users' sense of security.
- Not lighting an area can deter nighttime use in areas where pedestrians are not encouraged to use the space at night.

#### 3.4.1.1 Design Criteria

The average illuminance values for lighting rest areas are given in **Table 3-14**.

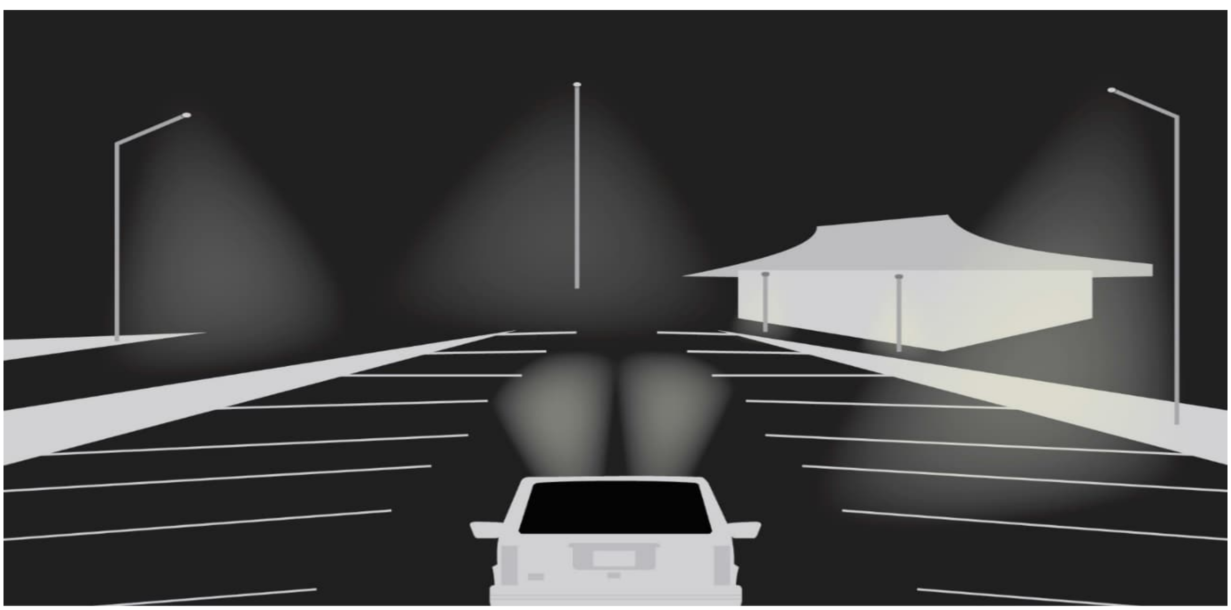
**Table 3-14. Design Criteria for Rest Areas**

| Roadway Classification | Pedestrian Activity Classification | Average Maintained Horizontal Illuminance ($E_h$) Foot-candle (lux) | | Uniformity Ratio (Avg/Min.) | Veiling Luminance Ratio $LV_{max}/L_{avg}$ |
|---|---|---|---|---|---|
| | | Pavement Classification | | | |
| | | R1 (Ave) | R2 and R3 (Ave) | | |
| Ramp Gores and Interior Roadways | All | 0.4 (4) | 0.6 (6) | 3:1 to 4:1 | 0.4 |
| Parking and major Activity Areas | All | 0.8 (8) | 1.1 (11) | 3:1 to 4:1 | 0.4 |
| Minor Activity Areas | All | 0.4 (4) | 0.5 (5) | 6:1 | 0.4 |

- Mounting height is typically 25 to 30 feet for roadways, 20 to 25 feet for parking lots, and 10 to 15 feet for pedestrian areas. The common mounting height for pedestrian poles is 12 feet.
- The recommended spacing is 5:1 spacing-to-mounting-height ratio. Modify accordingly to meet lighting criteria and other critical design issues.
- If the rest area is adjacent to the main roadway, the roadway should be adequately lighted to minimize excessive contrast and veiling luminance (glare) from the rest area.

### 3.4.1.2 Design Examples

**Figure 3-14. Rest Area, Isometric View**



### 3.4.2 Temporary Roadway Lighting

Temporary roadway lighting is intended to match or exceed existing lighting levels when existing lighting is removed due to construction. It should be considered at the start and end of traffic detour routes.

#### 3.4.2.1 Design Criteria

When the existing lighting level is unknown, the light level should be selected from the appropriate lighting application listed in the previous section; the existing roadway classification should be used to select the lighting criteria. Refer to **Table 3-15** for the design criteria for lighting a temporary roadway.

**Table 3-15. Design Criteria for Temporary Roadway Lighting**

| Location | Luminance (cd/m$^2$) | Illuminance (fc) |
|---|---|---|
| Roadway | Equal to or greater than preconstruction light levels | Equal to or greater than preconstruction light levels |
| Vertical (Facing Shoulder) | Equal to or greater than preconstruction light levels | Equal to or greater than preconstruction light levels |

- At a minimum, the roadway should be lighted to existing design levels when temporary lighting is applied.
- Temporary lighting can be installed as a one-for-one replacement of existing luminaires.
- Temporary lighting should be considered at the following areas if there is adjacent electrical service: emergency pull-off areas, lane shifts, roadway merge and diverge points, intersections, and crosswalks.
- The selected temporary luminaire should imitate the existing luminaire lumen output and distribution to appropriately light the roadway.
- Removed luminaires may be reset on temporary light standards to provide temporary lighting.
- Temporary lighting may be cobra heads mounted to wooden utility poles or barrier-mounted metal poles.
- Power may be supplied by overhead electrical when a nonbreakaway pole is installed.
- 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 must meet all the breakaway requirements that permanent lighting must meet. Nonbreakaway poles should be protected by barrier or installed on a barrier.
- When traffic speeds are less than 40 mph, temporary lighting may be installed a minimum of 6 feet behind the front face of the curb.

### 3.4.3 Temporary Construction Lighting

The MUTCD states that any nighttime work shall require lighting of the work area, equipment crossing, and flagger stations. The current edition of the MUTCD must be consulted to determine the appropriate lighting levels for general illumination and precision tasks in the temporary traffic control zone, along the approach to the temporary traffic control zone, and at flagger stations. The existing roadway classification should be used to select the lighting criteria.

- Temporary streetlights may provide additional light within the work zone but shall not be used to meet the minimum requirements for traffic control lighting.
- 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.
- Construction lights should be aimed at an angle of 45° or less to minimize glare to the motorists, which improves construction worker safety.
- Luminaires should be aimed in the direction of travel to minimize glare to motorists to improve visibility of roadway workers and flaggers.

### 3.4.4 Weigh Stations

- For lighting at weigh stations, there is typically no involvement by TDOT in the design, installation, or maintenance. Refer to **Table 3-14** for appropriate illuminance and luminance design values under Chapter 4 for lighting design calculations.
- Lighting is typically provided at all permanent truck weigh stations where weighing occurs after daylight hours. Illuminate the weighing area, parking area, speed change lanes, ramps, and gore areas.

### 3.4.5 Navigation and Obstruction Lighting

- Highway structures over navigable waterways require waterway obstruction warning luminaires in accordance with U.S. Coast Guard requirements. The TDOT Structures Office will coordinate with the Coast Guard.
- Any need for aviation obstruction warning luminaires on highway structures will be coordinated with the Federal Aviation Administration (FAA) by the Traffic Design Office. For information on navigable airspace obstructions, consult the FAA Advisory Circular AC 70/7460-2J, Proposed Construction or Alteration of Objects that May Affect the Navigable Airspace.

### 3.4.6 Decorative Lighting

There is a growing desire for decorative scaled lighting on state roadways and bridges. Decorative street lighting that replaces an existing conventional street lighting installation must provide uniform illumination along the state’s highways. The existing roadway classification should be used to select the lighting criteria.

- Decorative lighting using higher-wattage luminaires on shorter poles and with shorter spacing could contribute to disability glare. Special attention should be paid when using higher-wattage luminaires, shorter poles, or shorter spacing.

At the request of a Local Agency, decorative lighting may be permitted by TDOT on a state facility if TDOT's minimum requirements are met. TDOT will install and may fully fund new decorative lighting if the Local Agency agrees to maintain them after construction. All requests for special or decorative lighting shall be reviewed and approved by the TDOT Traffic Services Manager before design begins.

# CHAPTER 4

# LIGHTING DESIGN

## 4.1 Design Methodologies

This section describes two design methodologies: illuminance and luminance. AASHTO strongly recommends the illuminance or luminance design methods in its latest design guidelines. TDOT requires that the illuminance design methodology be applied for all TDOT projects. However, due to the complexity and repetitive nature of the calculations to obtain the optimum design, TDOT requires that computerized design techniques be used.

