CHAPTER 15

ROADWAY AND INTERSECTION LIGHTING

15.1 General Information

The primary objective of roadway lighting is to enhance roadway safety. Properly designed roadway lighting should provide a level of visibility that enables the motorist and pedestrian 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:

- 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 street crime at night or in other dark situations;
- Enhances commercial and other activity zones to attract users.

The criteria found in this standard when used in conjunction with *TDOT Standard Specifications for Road and Bridge Construction* and the *TDOT Standard Drawings* provides the engineer with minimum requirements for roadway lighting in the state of Tennessee.

15.1.1 Need for Engineering Expertise

Most states require that final design documents be signed and sealed by a registered professional engineer. The registrant is normally required to only sign and seal documents that the registrant prepared or documents where the registrant was responsible for the direction and control of the work. Lighting designs, as described in this guide, meet the criteria for the requirements of an engineering seal. The required expertise is in the area of roadway lighting and associated electrical systems. The expertise required for TDOT lighting designs includes:

- Lamp types and characteristics, including depreciation factors;
- Ballast types and characteristics;
- 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 when appropriate to 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;
- 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 above.

15.1.2 Priorities and Funding Guidelines

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 and assume all costs for installation of new roadway lighting as part of the related Interstate highway construction project when:
  - Freeway lighting is determined to be warranted by the Traffic Engineering Office and as prescribed by IES, the *AASHTO Roadway Lighting Design Guide, and the FHWA Lighting Handbook*;
  - 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 the local governing agency submits a request for the interchange lighting to the TDOT Commissioner in writing. The local governing agency must also submit funding to cover 50% 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 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 prepare relocation plans and submit through TDOT Utilities Office. The TDOT Utilities Office will determine reimbursement eligibility. Relocation shall be accomplished by the local agency upon additional review and approval of plans by the Traffic Operations Division;
  - Installation or relocation of roadway lighting in a State project occurs only at the local agency's request. The Design Division Director shall approve the installation or relocation of roadway lighting projects. The project must be constructed under specific funding allowing such usage;
  - The local governing agency may request 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 Engineering Office.
- **Bridges:** On new or widened bridges in urbanized areas, TDOT will provide conduit, pull boxes and foundations in the parapet wall for the future installation of lighting. Where there is existing lighting on a bridge project, TDOT will replace the lighting.

15.2 Analyzing Roadway Lighting Needs

Driver visibility should be considered when analyzing roadway lighting needs. Principal considerations for the lighting needs analysis are:

- Vehicular traffic volume;
- Interchange spacing;
- Relative frequency of vehicular traffic maneuvers;
- Land development;
- Artificial lighting conditions of the surrounding area;
- Night-to-day crash ratio.

15.2.1 Freeways

Use the criteria presented in the following sections when analyzing the lighting needs for freeway facilities.

- **Continuous Freeway Lighting:** CFL should be considered under the following conditions:
  - **Freeway Volume:** On those freeway sections in and near cities where the current ADT is 30,000 or more, CFL should be considered.
  - **Interchange Spacing:** CFL should be considered 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.
  - **Land Development/Lighting Conditions:** Consider providing CFL where, for a length of two miles or more, the freeway passes through a substantially developed suburban or urban area in which one or more of the following conditions exist:
    - Local traffic operates on a complete street grid having some form of street lighting, parts of which are visible from the freeway;
    - The freeway passes through a series of residential, commercial or industrial areas which include roads, parking areas or yards that are lighted;
    - 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; or
    - Freeway cross-section elements (e.g. median, shoulders), are substantially reduced in width below desirable criteria in relatively open country.

- **Night-To-Day Crash Ratio:** CFL should be considered where the night-to-day ratio of crash rates is at least 2.0 or higher than 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. The number of nighttime crashes also should be evaluated.

- **Local Agency Needs:** CFL should be provided 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.

➢ **Complete Interchange Lighting:** CIL is defined as a lighting system that provides relative uniform lighting within the limits of the interchange, including:

- Main lanes;
- Direct connections;
- Ramp terminals;
- Frontage road or crossroad intersections.

CIL should be considered under the following conditions:

- **Ramp Volume:** CIL should be considered where the total current ADT ramp traffic entering and exiting the freeway within the interchange area exceeds 10,000 for urban conditions, 8,000 for suburban conditions, or 5,000 for rural conditions.

- **Crossroad Volume:** CIL should be considered where the current ADT on the crossroad exceeds 10,000 for urban conditions, 8,000 for suburban conditions, or 5,000 for rural conditions.

- **Land Development/Lighting Conditions:** CIL should be considered at locations where there is substantial commercial or industrial development which is lighted during hours of darkness, and is located in the vicinity of the interchange; or where the crossroad approach legs are lighted for 0.5 miles or more on each side of the interchange.

- **Night-To-Day Crash Ratio:** CIL should be considered where the night-to-day ratio of crash rates within the interchange area is at least 1.5 or higher than 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. The number of nighttime crashes also should be evaluated.

- **Local Agency Needs:** CIL should be considered 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.

- **Continuous Freeway Lighting:** CIL should be considered at interchanges where continuous freeway lighting is provided.

➢ **Partial Interchange Lighting:** PIL is defined as a lighting system that provides illumination only of decision making areas of roadways including:

- Acceleration and deceleration lanes;
- Ramp terminals;
- Crossroads at frontage road or ramp intersections;
- Other areas of nighttime hazard.

Where partial interchange lighting is provided, luminaires should be located to best light the through lanes and speed change lanes at diverging and merging locations (decision-making areas). Figure 15.1 shows examples of partial interchange lighting with separate illustrations for different ramp conditions for crossing types A and B. The lighting engineer should display sound engineering judgment in determining whether the number of fixtures shown is sufficient. Recommendations provided shall consider light level uniformity to whatever extent is possible keeping in mind that the primary concern is safety. In conjunction with lighting the gore/nose areas at the interchange, PIL should also include lighting at complex ramp terminals and simple ramp terminals as shown below. For crossing types C and D, the engineer shall provide roadway illumination consistent with design criteria as shown in Figure 15.2. In an effort to provide affordable solutions to the local agencies growing desire to provide lighting in more locations and under more affordable conditions, PIL may be considered at interchanges under the following conditions:

- **Ramp Volume:** PIL should be considered where the total current ADT ramp traffic entering and exiting the freeway within the interchange area exceeds 5,000 for urban conditions, 3,000 for suburban conditions, or 1,000 for rural conditions.
- **Freeway Volume:** PIL should be considered where the current ADT on the freeway through traffic lanes exceeds 25,000 for urban condition, 20,000 for suburban conditions, or 10,000 for rural conditions.

Figure 15.1 – Partial Interchange Lighting (Crossing Types A and B)

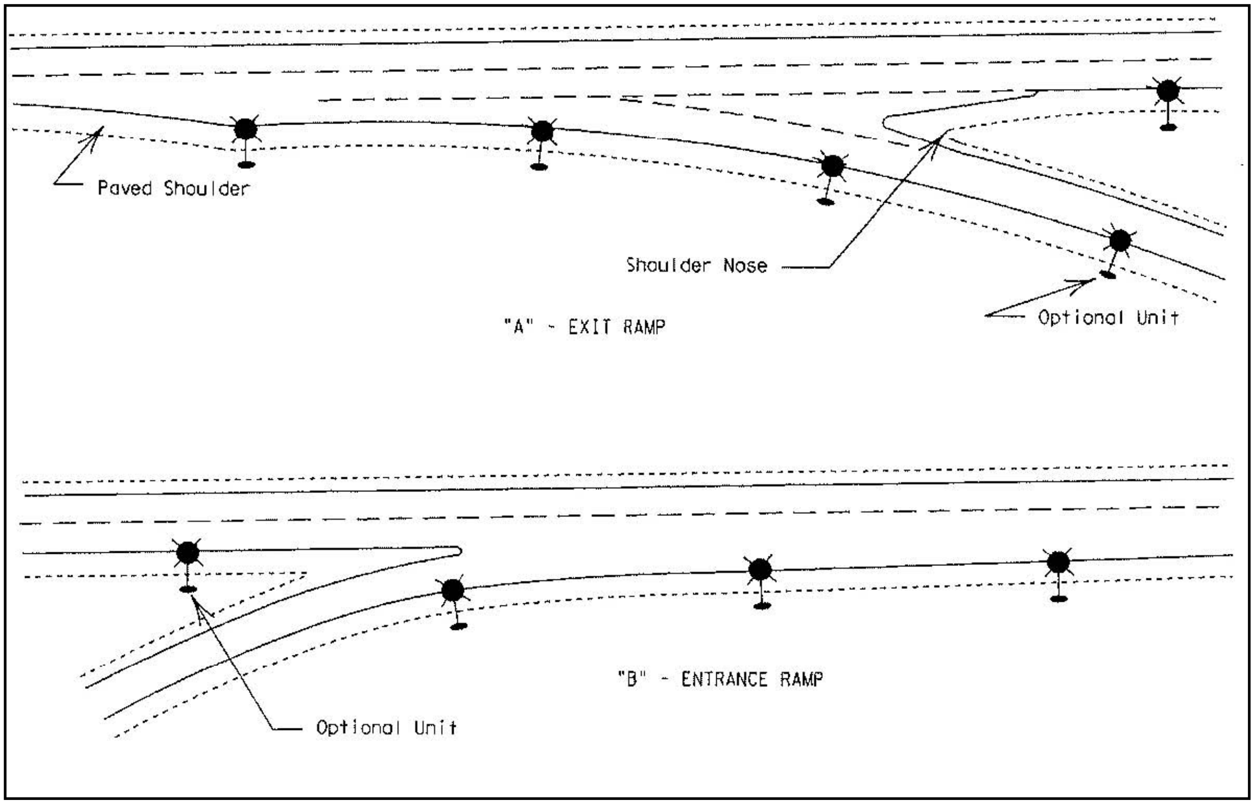
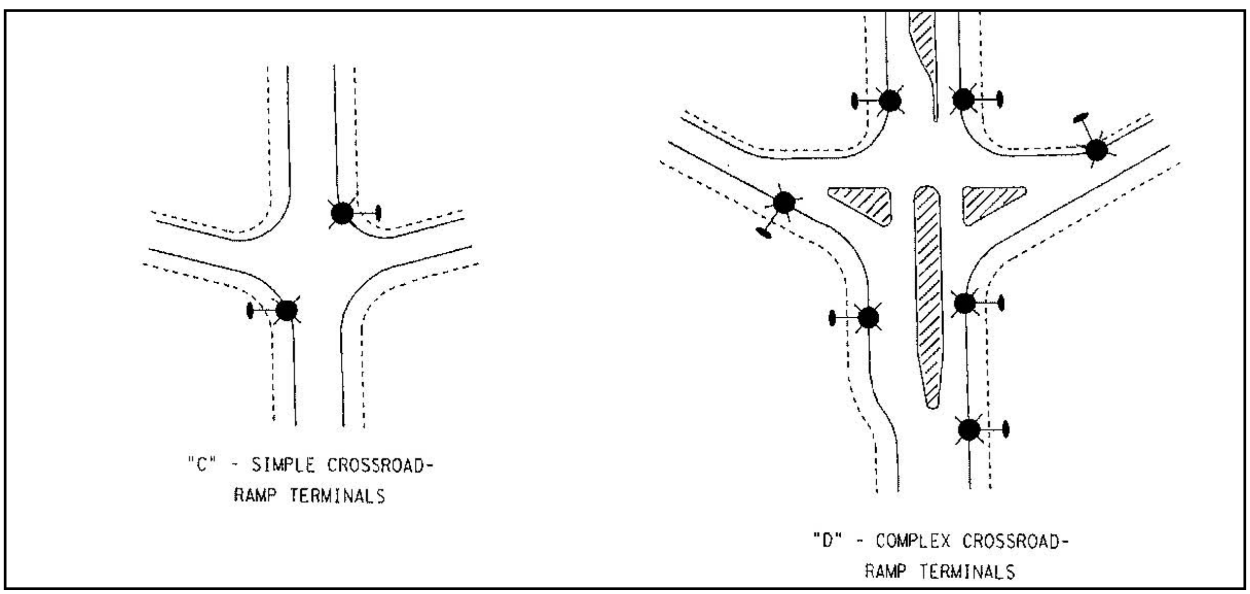