### 4.1.1 Illuminance Methodology

The illuminance methodology is used to determine the combined amount of light reaching critical pavement locations from contributing luminaires (i.e., a measure of light quantity). This methodology also assesses how uniformly the luminaires' combined luminous flux is horizontally distributed over the pavement surface (i.e., a measure of light quality). An inherent disadvantage of the illuminance methodology is that it accounts for only incident light and does not assess the effect on visibility due to reflected light from an object or surface. This sensation is known as "brightness." Components of illuminance design include the average maintained horizontal illumination ($E_h$), or quantity of light, and the uniformity ratio ($E_h/E_{min}$), or quality of light, maximum veiling luminance ($LV_{max}$), and veiling luminance ratio ($LV_{max}/L_{avg}$).

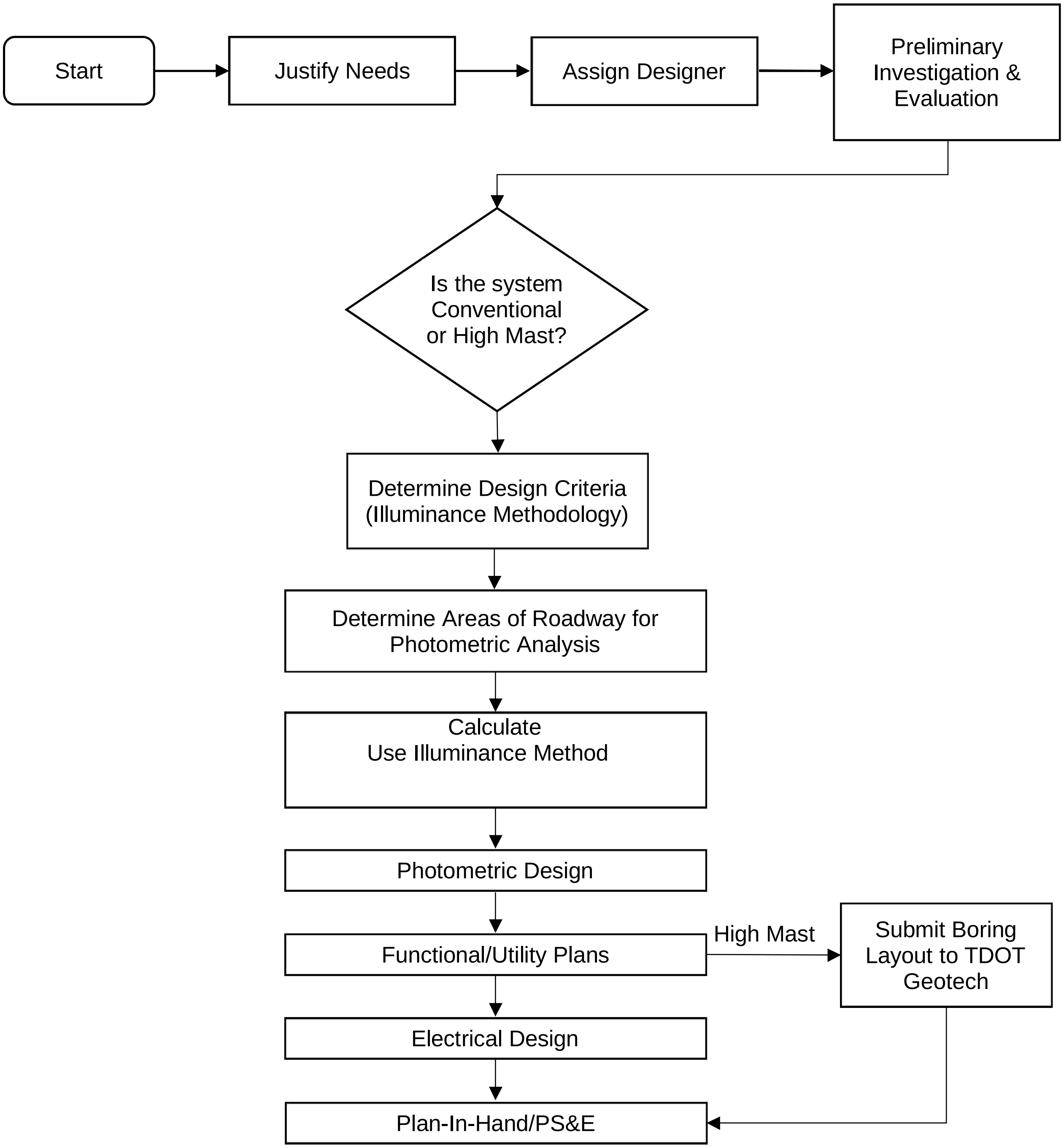
### 4.1.2 Luminance Methodology

The luminance methodology is used to simulate driver visibility by assessing the quantity and quality of light reflected by the pavement surface to the motorist's eye from contributing luminaires. In theory, luminance is a good measure of visibility. However, the results of using the luminance methodology in highway lighting applications are greatly affected by one's ability to accurately estimate the reflectance characteristics of the pavement surface, both now and in the future. As such, a computer program is required in TDOT lighting designs to aid and provide consistency in some of these estimations. Factors affecting pavement reflectivity include initial surface type, pavement deterioration, resurfacing material type, assumptions regarding weather conditions, and so on. It is difficult to predict or control such factors. Compared with illuminance, the luminance methodology is considerably more complicated to understand and use. Components of luminance design include average maintained luminance ($L_{avg}$), minimum luminance ($L_{min}$), maximum luminance ($L_{max}$), maximum veiling luminance ($LV_{max}$), and ratios of $L_{avg}$ to $L_{min}$, $L_{max}$ to $L_{min}$, and veiling luminance ratio ($LV_{max}$ to $L_{avg}$).

## 4.2 Design Process

This section discusses the design process of the illumination system that TDOT applies to its projects. Refer to **Figure 4-1** for details.

**Figure 4-1. Lighting Design Process Flow Chart**




## 4.3 Design Considerations

Based on the *FHWA Lighting Handbook*, the following design considerations should be evaluated as well:

- **Availability of Power:** Availability of electrical power is essential in providing the roadway lighting. The lighting designer should obtain the following information from the utility provider/maintaining agency:
    - o Determine the specific light fixtures recommended for use;

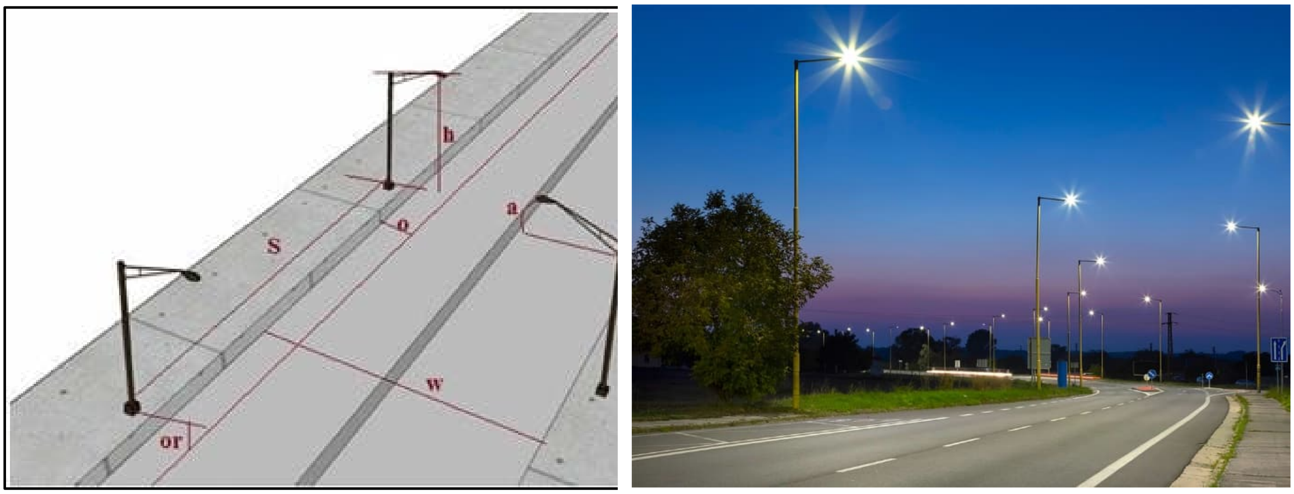
  - Determine the service voltage available by contacting the local utility;
  - Determine the local specifications for wire size used;
  - Determine the maximum allowable circuit breaker size;
  - Determine acceptable locations for proposed control centers and service points by submitting the proposed control center proposed layout sheets to the local utility to confirm these locations;
  - Determine any special mounting height requirements.
- **Proximity to Aircraft Landing Facilities:** Installation of the illumination systems near aircraft landing facilities could impose potential hazards to air traffic operations. Aircraft landing facilities should be contacted and consulted in advance regarding the specific requirements and/or limitations such as pole height and/or optical luminaire.
- **Proximity to Railroads:** Installation of the illumination systems near railroads could impose potential hazards to rail traffic operations. Railroad facilities should be contacted and consulted in advance regarding the specific requirements and/or limitations such as track clearance.
- **Presence of Overhead Distribution and Transmission Lines:** Installation of the illumination systems where overhead distribution and transmission lines exist could impose potential hazards to electricity distribution and transmission. Utility providers should be contacted and consulted in advance regarding the requirements and/or vertical limitations such as utility clearance distance from high-voltage transmission lines.
- **Environmental Issues:** Built environment is a unique factor when providing illumination systems. Local context should be taken into consideration, especially local ordinances, local requirements, and community concerns.
- **Maintenance and Operations Considerations:** TDOT does not maintain roadway lights. However, maintenance and operations considerations should be incorporated into the design process. It is important that the specified products selected in the design phase be maintained in a cost-benefit budget over the project life.
- **Roadside Safety Considerations:** Installation of the illumination systems near railroads could impose potential hazards to both the vehicular traffic and nonvehicular traffic. Guidelines in the AASHTO *Roadside Design Guide* should be followed when addressing such issues.
- **Historical Safety Performance:** Historical crash data, if available, should be reviewed to identify problematic crash locations before starting the design process of the illumination system.