Figure 15.2 – Partial Interchange Lighting (Crossing Types C and D)



- **Night-To-Day Crash Ratio:** PIL should be considered where the night-to-day ratio of crash rates within the interchange area is at least 1.25 or higher than statewide average for all unlighted similar sections, and a study indicates that lighting may be expected to result in significant reduction in the night crash rate. The number of nighttime crashes also should be evaluated.
- **Local Agency Needs:** PIL should be considered 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.
- **Continuous Freeway Lighting:** PIL should be considered where continuous freeway lighting is justified, but not initially installed. The freeway section should be in or near a city where the current ADT is 30,000 or more, or the interchange should be among three or more successive interchanges located with an average spacing of 1.5 miles or less with adjacent areas outside of right-of-way being substantially urban in character.
- **Complete Interchange Lighting:** PIL should be considered where complete interchange lighting is justified, but not initially fully installed, a partial lighting system which exceeds the normal partial installation in number of lighting units is considered to be justified.

➢ **Crossroad Ramp Terminal Lighting:** Crossroad ramp terminal lighting should be considered, regardless of traffic volumes, where the crossroad ramp terminal of freeway interchanges incorporates raised channelizing or divisional islands or where there is poor sight distance.

15.2.2 Streets and Highways Other Than Freeways

Use the criteria presented in the following sections when analyzing the lighting needs for Streets and Highways Other Than Freeways.

➢ **General Considerations:** Urban and rural conditions, traffic volumes (both vehicular and pedestrian), intersections, turning movements, signalization, channelization, and varying geometrics are factors that should be considered when determining the lighting needs of streets and highways other than freeways. Generally, the following are considered when assessing the lighting needs of such facilities (e.g. streets):

- **Facilities with Raised Medians:** Consider highway lighting along facilities that have raised medians.
- **Major Urban Arterials:** Consider highway lighting along major arterials that are located in urban areas.

- **Intersections:** Consider intersection lighting at rural intersections that meet any one of the following conditions:
    - o There are 2.4 or more crashes per million vehicles in each of three consecutive years;
    - o 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;
    - o 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;
    - o 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;
    - o Substantial nighttime pedestrian volume exists;
    - o Less than desirable alignment exists on any of the intersection approaches;
    - o The intersection is an unusual type requiring complex turning maneuvers;
    - o Commercial development exists in the vicinity which causes high nighttime traffic peaks;
    - o Distracting illumination exists from adjacent land development; and/or
    - o There exists recurrent fog or industrial smog in the area.
    - o For roundabouts, see *IES Design Guide for Roundabout Lighting. Publication DG-19-08* for guidance.
- **Isolated Intersections:** Consider providing lighting along isolated intersections located 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.
- **High Conflict Locations:** Consider providing lighting along roadway sections with high vehicle-to-vehicle interactions (e.g., sections with numerous driveways, significant commercial or residential development, high percentage of trucks). Lighting generally improves traffic safety and efficiency at such locations.
- **Complex Roadway Geometry:** Consider providing lighting at spot locations in rural areas where the driver is required to pass through a roadway section with complex geometry.

- **Night-to-Day Crash Ratio:** Lighting should be considered at locations or sections of streets and highways 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.
- **Local Agency Needs:** Lighting should be considered 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.

➢ **TDOT Requirements:**

- **Lighting on Streets and Highways Other Than Interstates:** TDOT provides lighting for interstate highways and bridges. New lighting installations on the State highway system will be reviewed by TDOT using breakaway, non-breakaway and utility distribution poles (joint usage). The following are prime considerations when installing lighting on state highways:
    - Providing adequate levels of illumination;
    - Minimizing the amount of glare;
    - Reducing the number of poles required.
- **Submittal of Street Lighting Designs:** Street lighting plans submitted to the TDOT Traffic Engineering Office for approval must provide photometric calculations and the type of lighting equipment to be installed. Poles that will be used for street lights 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 plans submittal. If questions arise in the interpretations of the rules and regulations regarding roadway lighting, the TDOT Traffic Operations Division Director will make the final administrative and engineering determinations.

➢ **Other Design Considerations:**

- The recommended mounting height is 45 feet. 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 the fixed objects most frequently involved in motor vehicle accidents. Where electrical distribution or communication lines are in existence, mounting heights less than 45 feet may be approved in order to utilize existing poles to the full 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 Illuminating Engineering Society (RP-8-14 & other related Publications);

- Pole setback from the edge of the pavement shall be 20 feet minimum, or at the right-or-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 two feet from the face of the curb;
- Where a utility strip or grass plot is located between the face of curb and the sidewalk, poles may be allowed in this area if they can be set at least two feet from the face of the curb;
- Poles shall not be set in the median of the roadway, except where a 20 foot minimum setback can be obtained, or where protected by guardrail already existing for other safety considerations;
- Mast arm length shall be no greater than six feet, except as approved for the lighting design;
- Foot-candle levels shall be used as recommended in Tables 15.3 and 15.4;
- Concrete pole bases should be flush but shall not extend over four inches above ground level;
- 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 eminent danger of an impacted support striking a pedestrian, private property or other traffic. Where sidewalk and curb and gutter are present, non-breakaway poles shall be used in the installation. All poles must be installed a minimum of four feet behind the face of the guardrail. Poles to be located behind existing guardrail, rock bluffs, embankments or ditches are not required to be 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 of 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. The luminaire

mounting height for joint usage installations may be approved for less than 45 feet but should not be less than 25 feet;

- 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 by using transition lighting or Adaptation Lighting. When transition lighting (See Page 15.21) 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 15.1 is a practical formula for calculating the required roadway length for transition lighting.

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

Equation 15.1 – Roadway Length for Transition Lighting

Where,

L = Length of Transition Lighting

S = Speed Along Roadway Section in 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 different level of illumination).

- **Ornamental Lighting:** There is a growing desire for Ornamental and Pedestrian 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. Since the use of higher wattage luminaires on shorter poles and shorter spacing could contribute to disability glare, special attention should be paid when using higher wattage luminaires, shorter spacing or shorter poles. However, the use of shorter poles in roadway lighting does not inherently produce glare. There are some ornamental luminaires with distribution patterns that will control the light and meet *ANSI/IES RP-8-14* and AASHTO requirements. At the request of a Local Agency, ornamental lighting may be permitted by TDOT on a State facility if TDOT's minimum requirements are met and the Local Agency is responsible for construction, funding, ownership, and maintenance of such lighting both during and after construction. All requests for special or ornamental lighting shall be reviewed and approved by the TDOT manager before design begins.
- **Lighting on Bridges:** All street lighting designs submitted for luminaires to be mounted on bridges must be approved by the TDOT Structures Division. This portion of the lighting plan layout must show how the conduit is to be routed on the structure of the bridges. When the TDOT's bridge projects are in the early phase of development, the local agencies should

contact TDOT Structures Division so that proposed changes needed to support future lighting can be incorporated into the designs for new bridges. TDOT may provide the conduit for the future street lighting during the construction of the bridges.

- **Median Street Lighting:** 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 four feet on either side of the drainage ditch. Light standards may be installed in depressed medians behind existing or proposed guardrail or barriers.

- **Lighting at Isolated Intersections:** Where an isolated intersection requires lighting, consideration should be given to providing additional lighting before and beyond the intersection. AASHTO guidelines refer to a light barrier created when glare from an isolated light source causes visibility to be restricted to the beginning of the light bubble. To extend visibility into the bubble; additional fixtures may be required for at least the required stopping sight distance. The engineer should use his or her judgment and experience to determine if such measures are needed.

- **Roadway Lighting Plans Exceptions:** If questions arise in the interpretations of the rules and regulations regarding roadway lighting, the TDOT Traffic Operations Division Director will make the final administrative and engineering determinations. Requests for street lighting that is to be installed with TDOT Local Programs Office funding should be submitted to the TDOT Commissioner's Office.

15.2.3 Other Locations

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

- **Highway Sign Illumination:** TDOT does not generally light highway signs.

- **Rest areas:** For lighting at rest areas, there is typically no involvement by TDOT in the design, 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.

- **Weigh stations:** For lighting at weigh stations, there is typically no involvement by TDOT in the design, installation or maintenance. 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.
- **Tunnels:** A tunnel is defined as a structure over a roadway, which 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 such items as:
    - Portal to portal tunnel length (i.e., short or long);
    - Tunnel portal design;
    - Geometry of tunnel and its approaches;
    - Vehicular and pedestrian traffic characteristics;
    - Treatment of pavement, portal, interior, and environmental reflective surfaces;
    - Climate and orientation of tunnel; and
    - Visibility objectives to provide for safe and efficient tunnel operation.

  For tunnel lighting use the requirements in the ANSI/IESNA PR-22-05 publication IESNA Recommended Practice for Tunnel Lighting.
- **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 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*.
- **Temporary and Replacement Lighting:** The need to provide temporary highway lighting will be considered on a case-by-case basis. For example, construction zones requiring complex traffic maneuvers (e.g. crossovers) may justify the provision of temporary lighting. In addition, if existing lighting is affected or relocated during construction, temporary replacement lighting should be provided in like kind and quality during the construction phase.