## 4.4 Design Configurations

### 4.4.1 Staggered Configurations

Historically, staggered configurations have been used for the illumination systems design (**Figure 4-2**). Because the arrangement of the light standards increases neutral contrast occurrences, the visibility of the objects in the roadway decreases significantly compared with the other two configurations (opposite configuration and median mounted configuration).

**Figure 4-2. Staggered Configurations**

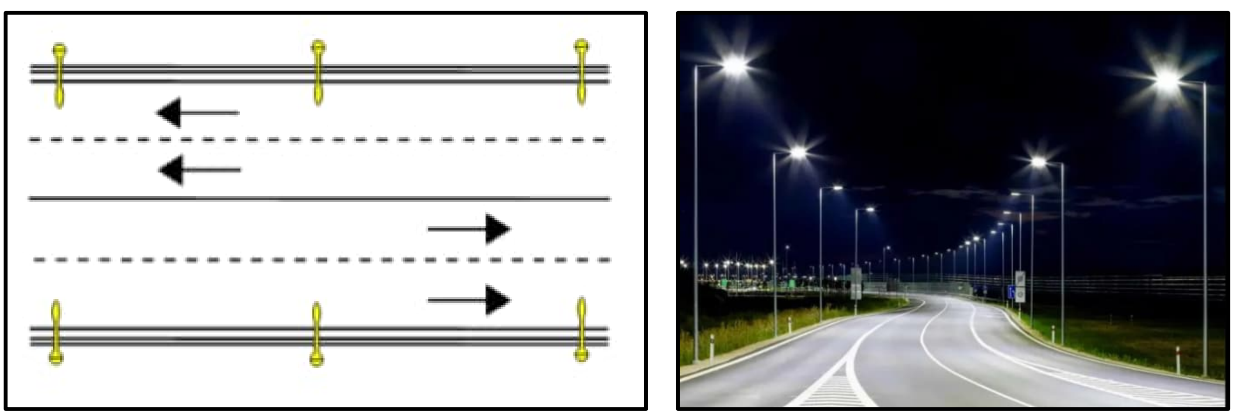



### 4.4.2 Opposite Configurations

In the opposite design configurations, pairs of luminaires are located on the opposite sides of the roadway (**Figure 4-3**). Single luminaire located on one side of the roadway is accepted for a narrow roadway, typically two lanes wide, if the design criteria are met.

Compared with median-mounted configurations, opposite design configurations have the capabilities of providing the best visibility of the objects on the roadway.

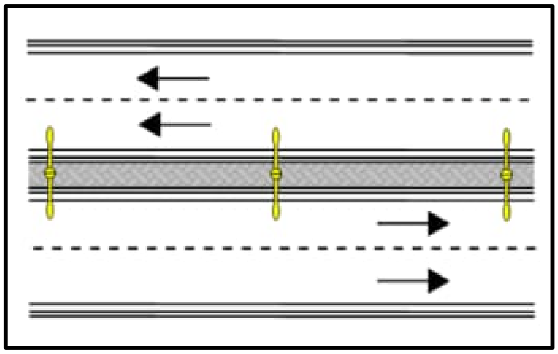
**Figure 4-3. Opposite Configurations (Two Sides)**

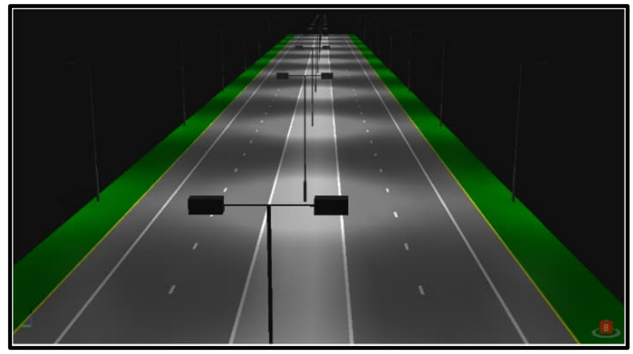


### 4.4.3 Median-mounted Configurations

In the median-mounted configurations, single luminaire is located in the median of the roadway (**Figure 4-4**). Ideally, such configurations protect the mounted standards with either a barrier or a raised median. Compared with opposite design configurations, median-mounted configurations reduce the initial costs by eliminating mounted standards, minimizing electrical conduits, and reducing the power supply. However, they reduce the amount of the visibility and increase the potential of light trespass. They also increase maintenance difficulty and cause potential hazards such as glare and light levels.

**Figure 4-4. Median-mounted Configurations**





## 4.5 Photometric Analysis

The approved software for roadway lighting photometric analyses is AGi32. Other photometric analysis requirements include the following:

- Background, sheets, and sketches for the project shall include stations and offsets, names of interstate roads, state routes, and intersections. The CAD file of the project can be imported with these fixtures into AGi32 for photometric analysis.
- No yellow colors shall be used in the sketch of the site. Two templates shall be prepared: one for the minimum foot-candle (fc) and one for the maximum (fc) with the recommended colors black and red, respectively.
- BUG ratings are the new measures that have replaced veiling. Using a BUG scale, the best values are 0,0,0 and the worst are 5,5,5. TDOT recommends a maximum BUG value of 3,3,3. The recommended maximum BUG value produces moderately high ambient lighting.
- CCT shall be as follows:
  - Interstate systems including interchanges and associated ramps: 4,000 K
  - State routes (especially those near residential areas) and local roadways: 3,000 K
- The LLF for LED shall be the manufacturer’s recommendations; however, the LLF shall not be less than 0.8 in AGi32. If the manufacturer provides luminaire parameters, the LED LLF can be calculated using the following formula:

  LLF = LDD × LLD

  Where:

  LDD = luminaire dirt depreciation

  LLD = lamp lumen depreciation

LED lumen depreciation is expected to be around 30 percent of light output, and the expected cleaning schedule for the luminaire is usually every 5 to 10 years based on FHWA street and roadway lighting design (**Table 4-1**).

**Table 4-1. LED Light Loss Factors**

| Light Source | LDD | LLD | LLF |
|---|---|---|---|
| LED | 0.9 | 0.9[a] | 0.81 |

Note: [a] 0.9 or manufacturer value at 60,000 hours if $L_{70}$ is greater than 100,000 hours

- Because LED consumes less than 50 percent of energy compared with high-intensity discharge, luminaire wattage values shall reflect this.
- High mast mounting height shall not be less than 80 feet and not more than 180 feet. TDOT recommends a range of 100 feet to 150 feet for most locations. Luminaires per ring for the high-mast structure shall be even numbers such as 4, 6, 8, and 12. Shields shall be used if residential areas and businesses are near the high-mast pole locations. Unhindered access shall be provided for maintenance purposes when determining a high-mast location. High-mast poles can be moved 15 feet in longitudinal direction following the roadway, but not closer to or farther from the roadway.
- The maximum spacing for light poles is set using AGi32. The recommendation for maximum offset and mast arm pole spacing is 250 feet.
- Type C pull boxes shall be used for all roadway lighting where spacing exceeds 250 feet, unless there is a sharp bend or jack and bore location involving existing roads and business entrances.
- Regular trenching having a depth of 24 inches shall be used for all locations outside existing roads and business entrances. However, a trenching depth of 36 inches shall be used if the directional boring location is under an interstate or interstate ramps.
- Statistical calculations shall include both inside and outside shoulders.
- Statistics shall include the minimum, average, and uniformity (the average divided by the minimum) values which should meet the design criteria for each facility type.

AASHTO determined the minimum luminaire foot-candle of 0.2, average foot-candle, and uniformity ratio values shall be taken from the design criteria values from the respective road classifications. Under no circumstances can these three values (minimum, average, uniformity ratio) be taken individually. TDOT uses only the illuminance method. Any other method shall be approved by the TDOT Traffic Services Section Manager.

## 4.6 Offset Lighting

The following guidance shall be used for offset lighting:

- Offset lighting shall be used for interstate systems and for locations where enough right-of-way is available. The minimum setback is 20 feet from the travel lane, but under no circumstances can the setback exceed 25 feet unless approved by the TDOT Traffic Services Section Manager. If the offset lighting pole is within the clear zone, breakaway supports shall be used.
- Offset lighting pole mounting heights shall be 40 feet to 55 feet unless placed on a median barrier or retaining wall. Detailed information on luminaire mounting height has been provided in Chapter 5.

- Offset lighting cannot be used to light a multiuse path or greenway. For these situations, a typical street light pole of less than 40 feet with mast arms shall be used unless decorative street light poles are requested by the local agency.

## 4.7 Roadway Pavement Classification Types

**R1 (Concrete):** Pavement surface material made of Portland cement concrete with a minimum of 15 percent of the aggregate composed of artificial brightener aggregates.

**R2 (Asphalt):** Asphalt composed of diffuse and reflectance surface characteristics with minimum of 60 percent aggregate and 10 to 15 percent artificial brightener aggregate. Not commonly installed in the United States.

**R3 (Asphalt):** Asphalt surface having slight specular reflectance and dark aggregate, with a rough texture. Commonly used in the United States.

**R4 (Asphalt):** Asphalt surface having a mostly specular surface with a smooth asphalt texture.

**Table 4-2. Pavement Classifications**

| Class | $Q_o$* | Mode of Reflectance |
|---|---|---|
| **R1** | 0.10 | Mostly diffuse |
| **R2** | 0.07 | Mixed (diffuse and specular) |
| **R3** | 0.07 | Slightly specular |
| **R4** | 0.08 | Mostly specular |

*$Q_0$ = Representative mean luminance coefficient. Because the R tables also provides considerations for the pavement's reflectance, it is recommended not to make any adjustments to the Qo values given for computer design calculations.

## 4.8 General Procedure for Lighting Calculation using AGi32

Illuminance calculation can be used to determine the effectiveness of roadway lighting design. TDOT requires photometric analysis for all of its roadway lighting projects. The following steps provide a general process of performing photometric analysis.

**Identify Design Parameters**: Based on the project specification, determine the curb-to-curb width of the corridor, the number of lanes in each direction, the presence of sidewalk, the right-of-way limit, and the luminaire setback.

**Identify Roadway Classification**: Assess the functionality of the roadway to determine the roadway classification: freeway, arterial, collector, or local road. Identify the level of conflict by vulnerable road users like pedestrian and bikers. For intersection analysis, consider the classification of the intersection roadways.

**Determine the Illumination Design Criteria**: Select the appropriate lighting design criteria value for the illumination analysis based on the roadway classification. For street and highway with anticipated pedestrian activity, corresponding average uniformity ratio values should be taken from **Table 3-11** on design criteria for lighting pedestrian facilities.

**Setting up AGi32**: The TDOT-recommended software for lighting analysis is AGi32. Under “System Settings,” ensure the display unit is in “feet.” Also, luminaire symbol, system font, model background, dimension precision, and initial curve increment (degree) can be modified.

**Preparing a CAD File**: A CAD base file for export into AGi32 should be created. Data in the CAD file should include, at minimum, roadway and shoulder edges, pavement markings, right-of-way, drainage features, structural features (bridge), and potential obstructions. Clean the master file and export as DWG or DXF file.

**Importing a CAD File:** While importing the base file, ensure the unit of the CAD file is in feet. Deselect layers not needed before importing and use the advance option tab to set the appropriate curve increment.

**Define Luminaires**: Determine the appropriate luminaire based on the lumen output, CCT, and the recommended BUG rating. Using the define luminaire dialog, the “smart symbol” can be used to set the appropriate luminaire from the manufacturer list, or the IES file from the manufacturer’s website can be imported to AGi32. Other features to set include luminaire arrangement, LLF, pole length, luminaire symbols, and arm length.

**Calculation Areas**: Place the calculation point grid on the corridor including bike lane and shoulder width. The appropriate pavement surface type should be selected. Ensure that IES RP-8-14 or the latest version is selected for the analysis. The selected metric summary should include average, minimum, and uniformity ratio.

**Placing of Luminaires:** To achieve appropriate spacing of luminaires, multiple placement iterations should be considered. Arrangement may include opposite, median, and staggered configuration. TDOT mounting height range should also be considered while selecting the mounting height. Set the luminaire template using isolines. TDOT guidelines should be followed while creating the luminaire template. Ideal arrangement will have the minimum foot-candle (fc) from adjacent luminaires crossing at the outer edges of the calculation areas.

**Running Calculations:** Calculations can be run using direct only method or full radiosity method. For exterior site lighting, flood lighting, and road lighting, direct only method should be used. Direct only method does not consider interreflections. Full radiosity method should be used for underpass or tunnel analysis. If necessary, luminaire spacing and/or lumen output and distribution could be adjusted through iterations until the values meet the desired criteria.

**Printing Results**: After meeting required criteria with the developed layout, the project layout with calculation summary should be printed. Luminaire pole stations and offset should be included in the layout before printing the design layout.

# CHAPTER 5

# LIGHTING PLAN AND DESIGN LAYOUT

## 5.1 Plan Preparation

Photometric, Line and Grade, Functional/Utility Only, Plan-In-Hand (PIH), and Plans, Specifications, and Estimates (PS&E) plans shall be prepared for all roadway lighting designs. Lighting plans are most often prepared in support of a larger roadway project. It is desirable to have the location of light poles included in the roadway functional/utility plans submittal. The lighting designer shall coordinate efforts with the primary roadway designer. The designers shall work together for project scheduling, sheet numbering, and review submittals and shall exchange roadway geometric updates throughout all stages of the lighting plans design. All sheets prepared by the lighting designer shall be signed and sealed exclusively by the lighting designer. The following includes sheets that constitute a complete roadway lighting plan for stand-alone lighting projects and are listed in the order that they should appear in the plans:

- Title Sheet: This sheet shall include a reduced-scale layout of the overall project showing locations of sensitive areas including environmental (streams and wetlands), residential, military and airport facilities.
- Estimated Roadway Quantities, Notes and Standard Drawings: For lighting projects prepared in conjunction with a roadway project, the tabulation of quantities, notes and footnotes to quantities, and the listing of standard drawings shall be included on this sheet. This sheet shall be submitted for inclusion with the roadway plan as a second sheet. For stand-alone lighting projects, the standard drawings, tabulated quantities, and notes shall be prepared on these sheets.
- Special Notes: Special notes for standard lighting designs may be included on the general notes sheet. Special notes for high-mast lighting shall be included on a separate sheet in the second sheet series.
- Control Center Details: This sheet shall include details for the wiring schematic, notes, and control center main breaker and branch circuits' breakers.
- Lighting Details: This mandatory sheet shall include a separate table for the light pole schedule and wire/conduit schedule. The light pole schedule shall include the pole location, mounting height, number and fixture type with wattage, control center number, and circuit number. The wire/conduit schedule shall include the quantity and size of each cable running through each conduit. Spare conduit shall also be included in this table when requested.
- Special Lighting Details: This sheet shall include details of special fixtures or other nonstandard TDOT items clearly identified and detailed.
- Present Lighting Layout Sheets: For large projects, lighting layout sheets shall be included. These sheets shall show coverage of the entire project with each proposed lighting layout sheet and the corresponding sheet number identified.

- Proposed Lighting Layout Sheets: These sheets should be developed as follows:
  - The plans should be designed for 1 inch = 50 feet scale for straight and curved roadway lengths and 1 inch = 100 feet scale for interchanges.
  - A separate plan sheet with tables that include, but are not limited to, the pole mounting height, luminaire type and wattage, conduits, and circuitry shall be provided.
  - The location of lighting standards in relation to the proposed roadway should be provided. Each standard shall be flagged to note the pole number, station, coordinates, and offset.
  - All conduits and wiring shall be shown and labeled per the wire/conduit schedule. Special conduit for directional boring and stream crossings, under road rigid conduit and otherwise, shall be clearly identified.
  - All control centers shall be located and numbered, and the power source location shall be identified. A separate plan sheet detailing the control center and its circuitry, wire/conductor size, and the electric feed point shall be provided.
  - North arrow, legend, and road names shall be on all layout sheets.
- Underpass Lighting Details: This sheet shall be created at a larger scale to clearly depict the underpass lighting system. The detail shall label the underpass fixture and number, conduit and junction boxes in bridge parapet, and the service connection. **Refer to Appendix A** – **Figure A-3** for under-bridge lighting details.
- Bridge Layout Sheets: It shall be the responsibility of the structural designer to include the lighting information provided by the lighting designer in the bridge layout sheets (i.e., Item 714-01, Structural Lighting – foundation of the proposed light poles by station on the bridge parapets, conduits, and junction boxes). The lighting designer shall provide the lighting design information to the TDOT Structures Division as depicted in **Appendix A** – **Figure A-2** and **Figure A-4**.
- Bore Locations and Geotechnical Notes and Bore Log Details: For lighting designs that include high-mast lighting, a bore location and geotechnical notes sheet and a bore log details sheet shall be included in the lighting plans. The bore location and geotechnical notes sheet shall depict the bore locations and numbers, geotechnical notes, and parameters used for the design of the high-mast pole foundation. The bore log details sheet shall show information obtained from each bore log, and includes, but is not limited to, bore depth, sample number, blow counts, N-value, soil description, SPT N-value, water levels, and any other information pertinent to the design of the high-mast pole foundation.
- High-mast Foundation Details: Per Standard Drawing T-L-1, this is the contractor’s responsibility and part of the construction process.