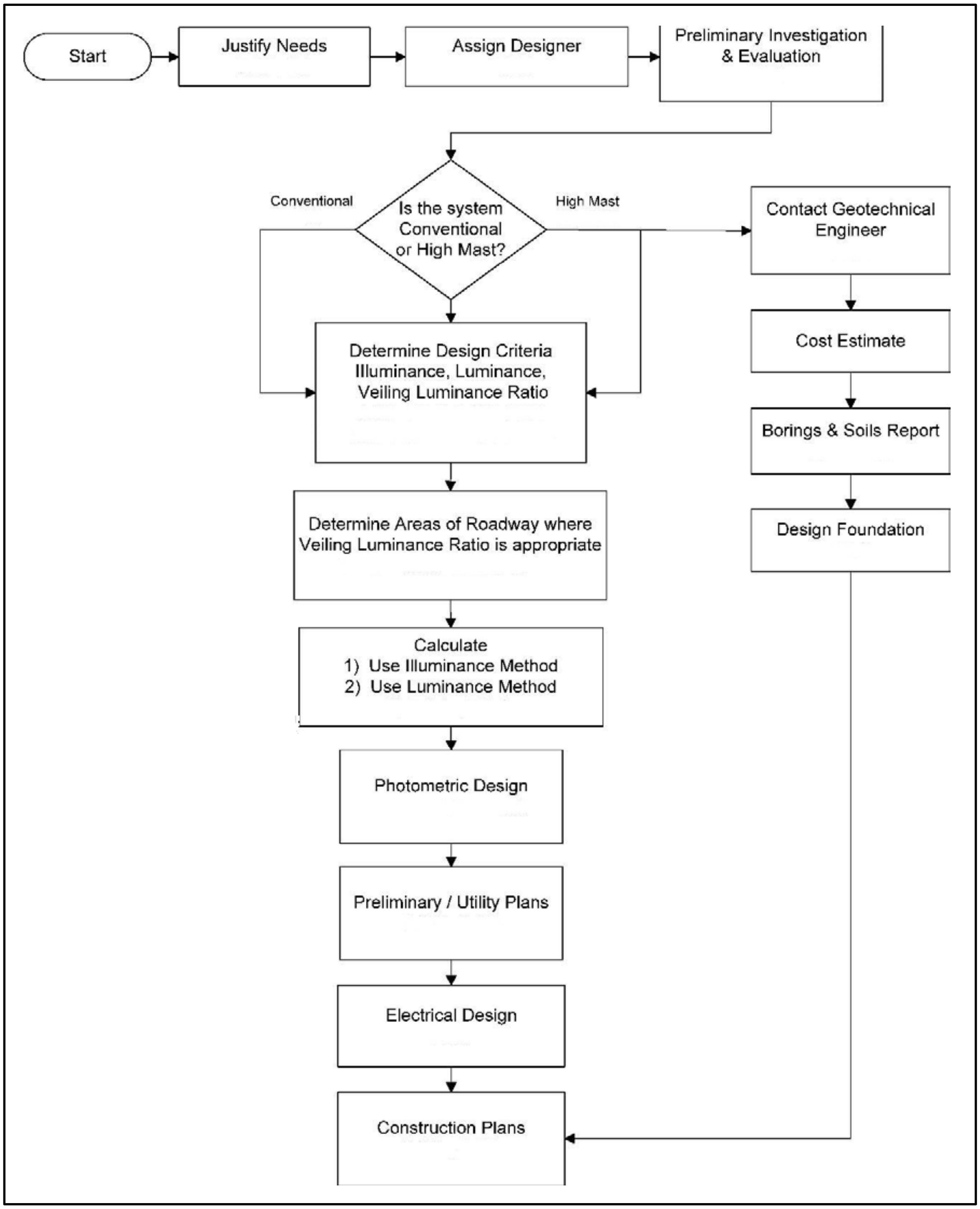
15.3 New Lighting Projects

The information in this section pertains to new lighting projects.

15.3.1 Lighting Design Process Flow Chart

A lighting design process flow chart is provided in Figure 15.3.

Figure 15.3 – Lighting Design Process Flow Chart



15.3.2 Design Process

- **Establish Contact with Utility Owner/Maintaining Agency:** Typically, the maintaining agency for a lighting system is the local government. The local government often contracts the local power company for maintenance operations. First contact should be with the governmental agency through involvement of the TDOT Traffic Operations Design Manager, to determine proper protocol for contact with the local power company. This will enable the lighting designer to prepare a lighting design that will satisfy both the TDOT Traffic Engineering Office's lighting design criteria and the Utility Owner/Maintaining Agency's specifications. The lighting designer should obtain the following information from the Utility Owner/Maintaining Agency:
    - Determine the specific light fixtures recommended for use;
    - Determine the service voltage available;
    - 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;
    - Determine any special mounting height requirements.
- **Conventional Photometric Design Overview:** The following briefly describes the steps used in any conventional highway lighting photometric design:
    1. **Select Lighting Equipment:** Select the lighting equipment and associated design parameters that will be used for the project. This will include items such as luminaire mounting height, pole setback, light source, lamp wattage, etc. It will be necessary to make some initial assumptions during preliminary design. Design parameters then may be iteratively changed to meet the highway lighting criteria. It will be necessary to contact the municipality slated to take possessions of the lighting system. It may also be necessary to coordinate design efforts with that municipality's agent hired to perform maintenance operations for the system.
    2. **Select Luminaire Arrangement:** Select an appropriate luminaire arrangement for the project. This will depend on local site conditions and engineering judgment. Alternative arrangements may need to be considered.
    3. **Luminaire Spacing:** Typically, luminaire spacing will be determined by computer software. The Department recommends that the designer use AGI32 computer software for lighting design layouts. Foot-candle (fc) is a unit of illuminance expressed in lumens per square foot (lm/ft^2). Therefore, the average horizontal

foot-candle on a highway is equal to the total lumens cast on the highway by a single unit divided by the spacing between units times the width of the roadway. Total lumens that a luminaire will cast on the roadway equals lamp lumens at replacement time times the coefficient of utilization times the luminaire maintenance factor. This relationship can be rearranged to solve for luminaire spacing as shown in Equation 15.2.

$$S = \frac{LL \bullet CU \bullet MF}{E_h \bullet W}$$

Equation 15.2 – Luminaire Spacing

Where:

S = Luminaire Spacing (feet)

LL = Initial Lamp Lumens (lm)

CU = Coefficient of Utilization

MF = Maintenance Factor (i.e., LLD • LDD)

E_h = Average Maintained Horizontal Illumination (foot-candle)

W = Width of Lighted Roadway (feet)

4. **Check Uniformity:** Once luminaire spacing has been determined, check the uniformity of light distribution and compare this value to the lighting criteria selected in Step 1. Adjust design parameters and recalculate as necessary to meet criteria. Use Equation 15.3 to determine the uniformity ratio.

$$UR = \frac{E_h}{E_{\min}}$$

Equation 15.3 – Uniformity Ratio

Where:

UR = Uniformity Ratio

E_h = Average Maintained Horizontal Illuminance

E_{min} = Maintained Horizontal Illuminance at the Point of Minimum Illumination on the Pavement

5. **Select Optimum Design:** Because computerized design is relatively quick and easy, consider developing and testing several alternative designs. It generally is not good engineering practice to consider only one design, even if found to satisfy the lighting criteria. There often are several alternatives that will work. Optimize and select the most cost-effective and maintenance-free design.

   Notes: A uniform spacing may not always be possible to maintain because of variation in roadway widths and alignment. Formulas shown above were extracted from *ANSI/IES RP-8-14*.

15.3.3 Design Considerations

When selecting design criteria for a lighting project, it is necessary to determine classifications for the roadway facility, the area the roadway traverses, and the pavement type. The following sections discuss these classifications for the purpose of highway lighting design only.

15.3.4 Determine Classifications

Determine the roadway classification, area classification, pavement classification, and environmental conditions. Verify with the TDOT Traffic Engineering Office the classification of any interchange or freeways as urban, suburban, or rural.

- **Roadway Classification:** Use the following definitions to classify roadway facilities for TDOT highway lighting projects:
  - **Freeway:** A divided major highway with full control of access and with no crossings at grade.
    - **Freeway Class A:** Roadways with greater visual complexity and highway traffic volumes. Usually this type of freeway will be found in major metropolitan areas in or near the central core, and will operate through some of the early evening hours of darkness at or near design capacity;
    - **Freeway Class B:** All other divided roadways with full control of access
  - **Expressway:** A divided major arterial highway for through traffic with full or partial control of access and generally with interchanges at major crossroads. Expressways for non-commercial traffic within parks and park-like areas generally are known as parkways.
  - **Major:** The part of the roadway system that serves as the principle network for through traffic flow. The routes connect areas of principle traffic generation and important rural highways entering the city.
  - **Collector:** The distributor and collector roadways serving traffic between major and local roadways. These are roadways used mainly for traffic movements within residential, commercial, and industrial areas.
  - **Local:** Roadways used primarily for direct access to residential, commercial, industrial, or other abutting property. They do not include roadways carrying through traffic. Long local roadways generally will be divided into short sections by the collector roadway system.
  - **Isolated interchange:** A grade-separated roadway crossing, which is not part of a continuously lighted system, with one or more ramp connections with the crossroad.

- **Isolated Intersection:** The general area where two or more non-continuously lighted roadways join or cross at the same level. This area includes the roadway and roadside facilities for traffic movement in that area. A special type is the channelized intersection, in which traffic is directed into definite paths by islands with raised curbing.
- **Isolated Traffic Conflict Area:** A traffic conflict area is an area on a road system where an increased potential exists for collisions between vehicles, vehicles and pedestrians, or vehicles and fixed objects. Examples include intersections, crosswalks and merge areas. When this area occurs on a roadway without a fixed lighting system (or separated from one by 20 seconds or more of driving time), it is considered an isolated traffic conflict area.

➢ **Ancillary Classifications:**

- **Alley:** A narrow public way within a block, generally used for vehicular access to the rear of abutting properties.
- **Sidewalk:** Paved or otherwise improved areas for pedestrian use, located within public street right-of-way which also contains roadways for vehicular traffic.
- **Pedestrian Way:** Public sidewalks for pedestrian traffic generally not within right-of-way for vehicular traffic. Included are skywalks (pedestrian overpasses), subwalks (pedestrian tunnels), walkways giving access to park or block interiors, and crossings near centers of long blocks.
- **Bikeway:** Any road, street, path, or way that is specifically designated as being open to bicycle travel, regardless of whether such facilities are designed for the exclusive use of bicycles or are to be shared with other transportation modes. Five basic types of facilities are used to accommodate bicyclists:
  - **Shared Lane:** Shared motor vehicle/bicycle use of a standard width travel lane.
  - **Wide Outside Lane:** An outside travel lane with a width of at least 13.8 feet.
  - **Bike Lane:** A portion of the roadway designated by striping, signing, and/or pavement markings for preferential or exclusive use of bicycles.
  - **Shoulder:** A paved portion of the roadway to the right of the edge stripe designed to serve bicyclists.

- **Separate Bike Path:** A facility physically separated from the roadway and intended for bicycle use (See *IESNA DG-5-94, Lighting for Walkways and Class 1 Bikeways* for requirements in these areas).

- **Median:** The portion of a divided roadway physically separating the traveled ways for traffic in opposite directions. TDOT discourages lighting poles mounted in the median or on median barrier walls.

➢ **Area Classification:** For TDOT lighting projects, use the following definitions to classify the area in which the roadway traverses:

- **Commercial:** That portion of a municipality in a business development where ordinarily there are large numbers of pedestrians and a heavy demand for parking space during periods of peak traffic or a sustained high pedestrian volume and a continuously heavy demand for off-street parking space during business hours. This definition applies to densely developed business areas outside of, as well as those that are within, the central part of a municipality.

- **Intermediate:** That portion of a municipality which is outside of a downtown area but generally within the zone of influence of a business or industrial development, often characterized by a moderately heavy nighttime pedestrian volume and a somewhat lower parking turnover than is found in a commercial area. This definition includes densely developed apartment areas, hospitals, public libraries, and neighborhood recreational centers.

- **Residential:** A residential development, or mixture of residential and commercial establishments, characterized by few pedestrians and a low parking demand or turnover at night. This definition includes areas with single family homes, townhouses, and/or small apartments. Regional parks, cemeteries, and vacant lands also are included.

➢ **Pavement Classification:** Table 15.1 shows pavement type classifications of the roadway facility:

Table 15.1 – Pavement Classification

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

*Q_o = 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.