## 5.2 Photometric / Line & Grade Plan Preparation

The designer shall prepare all components necessary for photometric plan submittal. The designer shall submit to the TDOT Traffic Services Manager the plan sheets showing the overall project. Ensure that the photometric/line and grade plans include the following details:

- Stationing at appropriate intervals and stationing of noses and tangent points of ramps that are formed by the roadway proper and not by the shoulder
- Pavement, shoulder, and median widths at frequent intervals
- All roadway features that may affect the stationing or setback of poles (e.g., guardrail, barrier median, barrier curb, large signs, driveways, culverts, railroads, and pipelines)
- The approximate height of any utility lines over the roadway
- The location of power poles from which service may be obtained
- If signals are present or proposed, the location of the signal pole, power pole, and control cabinet
- Point-by-point photometric values shown on an AGI32 file, which shall be clearly legible for the reviewer
    - For conventional lighting, the point-by-point grid size should be a maximum of half the distance of the lane width by 10 to 20 feet along the roadway length (e.g., for a 12-foot lane, the grid size should be 6 feet by 10 feet).
    - For high-mast lighting, the point-by-point grid size should be a maximum of the lane width by 20 feet along the roadway length (e.g., for a 12-foot lane, the grid size should be 12 feet by 20 feet).
- The photometric/preliminary plans shall be designed to TDOT *Survey & Roadway Design Computer-Aided Drafting & Design Standards*. Section 5.4 describes additional drafting standards.
- Plan preparation checklists are listed in Section 5.7.1.
- Plans and work file submittals are discussed in Section 5.6.

## 5.3 Photometric/Line and Grade Plan Review

Upon receipt of the photometric/line and grade plans, the TDOT Traffic Services Manager shall verify the location of poles and luminaires. This will include cross-referencing results from the photometric design input and output work files to the preliminary design work files (MicroStation or Open Road Design) and verifying that they match the layout sheets submitted. Once the working files are reviewed and the lighting design is found to meet the lighting design criteria, the TDOT Traffic Services Manager shall approve the photometric/preliminary plans. The TDOT Traffic Services Manager shall have up to one month to review, evaluate and provide comments on the existing lighting conditions (when applicable) and the proposed lighting design prior to commencement of the functional/utility plans.

## 5.4 Lighting Computer-Aided Design Drafting Standards

Lighting plans shall follow the TDOT *Survey & Roadway Design Computer-Aided Drafting & Design Standards*. The following list details additional lighting design criteria that will aid in maintaining uniformity in all lighting plans submitted to TDOT:

- Lighting plans layout sheets shall be scaled to 1 inch = 50 feet for straight and curved roadway lengths and 1 inch = 100 feet for interchanges.
- Conventional light poles shall be numbered as LP 1, 2, 3, etc.
- High-mast poles (i.e., tower poles) shall be numbered as HM1, HM2, etc.
- Control centers shall be numbered as CC1, CC2, etc.

## 5.5 Site and Field Reviews

- Site Reviews: A necessary, but sometimes overlooked, part of a complete lighting design is the need for site reviews. The number of site reviews will depend on the complexity of the project. It is prudent that the lighting designer have at least one site review. The following benefits may be obtained through site reviews:
  - Site reviews can provide information that is not always visible from the survey (e.g., structures such as large trees, clusters of trees, ditches, and steep slopes). The lighting designer should be aware of the location of these obstacles to avoid pole placement in their vicinity. Removal of vegetation and trees should be considered only as a last resort.
  - The lighting designer can get a better idea of the magnitude and proximity of overhead obstructions, hazards, or structures to the roadway.
  - Site reviews can provide a better understanding of the neighborhood and other environmental issues that may factor into pole/fixture selection and placement.
  - Site reviews clearly show the roadway configuration. This will enable the designer to determine the lighting design criteria specific to the roadway configuration.
  - Site reviews will enable the lighting designer to discuss with the local utility company potential service point locations by identifying existing or proposed power sources and service points throughout the immediate project area.
  - Site reviews will enable the lighting designer to verify that the locations of proposed poles are not in conflict with existing or proposed utilities, and at-grade and aerial roadway structures.
- Field Review: Prior to finalizing plans, the lighting designer should conduct a field reviews according to the PDN process to determine whether proposed pole and luminaire locations will interfere with existing or proposed underground utilities, and at-grade and aerial roadway structures.
- High-mast Lighting: The lighting designer will send a table with the high-mast stations, offsets, and bearings to the geotechnical engineer to start the soil testing/borings.

## 5.6 Photometric Plan and Work File Submittal

For Photometric, Line and Grade, Functional Plans/Utility Only, Plan-In-Hand, and PS&E Plans submittal, the lighting designer is required to provide specific files such as the AGi32 to the TDOT Traffic Services Office. These files shall follow the naming convention set forth in the TDOT *Survey & Roadway Design Computer-Aided Drafting & Design Standards*. In addition, the working units for all files shall coincide with the working units set forth in the TDOT *Survey & Roadway Design Computer-Aided Drafting & Design Standards*.

- Utility Only Projects: These projects are submitted by the local utility company to retrofit the existing light poles with LEDs and to relocate some of the utility light poles whether existing or new poles. The utility needs to submit a file showing projection lighting values (minimum, average, and uniformity) on the roadway, luminaire type with wattage, setback of light poles from the roadway, and distance between light poles.

## 5.7 Lighting Design

Lighting design must conform to the current Lighting Design Standards and Specifications.

### 5.7.1 Lighting Design Checklists

To reduce plan revisions, errors, and standardize the preparation, format and content of plans, Lighting Design Checklists should be used by all designers, consultants, and personnel checking plans. These forms should be used on all lighting projects. The procedure for use of the form is as follows:

- Fill in the heading information on each sheet.
- The designer or project supervisor will check off each blank with their initials (legible) when sure that each item is completed on the plans. N/A may be used if an item is not required in a project.
- Before submitting plans for a field review, the checklist shall be completed down to that stage of plan development. These checklists are intended as a design aid.

### 5.7.2 Lighting Design Controls

#### 5.7.2.1 Electrical Systems

Roadway lighting is generally bundled with roadway transportation projects, which are characterized or defined as civil engineering designs. Often a civil engineer would place emphasis on the photometric portion of the lighting design, whereas the electrical engineer may place chief focus on the electrical components of the design. It is important to note that a sound engineering lighting design consists of two equally important components, the photometric design and the electrical design. The methodology for selecting and designing to a specific photometric design criteria is defined in Chapter 4. Upon completion of the photometric design, the electrical design can be initiated.

#### 5.7.2.2 Electrical Design Procedure

The steps in performing electrical design are outlined as follows:

1. **Determine lighting design service voltage**: This requires coordination between the designer and Utility Owner to ensure the nominal service voltage is achieved. Typically, the single-phase service voltage may be 120 volts (V), 240 V, or 277 V. The designer should check if a higher service voltage (480 V) from the Utility Owner/Maintaining Agency (UO/MA) is available.
2. **Determine wire size**: The standard minimum wire sizing is the AWG #8 and upsized upon requirement with the maximum size of #2. Adequate wire size is verified by the

voltage drop calculations for each circuit. Sound engineering judgment shall be used in selecting the adequate wire size. Only use copper wiring.

3. **Select circuit breaker**: The lighting design shall verify from the UO/MA the allowable main circuit breaker to be used. A standard-size circuit breaker per NEC requirement should be used, and a spare circuit breaker should be included in each control center. Appropriate safety factor should be considered in selecting the size of the breaker.
4. **Establish control center location**: The lighting designer shall establish the safe location of the control centers. Location shall be verified and approved by the UO/MA and TDOT Project Manager.
5. **Calculate voltage drop**: Steps 1 to 4 are essential in voltage drop calculation. The maximum voltage drop shall not exceed 5 percent. The lighting designer should follow the voltage drop calculations detailed in the following section.
6. **Select and size equipment**: Recommended safety factors and industry standards should be used in selecting and sizing electrical systems. Underground conduits should be 2” diameter minimum and exposed ridged metal conduits should be 1” diameter minimum. The sizing of conduit(s) should be such as to not fill over 60% of the internal area of the conduit.
7. **Provide wiring schematic**: The designer shall provide detailed wiring routing for the lighting system.
8. **Avoid inappropriate equipment sizing**: The lighting designer shall comply with the latest edition of the National Electric Code. Inappropriate equipment sizing can result in major cost overrun.
9. **Provide electrical design quantities**: The lighting designer shall provide the tabulated electrical design quantities based on the final electrical design.

#### 5.7.2.2.1 Voltage Drop Calculation

The typical highway lighting distribution circuit is 120/240 V or 240/480 V, single phase, 60-cycle alternating current service. The power supply to the lighting system consists of two conductors and an insulated ground wire. Typically, the lights are connected using both legs of the circuit to obtain 240 V or 480 V at the luminaires. The following equation and parameters are used in voltage drop calculation:

- Service voltage (VL) is provided by the electrical company.
- Wire resistance (R) is selected based on **Table 5-1**.
- The distance (L) from each luminaire to the circuit breaker is determined.
- Percentage voltage drop for luminaire to the circuit breaker is determined.
- Voltage drop should not exceed 5 percent as defined in this section.
- Calculating voltage drop will determine the total number of luminaires that may be connected to each branch circuit breaker.