➢ **Lighting Design Levels**

- **Crossroads at Interchanges:** Lighting levels on crossroad approaches should not be reduced through an interchange area. If existing crossroad lighting currently is deemed inadequate, it should be considered for upgrading to ensure safe and efficient traffic operation.
- **Partial Interchange Lighting:** Where partial interchange lighting is provided, luminaires should be located to best light the speed change lanes at diverging and merging locations. The design controls of basic levels of lighting and uniformity should be subordinate to overall lighting of the roadway area at these locations. The designer should use engineering judgment when considering the light levels on the through lanes.
- **Bridge Structures and Underpasses:** Where justified, underpass lighting level and uniformity ratios should duplicate, to the extent practical, the lighting levels on the adjacent facility. On continuously lighted freeways and lighted interchanges, the lighting of bridges and overpasses should be at the same level and uniformity as the roadway.
- **Transition Lighting:** Transition lighting is a technique intended to provide the driver with a gradual reduction in lighting levels and glare when leaving an illuminated area. Several implementation

methods exist. The designer also may consider extending delineation 1000 feet beyond the last luminaire for traffic lanes emerging from a lighted area (e.g. ambient light). This will provide an additional measure of effectiveness. Vision adjustment when approaching a lighted area is not impacted greatly and therefore requires no special consideration. For more information on transition lighting, refer to Section 15.2.2.

- **Navigation and Obstruction Lighting:** The lumen output for waterway and aviation obstruction luminaires will be based on the requirements of the U.S. Coast Guard and the Federal Aviation Administration, respectively.
- **Other Locations:** Where lighting is justified for tunnels, overhead signing, and other facilities not covered under this section, contact the Traffic Design Office for further information.

➢ **Luminaire Considerations:** Design issues related to luminaires are discussed as follows:

- **Light Distribution:** Light distribution is a major factor in highway lighting design. It affects the selection of luminaire mounting height, placement, and arrangement. Specific photometric data and light distribution sheets are available from each luminaire manufacturer. Manufacturers typically classify their luminaire products based on the IES luminaire classification system. The following briefly describes the IES classification system:
    - **Vertical Light Distribution:** There are three IES classifications of vertical light distribution – short, medium, and long. The selection of a particular vertical light distribution is dependent upon the luminaire mounting height and application. The following defines each type:
        - **Short Distribution:** The maximum candlepower strikes the roadway surface between one and 2.25 mounting heights from the luminaire. The theoretical maximum luminaire spacing, using the short distribution, is 4.5 mounting heights.
        - **Medium Distribution:** The maximum candlepower is between 2.25 and 3.75 mounting heights from the luminaire. The theoretical maximum luminaire spacing is 7.5 mounting heights. Medium distribution is commonly used in highway applications.
        - **Long Distribution:** The maximum candlepower is between 3.75 and 6.0 mounting heights from the luminaire. The theoretical maximum luminaire spacing is 12 mounting heights. From a practical standpoint, the medium distribution is predominantly used in

highway practice, and the spacing of luminaires normally does not exceed five to six mounting heights. Short distributions are not used extensively for reasons of economy, because extremely short spacing is required. At the other extreme, the long distribution is not used to any great extent because the high beam angle of maximum candlepower often produces excessive glare.

- **Lateral Light Distribution:** IES has developed seven classifications for lateral light distribution. The following provides application guidelines for each luminaire type:
  - **Type I:** The Type I luminaire is placed in the center of the roadway or area where lighting is required. It produces a long, narrow, oval-shaped lighted area. Some types of high-mast lighting are considered a modified form of Type I.
  - **Type I – 4-Way:** This luminaire type is located over the center of the intersection and distributes the lighting along the four legs of the intersection.
  - **Type II:** The Type II luminaire is placed on the side of the roadway or edge of the area to be lighted. It produces a long, narrow, oval-shaped lighted area which is usually applicable to narrower roadways.
  - **Type II – 4-Way:** This luminaire type is placed at one corner of the intersection and distributes the light along the four legs of the intersection.
  - **Type III:** The Type III luminaire is placed on the side of the roadway or edge of the area to be lighted. It produces an oval-shaped lighted area and is usually applicable to medium width roadways.
  - **Type IV:** The Type IV luminaire is placed on the side of the roadway or the edge of area to be lighted. It produces a wider, oval-shaped lighted area and is usually applicable to wide roadways.
  - **Type V:** The Type V luminaire is located over the center of the roadway, intersection, or area to be lighted. It produces a circular, lighted area. Type V often is used in high-mast lighting applications.
- **Control of Distribution:** As the vertical light angle increases, disability and discomfort glare also increase. To distinguish the glare effects on the driver created by the light source, IES has defined the vertical control of light distribution as follows:

  - **Cutoff (C):** A luminaire light distribution is designated as C when the candlepower per 1000 lamp lumens does not numerically exceed 25 (2.5%) at an angle of 90° above nadir (i.e., horizontally), and 100 (10%) at a vertical angle 80° above nadir. This applies to any lateral angle around the luminaire.
  - **Semi-Cutoff (SC):** A luminaire light distribution is designated as SC when the candlepower per 1000 lamp lumens does not numerically exceed 50 (5%) at an angle of 90° above nadir (i.e., horizontally), and 200 (20%) at a vertical angle of 80° above nadir. This applies to any lateral angle around the luminaire.
  - **Non-Cutoff (NC):** A luminaire light distribution is designated as NC where there is no limitation on the zone above the maximum candlepower.

  A plan view of the theoretical light distribution (i.e., roadway coverage) and schematics of the intended application of each type of IES luminaire are illustrated in Figure 15.4.

- **Mounting Heights:** Higher mounting heights used in conjunction with higher wattage luminaires enhances lighting uniformity and typically reduces the number of light poles needed to produce the same illumination level. In general, higher mounting heights tend to produce a more cost-effective design. For practical and aesthetic reasons, the mounting height should remain constant throughout the system. The manufacturer's photometric data is required to determine an appropriate mounting height. Typical mounting heights used by TDOT for conventional highway lighting purposes range from 35 feet to 55 feet. Mounting heights for light towers typically are greater than 80 feet.

- **Coefficient of Utilization:** A utilization curve is used to obtain a luminaire’s CU. Manufacturers typically provide utilization curves and Isolux diagrams with each of their respective luminaire products. Figure 15.5 illustrates a sample utilization curve. The utilization curve relates to the luminaire rather than to the light source. It provides the percentage of bare lamp lumens which are utilized to light the pavement surface. If the luminaire is placed over the traveled way (i.e. out from the curb or edge of pavement), the total lumen utilization is determined by adding the street-side and curb-side (i.e. house-side) light. In essence, the utilization curve defines how much of the total lumen output reaches the area being lighted.

Figure 15.4 – Plan View of Roadway Coverage from IES Luminaires

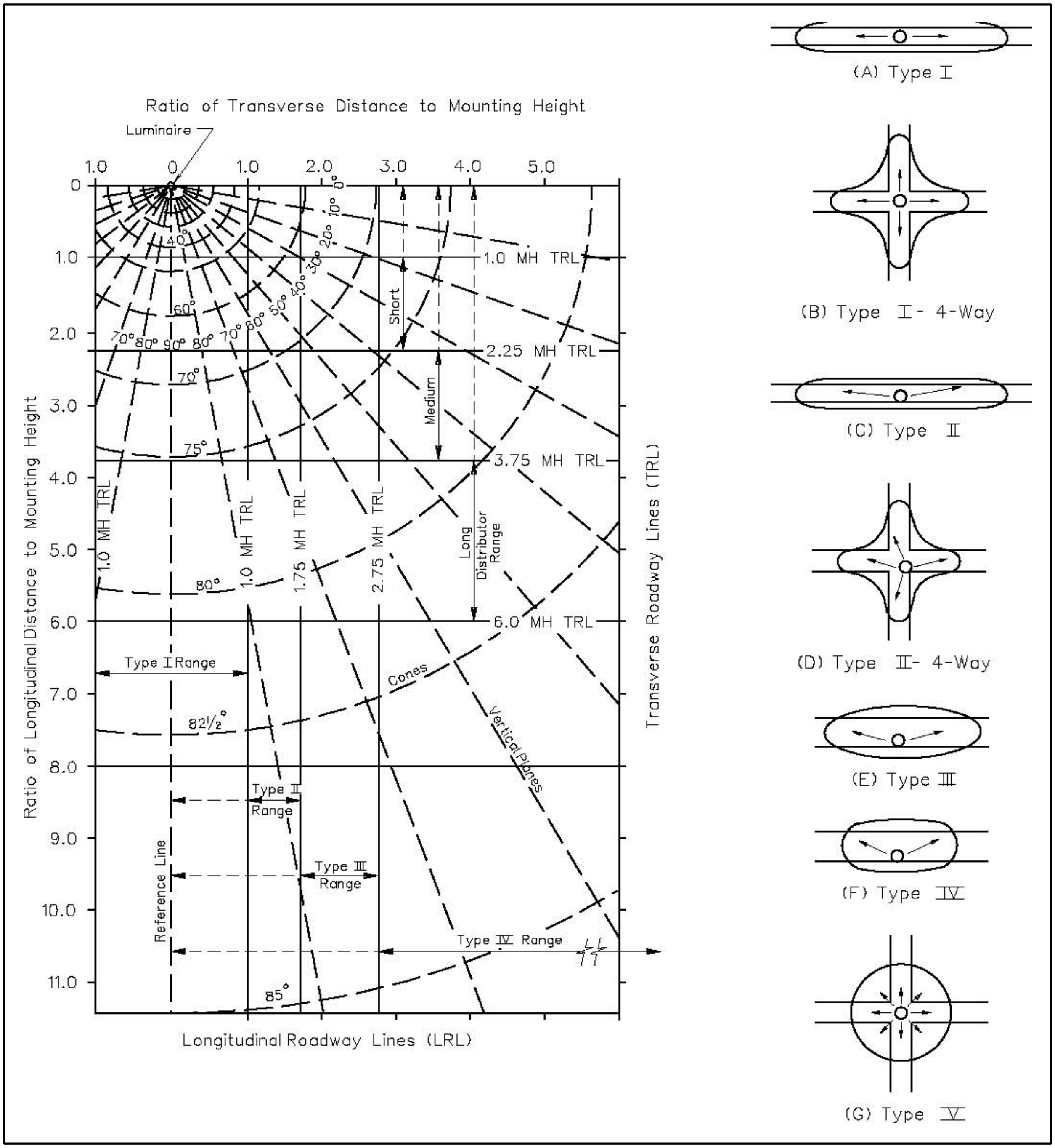
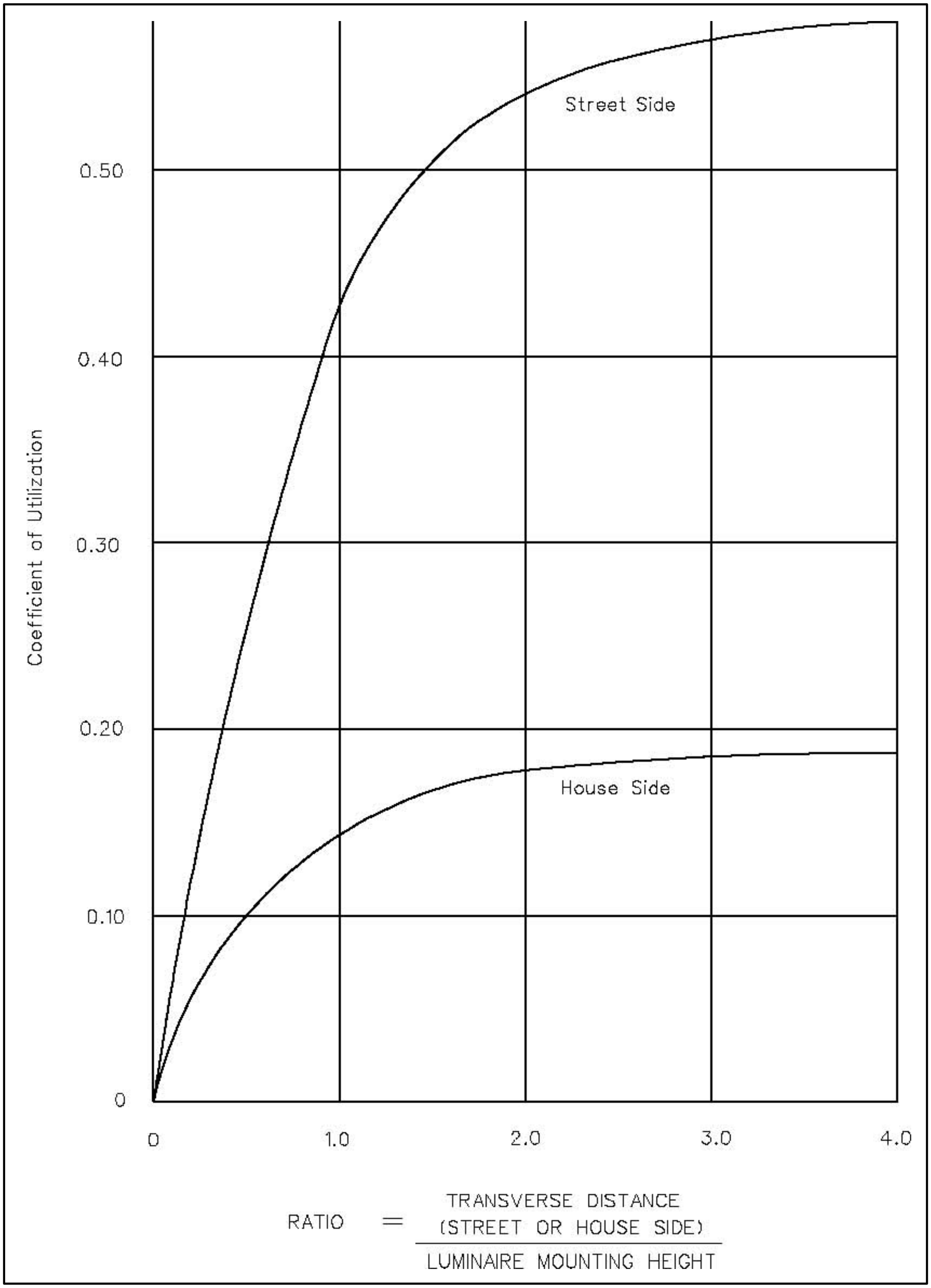


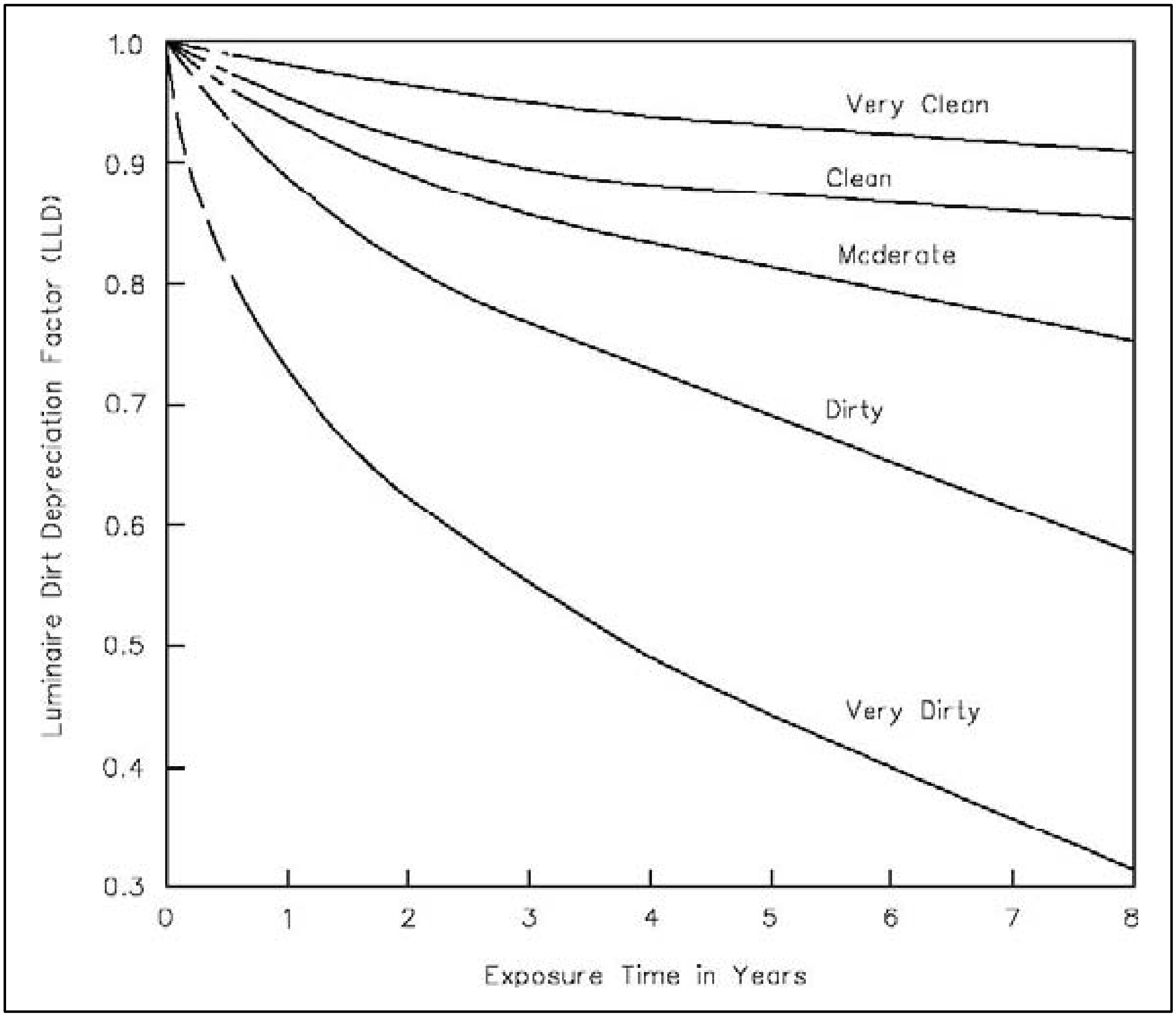
Figure 15.5 – Sample Utilization Curve



Note: The utilization curve will vary with each manufacturer and luminaire type.

- **Light Loss Factors:** The efficiency of a luminaire depreciates over time. The designer must estimate this depreciation to properly estimate the light available at the end of the lamp's serviceable life. The following briefly discusses these factors:
    - **Lamp Lumen Depreciation Factor:** As the lamp progresses through its serviceable life, the lumen output of the lamp decreases. This is an inherent characteristic of all lamps. The initial lamp lumen value is adjusted by a lumen depreciation factor to compensate for the anticipated lumen reduction. This assures that a minimum level of illumination will be available at the end of the assumed lamp life. This information is usually provided by the manufacturer.
    - **Luminaire Dirt Depreciation Factor:** Dirt on the exterior and interior of the luminaire, and to some extent on the lamp itself, reduces the amount of light reaching the pavement. Various degrees of dirt accumulation may occur depending upon the area in which the luminaire is located. Industrial areas, automobile exhaust, diesel trucks, dust and other environs all affect the dirt accumulation on the luminaire. Higher mounting heights, however, tend to reduce the vehicle-related dirt accumulation. The relationship between the ambient environment and the expected level of dirt accumulation is shown in Figure 15.6.
    - **Equipment Factor:** Equipment factor is a general factor encompassing luminaire losses due to all other factors such as ballast factor, manufacturing tolerances, voltage drop, lamp position, ambient temperature, and luminaire component depreciation.
    - **Light Loss Factor:** The reduction factor, referred to as the total LLF (Light Loss Factor is a combination of LDDF, LLDF, and EF including voltage drop. Values in the range of 60 to 80 percent (of initial design value) are used for high-pressure sodium (45 to 65 percent for MH) general application such as regularly maintained outdoor luminaires installed on lighting poles. The use of realistic luminaire depreciation, dirt, and equipment factors, is essential in lighting design to achieve the expected lighting levels on the roadway after the lighting system is installed. Values for these factors are obtained from manufacturers' product data.

Figure 15.6 – Roadway Luminaire Dirt Depreciation Curve

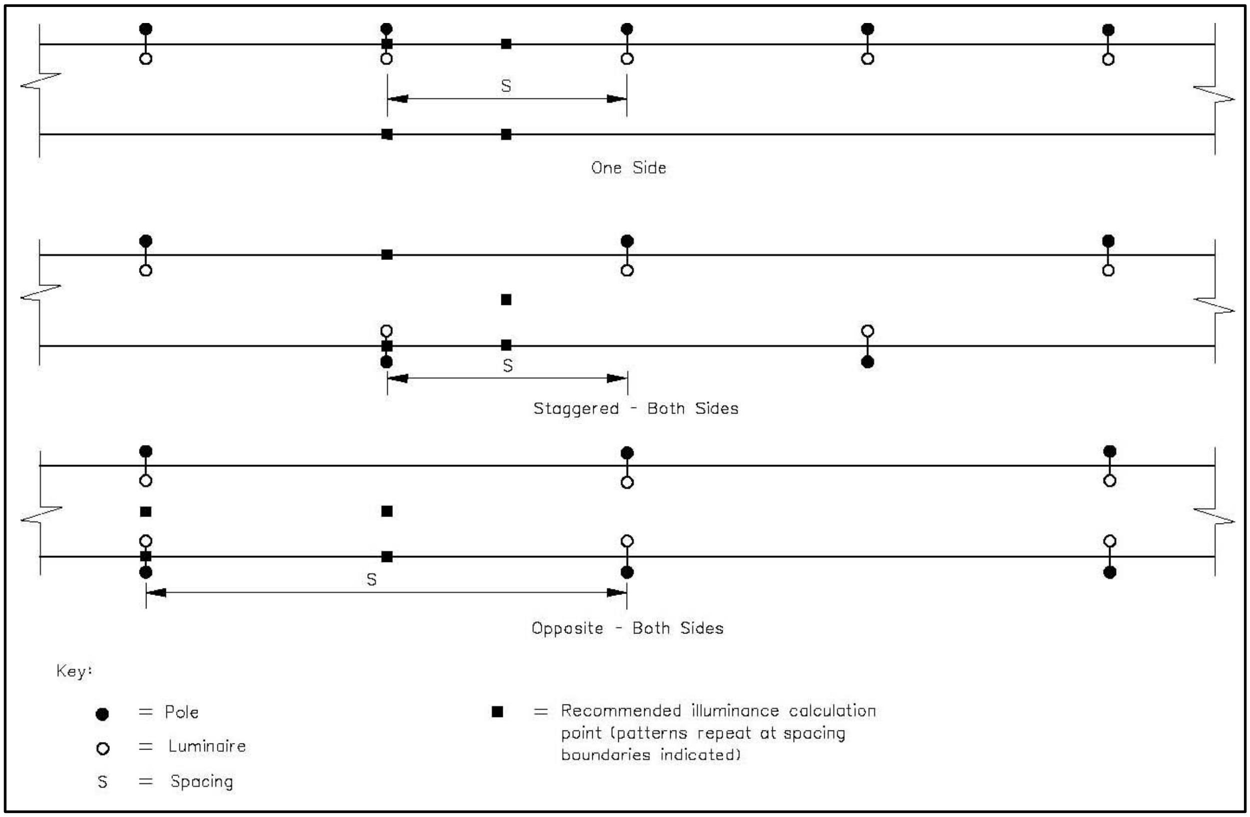


Notes:

- **Very Clean:** No nearby smoke or dust-generating activities and a low ambient contaminant level. Light traffic. Generally limited to residential or rural areas. The ambient particulate level is not more than 150 micrograms per cubic meter.
- **Clean:** No nearby smoke or dust-generating activities. Moderate to heavy traffic. The ambient particulate level is not more than 300 micrograms per cubic meter.
- **Moderate:** Moderate smoke or dust-generating activities nearby. The ambient particulate level is not more than 600 micrograms per cubic meter.
- **Dirty:** Smoke or dust plumes generated by nearby activities may occasionally envelope the luminaires.
- **Very Dirty:** Similar to Dirty, but the luminaires are commonly enveloped by smoke or dust plumes.