**Table 5-1. Conductor Properties**

| Wire Size AWG | Circuit Resistance (R) (Ohms/Foot) | Wire Size AWG | Circuit Resistance (R) (Ohms/Foot) |
|---|---|---|---|
| 14 | 0.0032614 | 2 | 0.0002009 |
| 12 | 0.0020498 | 1 | 0.0001600 |
| 10 | 0.0012899 | 1/0 | 0.0001271 |
| 8 | 0.0008089 | 2/0 | 0.0001009 |
| 6 | 0.0005099 | 3/0 | 0.0000796 |
| 4 | 0.0003210 | 4/0 | 0.0000625 |

Note: Resistances listed in the table are based on stranded copper conductor at 167°F

*Equation 2: Percentage Voltage Drop for One Luminaire*

$V_d = ( 2 \cdot L \cdot I \cdot R) / VL$

Where:

$V_d$ = percentage voltage drop for one luminaire in circuit

L = distance of luminaire to circuit breaker (feet)

I = current in conductor (amp, amperes). Current can be obtained by dividing wattage (power) by service voltage.

R = resistance per foot of conductor (ohms/foot)

VL = service voltage (120 V, 240 V, or 480 V)

Note: Voltage drop between one outside conductor and neutral equals one-half of voltage drop calculated by Equation 2 for two-wire circuits.

*Equation 3: Total Voltage Drop in One Branch Circuit*

Total $V_d = \Sigma V_d$

Where:

Total $V_d$ = total percentage voltage drop in one branch circuit

**5.7.2.2.2 Circuit Breaker Size Determination:**

The branch circuit breaker size and main circuit breaker size can be determined after the total voltage drop has been calculated. Once the total voltage drop criteria has been satisfied, then the branch circuit breaker and main circuit breaker sizes can be determined as follows:

**Branch Circuit Breaker Size**

Determine the total number of luminaires that can be supported on one branch circuit breaker.

Branch Circuit Breaker Size (BCB) = (Total No. of Luminaires x I) / 80%

Branch Circuit breaker size should be rounded to the nearest whole number. Standard size circuit breakers of 15, 20, 30, 40 and 60 amperes should be specified.

**Main Circuit Breaker Size**

Control Center Cabinets typically use four branch circuit breakers and one spare circuit breaker and shall be mounted on a concrete mounting pad and not on poles unless requested by the local utility company. However, if more circuits are required and can be supported, the Control Center Cabinet, with a starting size of 30 by 30 by 12 inches, could have up to six branch circuit breakers and a spare circuit breaker.

Main Circuit Breaker Size (MCB) = (Σ BCB) / 80%

Typically, the main circuit breaker size may be 60, 100 or 125 Amps. Larger sizes may be used if approved by the Utility Owner/Maintaining Agency.

## 5.8 Lighting Materials

The TDOT *Standard Specifications for Road and Bridge Construction* and TDOT Standard Drawings provide pole mounting details and details for foundation materials, depth, reinforcing, and so on. The following design consideration should be factored in lighting system design:

- **Foundation Height Relative to Final Grade:** For other than high mast (light towers), design pole foundations flush with the high edge of the surrounding grade. When located within the clear zone, ensure that the foundation and fractured breakaway device does not protrude more than four inches above the finished grade within a five-foot chord.
- **Steel Foundations:** The diameter of the steel tube ranges from eight inches to ten inches and is typically six feet long. The steel foundation will accommodate poles with 12 inches and 12 inches bolt circles for luminaire mounting heights ranging from 30 feet to 50 feet. If steel foundations deviate from standard drawing T-L-1, then TDOT Engineering/Structures must approve them.
- **Foundations for Temporary Lighting:** Foundations for temporary lighting will be determined on a case-by-case basis. This may include direct embedment of wood poles to a depth of 5.5 feet, for 30-foot poles, and 12 feet, for 65-foot poles.
- **Pole Mounting Parapets:** Ensure that the mounting design includes the necessary non-breakaway, high-strength bolts, leveling plate, and vibration pad.
- **Center Median Barriers:** TDOT discourages the installation of light poles on center median barriers. Any installation that requires lane closures on a freeway should be eliminated if at all possible.
- **Structural Design:** Poles will be designed and fabricated to meet or exceed AASHTO requirements as documented in AASHTO *Standard Specifications for Structural Supports for Highway Signs*, Luminaires, and Traffic Signals and *NCHRP Report 411*. See the TDOT *Standard Specifications* for the appropriate design criteria (e.g., wind loading, gust factor, luminaire mass and effective area).
- **High-mast (Light Tower) Foundations:** Refer to Section 5.8.1.

### 5.8.1 High-mast Lighting Design

The following should be considered while designing high-mast lighting systems:

- **Mounting Heights:** Mounting heights in high-mast lighting applications range from 80 feet to 180 feet. In general, heights of 100 feet to 150 feet have exhibited the most practical designs.
- **Light Source:** LED shall be used for all roadway lighting designs. The number of luminaires per pole typically ranges from four to six luminaires.
- **Locations:** In selecting tower locations, consider the following:
  - Critical Areas: Locate light towers so that the highest localized levels of illumination fall within the critical traffic areas (e.g. freeway/ramp junctions, ramp terminals, merge points).
  - Roadside Safety: Locate light towers outside the roadside clear zone and a sufficient distance from the roadway so that the probability of a collision is virtually eliminated.
  - Avoidance Issues: Special attention should be made to avoid underground utilities, drainage structures, overhead utility lines, and clusters of trees.
- **Design:** There are generally two methodologies for checking the adequacy of light uniformity: 1) the point-by-point method; and 2) the template method. The point-by-point method checks illumination by using the manufacturer's isolux diagram. AGi32 software shall be used to determine the high mast layout/locations.
- **Navigable Airspace:** Consult the *FAA Advisory Circular AC 70/7460-2J Proposed Construction or Alteration of Objects that May Affect the Navigable Airspace*. Consult the federal regulatory agency for design requirements and coordinate this effort with the TDOT Traffic Design Office.

### 5.8.2 Bridge Lighting Plan

Luminaires mounted on the bridge supports and bridge piers shall be approved by the TDOT Engineering/Structures Division to verify that the roadway lighting installations can be adequately supported by the bridge structure. The light standards may be installed 30 or 35 feet above the pavement if appropriate uniformity ratios can be achieved for that portion of the design. However, if the lighting design warrants, mountings of 40 to 45 feet may be considered to minimize bridge vibration due to traffic above the bridge. Bridge Lighting should:

- Be installed near piers where possible to prevent vibration.
- Show conduit and junction boxes installed in parapet walls.
- Show details for crossing joints.

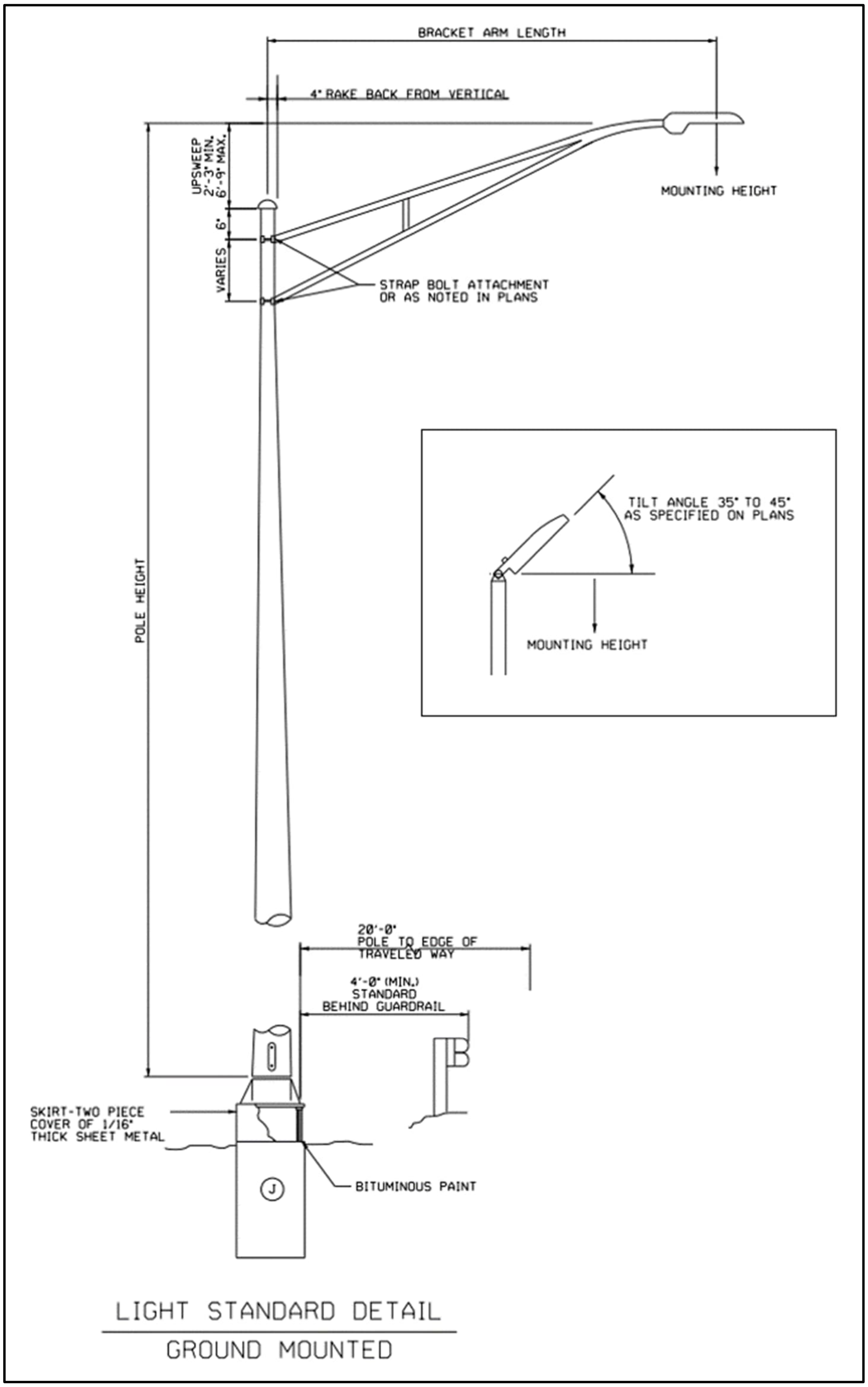
The footings' locations are provided by TDOT structures in the preliminary bridge layout. All items to be installed as a part of the construction of the bridge are to be included in the Lump Sum Item 714-01 (Structural Lighting).

- **Bridge lighting for Structural Submittal:** For overpass and underpass bridge lighting, the lighting designer shall submit the following to structures for inclusion in the bridge plans (See **Appendix A** for details):
  - Bridge name, site location, and log mile.
  - Structural lighting quantities for each bridge.
  - Locations of all conduits, junction boxes, etc.
- **Bridge lighting for lighting Plan:** For overpass and underpass bridge lighting, bridge lighting detail sheets shall be included in the lighting plans. Overpass and underpass lighting is detailed in separate formats as described below:
  - **Overpass Lighting:** For overpass lighting, the lighting plans shall include the following in the “lighting layout” (See **Appendix A** for details):
    - Pole number and light pole location;
    - Junction box location in parapet wall;
    - Conduit location in parapet wall.
  - **Underpass lighting:** For underpass lighting, the lighting plans shall show the bridge lighting as part of the lighting layout. In addition, a detail sheet shall be included for the underpass lighting. The detail sheet shall include the following (See **Appendix A** for details):
    - 1” = 50‘ scale;
    - Number and luminaire location under bridge;
    - Junction box location in parapet wall;
    - Roadside junction box locations;
    - Conduit location in parapet wall;
    - Strapped conduit location on existing bridge;
    - Electrical connection detailed.

### 5.9 Lighting Equipment

Because luminaires, electrical devices, and support structures change rapidly with new developments, this section presents an overview rather than an absolute requirement for lighting equipment and materials. See the TDOT (2021) *Standard Specifications for Road and Bridge Construction* and TDOT Standard Drawings for details on lighting equipment and materials that may be used on projects. This section provides specific design guidance for luminaires, electrical devices, and support structures used by TDOT. **Figure 5-1** illustrates the various components of a typical highway lighting structure.

**Figure 5-1. Highway Lighting Structure**



### 5.9.1 Components

#### 5.9.1.1 Foundations and Mounting

Luminaire assemblies generally are attached to poles mounted along the roadway on ground foundations or atop bridge parapets. Support for light poles may be either reinforced concrete or steel helix foundations and are constructed from typical designs. Concrete foundations for light towers in high-mast lighting applications acquire special designs and soil analyses to determine adequate depth and support. Most conventional light poles are mounted to breakaway foundations while poles mounted atop parapets and barriers are attached using high strength, non-breakaway bolts. Special vibration isolating materials are used to mount light poles on bridges. At signalized intersections, a roadway luminaire may be mounted on mast arms and strain poles when the signal pole is extended by a minimum of 8 feet above the top of the signal face. Luminaires mounted in underpasses and tunnels are either attached directly to the wall adjacent to or hung from vibration-dampening pendants above the travel lanes. Light sources that are used to externally illuminate overhead sign panels typically are fastened to the truss or cantilever support structure. Waterway and aviation obstruction warning luminaires are attached directly to the structures representing the hazard.

#### 5.9.1.2 Pole Bases

Luminaires can be mounted on several types of poles and selection is governed by project need. An important distinguishing characteristic of the pole base is whether it is classified by AASHTO and FHWA as an acceptable breakaway device. The following briefly describes the pole bases used by TDOT:

- **Breakaway Bolt Coupling**: These pole bases are designed to shear when the pole is hit by an errant vehicle. The bottom of each coupling is threaded onto a foundation anchor bolt, and the pole is attached to the top of the coupling. Four couplings are used with each pole. All wiring at the pole base will have quick-disconnect splices.
- **Frangible Transformer Base**: The frangible transformer base consists of a cast aluminum apron between the foundation and the base of the pole. It is designed to deform and break away when hit by an errant vehicle. All wiring inside the base will have quick-disconnect splices.
- **Anchor Base**: The anchor base consists primarily of a metal plate that is welded to the bottom of the pole. The plate allows the pole to be bolted directly to the foundation using high-strength anchor bolts without an intermediate breakaway connection. The anchor base is not a breakaway device.

#### 5.9.1.3 Pole

Light poles for luminaire mounting height ranges from approximately 30 feet to 65 feet. They may be fabricated as tapered or straight, single-section poles from materials such as aluminum, galvanized steel, and stainless steel. Light towers for high-mast lighting application generally range from 80 to 160 feet and are designed in multiple sections.

#### 5.9.1.4 Luminaires

A luminaire is a complete lighting unit consisting of LED arrays (modules), a lamp, or lamps, together with the parts necessary to regulate and distribute the light. Basic component of the luminaire includes the following:

- Optical system: The optical system consists of the light source, a reflector, and usually a refractor.
  - Light Sources: The different light sources used in highway applications have been discussed in Section 2.4 and Section 2.5. Consideration should be given to availability, size, power requirements, and cost-effectiveness.
  - Reflector: The reflector is used to redirect the portion of light that would otherwise be lost or poorly utilized. They are designed to function alone or work with a refractor. Reflectors are classified as either specular or diffused. Specular reflectors are designed from glossy or mirror-like surfaces, whereas diffuse reflectors use their rough surface to spread light over a wide area.
  - Refractor: Refractors are made of a transparent, clear material, usually high-strength glass, or plastic. The refractor, through its prismatic construction, controls and redirects both the light emitted by the lamp and the light redirected by the reflector.
- Housing Units: The housing integrates the lamp, reflector, refractor, and ballast into a self-contained unit. The housing is sealed to prevent dust, moisture, and insects from entering. Housing units are designed to accommodate access for lamp maintenance and adjustment (i.e., light direction and distribution).