- **Luminaire Arrangement:** Figure 15.7 illustrates typical luminaire arrangements for conventional highway lighting designs and the recommended illuminance calculation points for the various arrangements.

Figure 15.7 – Typical Luminaire Arrangements for Conventional Highway Lighting Design



15.3.5 Other Design Considerations

In addition to the items discussed in the previous sections, consider the following when designing the highway lighting system:

- **Signs:** Place light poles to minimize interference with the driver's view of the roadway and any highway signs. Do not permit luminaire brightness to seriously detract from the legibility of signs at night.
- **Structures:** Place light poles sufficiently away from overhead bridges and sign structures to minimize glare and distracting shadows on the roadway surface.
- **Trees:** Insufficiently pruned trees can cause shadows on the roadway surface and reduce the luminaire's effectiveness. Place the light standard and/or design the luminaire with a height and mast-arm length to negate such adverse effects.
- **Location:** Typically, lighting standards should be placed a minimum of 50 feet from overhead sign structures, and a minimum of 50 feet from overhead bridges.

15.3.6 Roadside Safety Considerations

Light poles should be installed so that they will not present a roadside hazard to the motoring public. However, the physical roadside conditions often dictate their placement. It is important to recognize this limitation. Overpasses, sign structures, guardrail, roadway curvature, right-of-way, gore clearances, proximity to roadside obstacles, and lighting equipment limitations are all physical factors that can limit the placement of light poles. The designer also must consider factors such as roadway and area classification, design speed, posted speed, safety, aesthetics, economics, and environmental impacts. In addition, there should be adequate right-of-way, driveway control, and utility clearance. Consider the following when determining the location of light poles:

- **Clear Zone:** Where practical, place light poles outside the roadside clear zone. See the TDOT Roadway Design Guidelines and *TDOT Standard Drawing RD01-S-12* for additional information on roadside clear zone.
- **Breakaway Supports:** Unless located behind a roadside barrier or crash cushion which is necessary for other safety-related reasons, conventional light poles placed within the roadside clear zone shall be mounted on breakaway supports. Poles outside the clear zone also should be mounted on breakaway supports where there is a possibility of them being struck by errant vehicles. Be aware that falling poles and mast arms may endanger bystanders (e.g., pedestrians, bicyclist, motorists). Consider the following during design:
    - **Pedestrians:** In areas where pedestrians, bicyclists, or building structures and windows may be struck by falling poles or mast arms after a crash, evaluate the relative risks of mounting the light pole

on a breakaway support. Examples of locations where the hazard potential of providing a breakaway support to pedestrian traffic would be greater than a non-breakaway support would be to vehicular traffic include transportation terminals, sports stadiums and associated parking areas, tourist attractions, school zones, central business districts, and local residential neighborhoods where the posted speed limit is 30 mph or less. In these locations, non-breakaway supports will be used. Other locations which require the use of non-breakaway supports, regardless of the amount of pedestrian traffic, are rest area and weigh station parking lots and combination luminaire and traffic signal poles.

- **Breakaway Bases:** All breakaway devices will comply with the applicable AASHTO requirements for breakaway structural supports.
- **Breakaway Support Stub:** Any substantial portion of the breakaway support that will remain after the light pole has been struck will have a maximum projection of four inches above the finished grade within a 5-foot chord above the foundation in accordance with AASHTO criteria.
- **Wiring:** All light poles that require breakaway supports will be served by underground wiring and designed with quick disconnect splices.
- **Light Towers:** Light Towers used in high-mast lighting applications will not be mounted on breakaway supports. Also, they will not be located within the roadside clear zone unless shielded by guardrail or crash cushions.
- **Bridge Parapets and Concrete Barriers:** Where poles are mounted atop bridge parapets and concrete barriers, they will be mounted on non-breakaway supports.

➢ **Gore Areas:** Where practical, locate light poles outside the gore areas of exit and entrance ramps. No lighting support should be placed within the clear zone of a gore area.

➢ **Horizontal Curves:** Place light poles on the inside of sharp curves and loops. Where poles are located on the inside radius of superelevated roadways, provide sufficient clearance to avoid being struck by trucks.

➢ **Maintenance:** When determining pole locations, consider the hazards which will be encountered while performing maintenance on the lighting equipment.

➢ **Barriers:** Use the criteria provided in chapters 1-305.25, 3.1, 2-135.00, and 2-135.05 in the TDOT Roadway Design Guidelines and TDOT Standard Drawing RD01-S-12 for additional information on roadside clear zone to design and place light poles in conjunction with roadside barriers. Consider the following additional guidelines:

- **Placement:** Where a roadside barrier is provided, place all light poles behind the barrier.
- **Deflection:** Light poles placed behind a roadside barrier should be offset by at least the deflection distance of the barrier. This will allow the railing to deflect without hitting the pole. If this clearance distance is not available, such as in extreme side slope conditions, designate the stiffening of the rail.
- **Concrete Barriers:** Light poles that are shielded by a rigid or non-yielding barrier do not require a breakaway support.
- **Impact Attenuators:** Locate light poles, either with or without a breakaway support, such that they will not interfere with the functional operation of any impact attenuator or other safety device.

➢ **Protection Features:** Do not use protection features, such as barriers, for the primary purpose of protecting a light pole.

➢ **Longitudinal Adjustments:** Locate light poles to balance both safety and lighting needs. Adjustments on the order of five feet are permissible in the field to accommodate utilities or drainage facilities provided the new location does not constitute a roadside hazard. Larger adjustments need approval by the Traffic Design Office.

➢ **ADA Requirements:** Contact the local agency for their specific ADA requirements.

15.4 Lighting Design

When designing a highway lighting system, there are numerous factors to consider. This section presents design considerations commonly encountered in highway lighting designs and presents TDOT's criteria, policies, and procedures on these issues. Table 15.2 presents typical highway lighting design parameters used by TDOT.

Table 15.2 – Typical TDOT Highway Lighting Design Parameters

Typical TDOT Highway Lighting Design Parameters (TDOT Recommends The Illuminance Method Of Design)	
Light Loss Factor (i.e., LLD • LDD)	0.70 – 0.81 [(1)]
Percent of Voltage Drop Allowed	3%
Typical Parameters for Conventional Lighting (Interstate — Rural)	Aluminum or Steel Pole, Single (or Twin) Tenon Mounting, 45-foot Mounting Height, 250W or 400W HPS Multi-Mount Luminaire, Breakaway Base where Justified
Typical Parameters for Conventional Lighting (Interstate — Urban)	Aluminum Pole, Off-set (or Mast Arm) Mounting, 45-foot Mounting Height, 250W or 400W HPS Horizontal-Mount Luminaire, IES Classification: Cutoff or Semi-Cutoff
Typical Pavement Classification	Class R1 (Concrete), Class R3 (Asphalt)
Typical IES Luminaire Classification for Conventional Highway Lighting	Type II, Type III, or Type IV Medium Distribution (M) Cutoff (C) or Semi-Cutoff (SC)
Typical Luminaire Pole Arrangement	Staggered, Opposite, or Same Side

[(1)] The Light Loss Factor may vary as the Dirt Depreciation Factor varies. In urban areas with higher pollution and/or smog, the designer should use the higher range of values. In remote areas the lower range of the Dirt Depreciation Factor may be used. When calculating the light loss factor, the designer should consider the location of the system (e.g. urban, rural areas, remote locations, etc.).

15.4.1 Methodologies

There are three lighting design methodologies available for use in highway lighting design, Illuminance, Luminance, and Small-Target-Visibility. The IES has been a leader in developing these methodologies (see the publication American National Standard Practice for Roadway Lighting, ANSI/IES RP-8-14). Calculations for both the Illuminance and Luminance methodologies along with consideration for Veiling Luminance should be used for all TDOT lighting projects. Both the Illuminance and Luminance methodologies require the designer to consider veiling luminance and limit the ratio to the values listed in Tables 15.3 and 15.4. The following sections briefly describe each of the available design methodologies.

- **Illuminance:** The Illuminance Methodology is the oldest and simplest to use of the three methodologies. Illuminance in roadway lighting is a measure of the light incident on the pavement surface. It is measured in foot-candles (Lux). 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 only accounts for 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 (Eh), or quantity of light, and the uniformity ratio (Eh/Emin), or quality of light, maximum veiling luminance (Lv), and veiling luminance ratio (Lv to Lave).

- **Luminance:** Luminance in roadway lighting is a measure of the reflected light from the pavement surface that is visible to the motorist's eye. Reflected light from an object or surface is known as brightness. Objects are distinguished by contrast from their difference in brightness. Brightness is expressed mathematically as luminance: the luminous intensity per unit area directed towards the eye. 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, etc. It is difficult to predict or control such factors. Compared to Illuminance, the Luminance methodology is considerably more complicated to understand and use. Components of luminance design include average maintained luminance (Lave), minimum luminance (Lmin), maximum luminance (Lmax), maximum veiling luminance (Lv), and ratios of Lave to Lmin, Lmax to Lmin, and veiling luminance ratio (Lv to Lave).

- **Veiling Luminance Ratio:** In conjunction with the luminance method, the evaluation of glare from the fixed lighting system is relevant and included with the luminance criteria. The disability glare (veiling luminance) has been quantified to give the designer the information to identify the veiling effect of glare as a percent of average overall luminance. A calculation of reflected light toward the eye of the observer is made for each roadway point 272 feet from the observer, summing the luminance from each luminaire. The distance between points should not exceed 15 feet. Calculations should include a minimum of three luminaire cycles downstream and one luminaire cycle upstream from reference (0.0) REF.