# CHAPTER 6

# REFERENCES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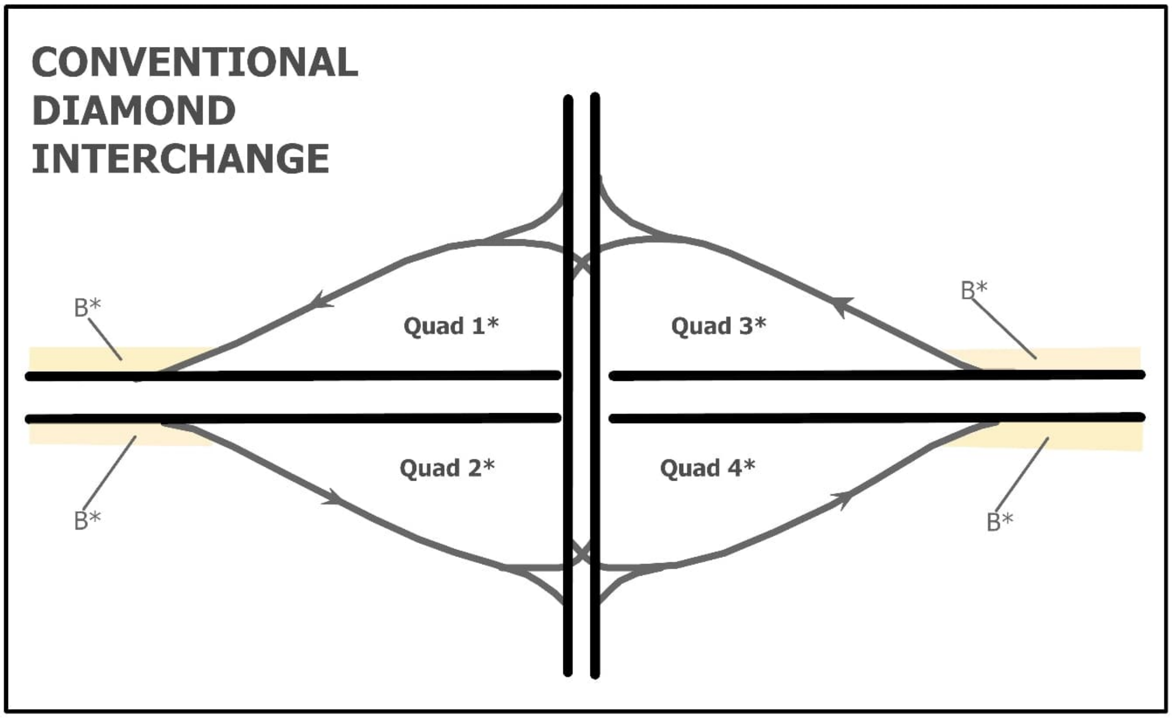
# Appendix A

## Figure A-1. Interchange Lighting Layout for a Diamond Interchange




**Begin by Installing two High Mast (HM) lighting in each quadrant (HM should be outside clear zone)*

*B* - Install offset lighting 1000ft to the ramp @ max spacing of 250ft*

**Figure A-2. Detail of Overpass Bridge Lighting for Submittal to Structures**

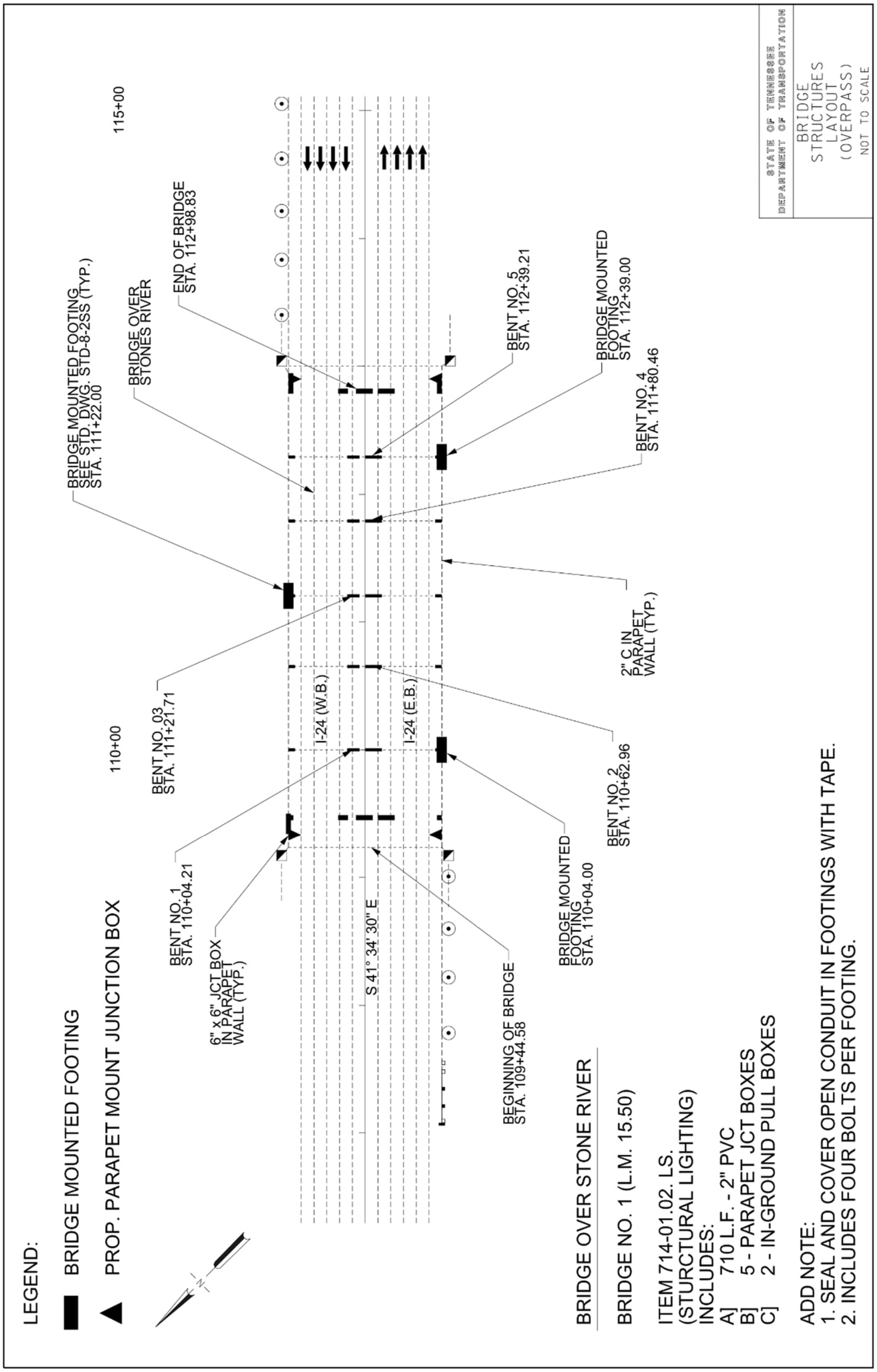


**Figure A-3. Detail of Underpass Bridge Lighting for Submittal to Structures**

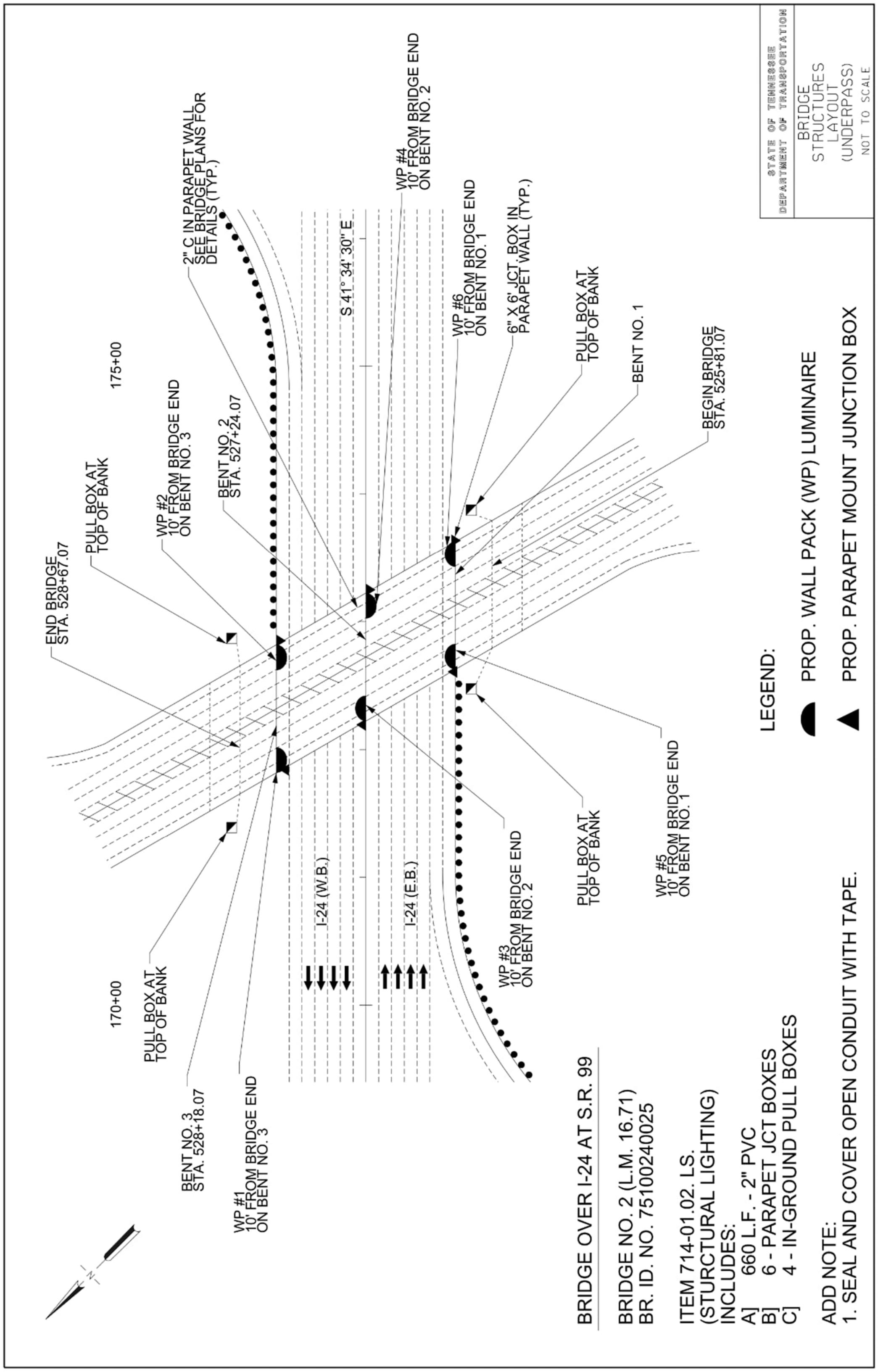


**Figure A-4. Detail of Proposed Lighting Layout at Bridge Overpass (NTS)**