Luminance calculations place the observer's (motorist's) eye height at 4.8 feet above grade. The 4.8 feet is a design figure used internationally and does not affect the driver eye height of 3.5 feet. The observer's line of sight is downward at one degree below horizontal and parallel to the edge of the roadway along lines one-quarter roadway lane width from the edge of each lane. As shown in Figure 15.8, the observer is positioned at a point 272 feet before the first point in the cycle to be evaluated. Because of the geometric configuration for analysis, the veiling luminance calculation is only typically required on straight roadways with clear visibility. This is not to say that the veiling luminance calculation is to be eliminated altogether, rather it should be eliminated only for:

- Short roadway sections and Isolated intersections;
- Curved roadway sections where the points of analysis are unachievable; or
- Where visibility of the calculation points are for any reason obstructed.

Veiling luminance ratio requirements are considered using both the luminance and illuminance design criteria. Criteria for veiling luminance ratio can be obtained from Tables 15.3 and 15.4.

Figure 15.8 – Calculation Points for Luminance and Illuminance Design Methods

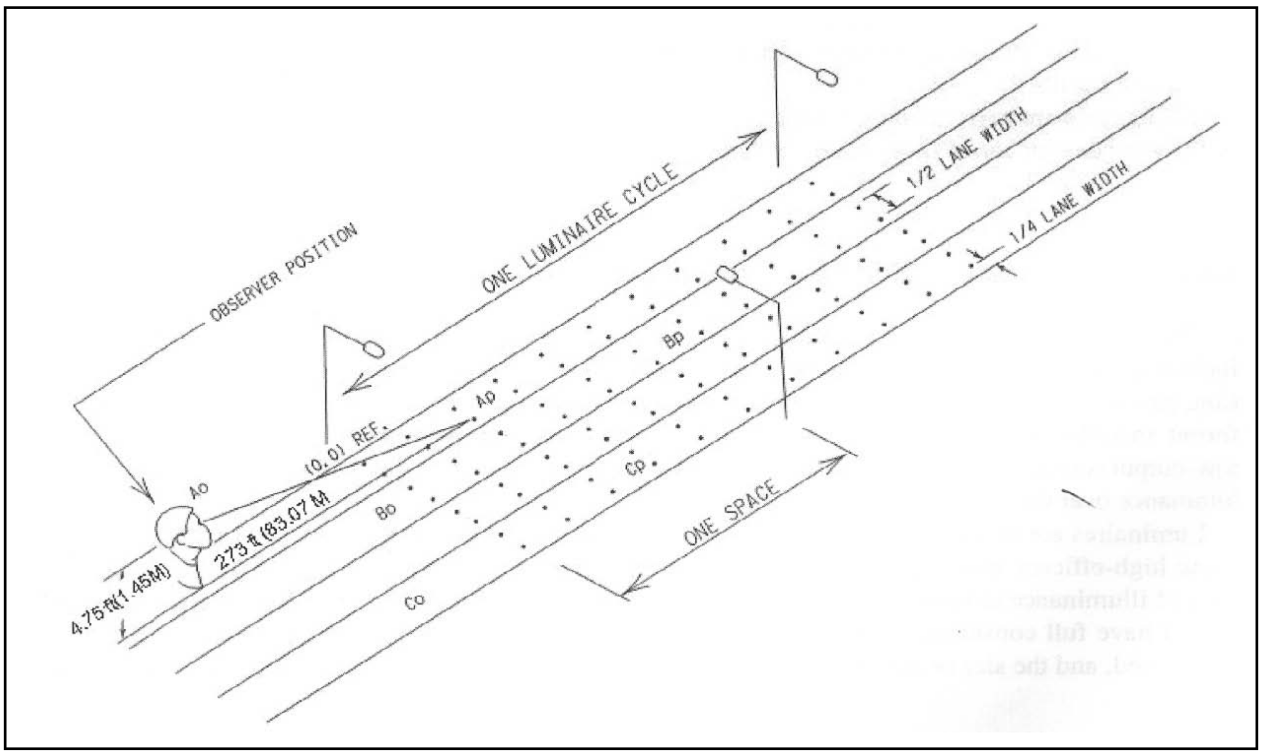


Table 15.3 – TDOT Illuminance Design Criteria

Roadway Facility Classification	**Area Classification (Pedestrian Conflict Areas) (2)**	**Average Maintained Horizontal Illuminance (E_h) Foot-candle (lux) (4)**			**Uniformity Ratio (6) (Avg/Min.) Max**	**Veiling Luminance Ratio (3) LVmax/Lavg**
		Pavement Classification				
		R1 (Min)	**R2 & R3 (Min)**	**R4 (Min)**		
Freeway (Interstate)	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)		
Expressway	Low	0.6 (6)	0.8 (8)	0.8 (8)		
	Medium	0.8 (8)	0.9 (9)	0.9 (9)		
	High	1.0 (10)	1.1 (11)	1.1 (11)		
Major Arterial	Low	0.6 (6)	0.8 (8)	0.8 (8)	3:1	
	Medium	0.8 (8)	1.2 (12)	1.0 (10)		
	High	1.1 (11)	1.6 (16)	1.4 (14)		
Minor Arterial	Low	0.5 (5)	0.7 (7)	0.7 (7)	4:1	
	Medium	0.8 (8)	1.0 (10)	0.9 (9)		
	High	0.9 (9)	1.4 (14)	1.0 (10)		
Collector	Low	0.4 (4)	0.6 (6)	0.5 (5)		0.4
	Medium	0.6 (6)	0.8 (8)	0.8 (8)		
	High	0.8 (8)	1.1 (11)	0.9 (9)		
Local	Low	0.3 (3)	0.4 (4)	0.4 (4)	6:1	
	Medium	0.5 (5)	0.7 (7)	0.6 (6)		
	High	0.6 (6)	0.8 (8)	0.8 (8)		
Alleys	Low	0.2 (2)	0.3 (3)	0.3 (3)		
	Medium	0.3 (3)	0.4 (4)	0.4 (4)		
	High	0.4 (4)	0.6 (6)	0.5 (5)		
Sidewalks	Low	0.3 (3)	0.4 (4)	0.4 (4)	6:1	
	Medium	0.6 (6)	0.8 (8)	0.8 (8)	4:1	
	High	0.9 (9)	1.3 (13)	1.2 (12)	3:1	
Walkways and Bikeways (2)	All	1.4 (14)	2.0 (20)	1.8 (18)	3:1	
Rest Areas And Weigh Stations						
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)			
Minor Activity Areas	All	0.4 (4)	0.5 (5)		6:1	

Table 15.4 – TDOT Luminance Design Criteria

<table>
<tr><th colspan="2">Road and Pedestrian Conflict Area</th><th rowspan="2">Average Luminance Lave (cd/m2) (Min)</th><th rowspan="2">Uniformity Ratio Lavg/Lmin (Maximum Allowed) (Max)</th><th rowspan="2">Uniformity Ratio Lmax/Lmin (Maximum Allowed) (Max)</th><th rowspan="2">Veiling Luminance Ratio LVmax/Lmin (Maximum Allowed) (Max) (3)</th></tr>
<tr><th>Road</th><th>Pedestrian Conflict Area (2)</th></tr>
<tr><td>Freeway Class A</td><td>N/A</td><td>0.6</td><td rowspan="5">3.5</td><td rowspan="5">6.0</td><td rowspan="11">0.3</td></tr>
<tr><td>Freeway Class B</td><td>N/A</td><td>0.4</td></tr>
<tr><td rowspan="3">Expressway</td><td>Low</td><td>0.6</td></tr>
<tr><td>Medium</td><td>0.8</td></tr>
<tr><td>High</td><td>1.0</td></tr>
<tr><td rowspan="3">Major Arterial</td><td>Low</td><td>0.6</td><td>3.5</td><td>6.0</td></tr>
<tr><td>Medium</td><td>0.9</td><td>3.0</td><td>5.0</td></tr>
<tr><td>High</td><td>1.2</td><td>3.0</td><td>5.0</td></tr>
<tr><td rowspan="3">Minor Arterial</td><td>Low</td><td>0.6</td><td>3.5</td><td>6.0</td></tr>
<tr><td>Medium</td><td>0.9</td><td>3.0</td><td>5.0</td></tr>
<tr><td>High</td><td>1.2</td><td>3.0</td><td>5.0</td></tr>
<tr><td rowspan="3">Collector</td><td>Low</td><td>0.4</td><td>4.0</td><td>8.0</td><td rowspan="6">0.4</td></tr>
<tr><td>Medium</td><td>0.6</td><td>3.5</td><td>6.0</td></tr>
<tr><td>High</td><td>0.8</td><td>3.0</td><td>5.0</td></tr>
<tr><td rowspan="3">Local</td><td>Low</td><td>0.3</td><td rowspan="3">6.0</td><td rowspan="3">10.0</td></tr>
<tr><td>Medium</td><td>0.5</td></tr>
<tr><td>High</td><td>0.6</td></tr>
</table>

Note: Use Illuminance requirements for sidewalks, walkways and bikeways.

The following notes may apply to the Illuminance Method and the Luminance Method:

1. Meet the Illuminance design method requirements and the Luminance design method requirements and meet veiling luminance requirements for both Illuminance and the Luminance design methods.
2. Assumes a separate facility. For Pedestrian Ways and Bicycle Ways adjacent to roadway, use roadway design values. Use R3 requirements for walkway/bikeway surface materials other than the pavement types shown. Other design guidelines such as IESNA or CIE may be used for pedestrian ways and bikeways when deemed appropriate.
3. LV(max) refers to the maximum point along the pavement, not the maximum in lamp life. The Maintenance Factor applies to both the LV term and the Lavg term.
4. There may be situations when a higher level of illuminance is justified. The higher values for freeways may be justified when deemed advantageous by the agency to mitigate off-roadway sources.
5. Physical roadway conditions may require adjustment of spacing determined from the base levels of illuminance indicted above.
6. Higher uniformity ratios are acceptable for elevated ramps near high-mast poles.
7. See AASHTO publication entitled, “A Policy on Geometric Design of Highways and Streets” for roadway and walkway classifications.

- **Small-Target-Visibility:** STV has been proposed as an alternative lighting design methodology to better define actual driver visibility requirements. Both luminance and STV are considerably more complex than illuminance. Luminance designs depend on pavement reflectance characteristics, observer position, and luminaire location and performance. STV designs depend on identical parameters and add the complexity of an array of seven-inch, flat targets placed perpendicularly to the pavement surface. The STV methodology is used to calculate the collective visibility of the targets, expressed as a weighted average, for a given design. Theoretically, STV should closely approximate actual driver visibility; however, there is not yet sufficient field experience to calibrate the STV model. The STV method has not been adopted by AASHTO because it does not adequately describe visibility in the roadway scene.
- **TDOT Design Methodology:** The Illuminance methodology shall be used in roadway lighting design on all TDOT lighting projects. This shall also include the calculations necessary to obtain the veiling luminance ratio. Due to the complexity and the repetitive nature of these calculations, TDOT will require the designer to use computerized design techniques.

15.4.2 Computerized Design

The highway lighting design process is an iterative process that is quite effectively implemented by computer. If criteria are not initially satisfied, it will be necessary to change design parameters (e.g. pole spacing, mounting height, luminaire wattage) until an acceptable alternative is found. This process will be repeated until the design is optimized to meet the selected criteria. For computerized designs prepared by outside consultants, the consultant will provide the program’s name and version and the input data and output reports in either printed, or electronic format, or both.

15.4.3 Electrical Design

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 while 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 Section 15.4.1. Upon completion of the photometric design, the electrical design can be initiated.

- **Electrical Design Steps:**
  1. **Determine the service voltage provided for the lighting design:** It is the responsibility of the lighting designer to verify, with the Utility Owner/Maintaining Agency (See Section 15.3.2), the service voltage that shall be provided for the lighting design. The designer

should indicate that the contractor coordinate with the power company to set the service transformer to the proper tap to ensure that the nominal service voltage is achieved. Typically, the single phase, service voltage may be 120 V, 240 V, or 480 V. If requested, the designer might be able to obtain a higher service voltage from the Utility Owner/Maintaining Agency.

2. **Determine the wire size to be used:** It is the responsibility of the lighting designer to verify, with the Utility Owner/Maintaining Agency, the wire size that may be used throughout the project. If no specific wire size is required to meet the specifications of a Utility Owner/Maintaining Agency, the lighting designer shall use sound engineering judgment to select adequate wire sizes for the lighting design.
3. **Circuit breakers:** It is the responsibility of the lighting designer to verify, with the utility owner/maintaining agency, the maximum allowable main circuit breaker size that may be utilized. Maintain standard sized circuit breakers in the control center. A spare circuit breaker should be included in each control center. When determining the size of the breakers an appropriate safety factor should be used.
4. **Establish location for control centers:** The lighting designer shall establish a safe location for the control centers. These locations shall be verified and approved by the Utility Owner/Maintaining Agency and the TDOT Project Manager.
5. **Voltage Drop Calculations:** Items 1 through 4 above are essential in the determination of the voltage drop calculation. The maximum voltage drop should not exceed 3%. However, with consent from the TDOT manager, voltage drop of up to 5% might be considered. The lighting designer should follow the voltage drop calculations as detailed below.
6. **Equipment Selection and Sizing:** The lighting designer shall use recommended safety factors and industry standards when selecting and sizing the electrical equipment.
7. **Wiring Schematic:** The lighting designer shall detail the wire routing for the lighting system.
8. **Inappropriate Equipment Sizing:** It is important to note, that inappropriate equipment sizing can result in major cost overrun. The lighting designer's design shall comply with the latest edition of the National Electric Code.

9. **Electrical Design Quantities:** Once the electrical design is finalized, the electrical design quantities shall be tabulated. The lighting designer shall be responsible for ensuring that the tabulated quantities mirror the final electrical design.

- **Voltage Drop Determination:** 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 generally consists of two conductors (line to line) 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. This shall be verified by the Utility Owner/Maintaining Agency. Voltage drop should be determined as follows:

  1. Determine the service voltage (VL) provided by the electrical company.
  2. Determine the lamp amperes (I) from Table 15.5 based on the lamp wattage and service voltage.
  3. Determine the resistance (R) of the wire size to be used from Table 15.6.
  4. Determine the distances (L) from each luminaire to the circuit breaker.
  5. Use the equations below in determining the percentage voltage drop for a luminaire in a two-wire single phase circuit,
  6. Or, use Equation 15.4 in determining the percentage voltage drop between outside conductors and neutral in three-wire single phase circuits. (See Note 3 in Equation 15.4).
  7. Use Equation 15.5 to determine the voltage drop for all of the luminaires being connected to the branch circuit breaker.
  8. Voltage drop should not exceed 3% as defined in this section.
  9. Calculating voltage drop, will determine the total number of luminaires that may be connected to each branch circuit breaker (See Circuit Breaker Size Determination on Page 15-42).

Table 15.5 – Lamp Amperes (HPS Mag Regular Ballast)

Watts	Lamp Amperes (I) 120 Volts	Lamp Amperes (I) 240 Volts	Lamp Amperes (I) 480 Volts
150	1.7	1.0	0.6
250	2.7	1.4	0.8
400	3.9	2.1	1.1
1000	9.1	4.6	2.3

Table 15.6 – 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

$$Vd = (2 \bullet L \bullet I \bullet R) / VL$$

Equation 15.4 – Percentage Voltage Drop for One Luminaire

Where:

Vd = percentage voltage drop for one luminaire in circuit

L = distance of luminaire to circuit breaker (ft)

I = current in conductor (lamp amperes) (See Note 1 below)

R = resistance per foot of conductor (ohms/foot) (See Note 2 below)

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

Notes:

1. Consult manufacturer's data for ampere for ballasts being considered.
2. Resistances listed in the table below are based on stranded copper conductor at 167°F operating temperature with an insulated covering and located in conduit (resistance in ohms/feet)
3. Voltage drop between one outside conductor and neutral equals one-half of voltage drop calculated by formula above for two-wire circuits.

$$\text{Total } Vd = \Sigma\, Vd$$

Equation 15.5 –Voltage Drop for Each Luminaire

Where:

Total Vd = total percentage voltage drop in one branch circuit

- **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:

  1. Determine the total number of luminaires that can be supported on one branch circuit breaker.
  2. Equation 15.6 shows the calculation to determine the size for a branch circuit breaker:
  3. Branch Circuit breaker size should be rounded to the nearest whole number. Standard size circuit breakers of 10, 20, 30, 40 and 60 amperes should be specified. Control Center Cabinets typically use four branch circuit breakers and one spare circuit breaker. However, if more circuits are required and can be supported, the Control Center Cabinet could have up to six branch circuit breakers and a spare circuit breaker.
  4. Equation 15.7 shows the calculation to determine the size for the main circuit breaker.
  5. 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.

$$BCB = (\text{Total No. of Luminaires} \times I) / 80\%$$

Equation 15.6 – Branch Circuit Breaker Size

Where:

BCB = Branch Circuit Breaker

I = Current in Conductor (Lamp Amperes) (See Table 15.5)

$$MCB = (\Sigma\ BCB) / 80\%$$

Equation 15.7 – Main Circuit Breaker Size

Where:

MCB = Main Circuit Breaker

BCB = Branch Circuit Breaker

15.4.4 Foundation, Pole Mounting, and Structural Considerations

The *TDOT Standard Specifications* and *TDOT Standard Drawings* provide pole mounting details and details for foundation materials, depth, width, reinforcing, etc. When designing a lighting system, also consider the following:

- **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. This permits drainage necessary to protect the foundation and reduces the likelihood of the foundation intensifying a collision. The foundation also is less likely to be destroyed during a collision. 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 steel (i.e. helix screw-in type) foundation is one that is commonly used by TDOT for conventional light poles. This foundation is placed in undisturbed earth using a clockwise rotation similar to a common screw. The diameter of the steel tube ranges from eight inches to ten inches and is typically six feet long. Shorter lengths may be appropriate for foundations in areas with shallow bedrock. The steel foundation will accommodate poles with 11.5 inches and 15 inches bolt circles for luminaire mounting heights ranging from 40 feet to 50 feet.
- **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 from 5.5 feet, for 30-foot poles, to 12 feet, for 65-foot poles. The use of butt base anchors also may be considered.
- **Pole Mounting on Parapets:** Poles for bridge lighting typically are mounted on specially designed concrete parapet sections. Ensure that the mounting design includes the necessary non-breakaway, high-strength bolts, leveling plate, and vibration pad.
- **Center Median Barriers:** TDOT strongly 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. Lane closures by local power companies are extremely hazardous to both the maintenance worker and the motorist. Consult the TDOT manager before beginning such a layout.
- **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:** Foundations for light towers used in high-mast lighting applications typically require specialized designs and soil surveys to ensure adequate support. A 4-foot diameter reinforced concrete foundation, to a depth as required by the soils analysis, usually is adequate for towers accommodating 80-foot luminaire mounting heights.

15.4.5 TDOT Foundation Design

When high mast interchange lighting is installed, the foundation design at each pole location shall be based on a soil test conducted and certified by a qualified, professional engineer. This certification shall be submitted along with the final construction plans to the TDOT Traffic Design Office for their records. Information from the soils testing may be also included in the plans. TDOT Standard Drawing T-L-1 tabulates estimated foundation depths as a function of pole height. When an outside consultant is used, the consultant will be charged with determining the necessary soils properties required to develop the foundation design. This information will be required at each tentative high mast pole location, as determined by an appropriate lighting design. Boring log information, extending from the surface of the ground to the minimum depth noted on TDOT Standard Drawing T-L-1 plus ten feet or to solid rock, whichever comes first, will be presented in the final design plans for the interchange lighting project. Critical soil parameters will be documented for use in the foundation design. Minimum information required at each boring site are types and depths of each soil strata, 'N' values (numbers of blows per foot using a split spoon sampler), and PP embankment, soil analysis shall be performed after compaction of the embankment. The foundation design will be performed in accordance with the latest version of AASHTO *Standard Specifications for Structural Supports for Highway Signs, Luminaires, and Traffic Signals*. As a secondary check, Equations 15.8 and 15.9 (presented in the Civil Engineering magazine, May 1969) may also be used:

$$L = \frac{2.13F}{2PpD_{-}} \left\{ \left(\frac{2.13F}{2PpD_{-}}\right)^2 + \frac{3.2M}{PpD_{-}} \right\}^{0.5}$$

Equation 15.8 – Length of Foundation

$$\Delta = \frac{2.16F}{KDL^2} \left\{ 1.33 \left(\frac{H}{L}\right) + 1 \right\}$$

Equation 15.9 – Lateral Movement of Foundation at Ground Line

Where:

L = Length of Foundation, feet
F = Resultant of all Horizontal External Loads, kips
Pp = Passive Pressure, ksf
D = Diameter of Foundation, feet (typically four feet)
M = Moment at Ground Line or Top of Footing, = F x H, feet-kips
Δ = Lateral Movement of Foundation at Ground Line, inches
K = Coefficient of Passive Subgrade Reaction, kcf
H = Distance from Ground Line to Resultant of Horizontal Loads, feet

The consultant will be charged with providing the most cost efficient design, whether it be drilled shaft, rock socket, or spread footing. The consultant shall determine the potential lateral movement of the foundation, and shall design to restrain the lateral movement to no more than 0.5 inches. Manday proposals and costs for the soils study will be reviewed and approved by the TDOT Geotechnical Engineering Office. Manday proposals and costs for the structural design of high mast foundations will be reviewed and approved by the TDOT Structures Division. Final foundation designs will be reviewed by the TDOT Structures Division. These reviews and approvals will be coordinated by the TDOT Traffic Engineering Office.

15.4.6 High-Mast Lighting Design

In general, the design of high-mast lighting systems follows the same design procedures as discussed in Section 15.3 and other sections of Section 15.4. In addition, consider the following:

- **Mounting Heights:** Mounting heights in high-mast lighting applications range from 60 feet to 180 feet. In general, heights of 100 feet to 150 feet have exhibited the most practical designs. Greater mounting heights require more luminaires to maintain illumination levels. However, greater heights allow for fewer poles and provide better light uniformity.
- **Light Source:** LED or HID are to be used for the lamps. The number of luminaires required will be determined by the area to be lighted. As a general starting point, it can be assumed that mounting heights of approximately 100 feet will require a minimum of 400,000 lumens, 600,000 lumens for mounting heights of approximately 120 feet to 130 feet, and 800,000 to 1,000,000 lumens for mounting heights of approximately 150 feet. The number of luminaires per pole typically ranges from four to six luminaires. Luminaires are typically installed in multiples of two in order to balance the lowering device ring.
- **Location:** In determining the location of light towers, review the plan view of the area to determine the more critical areas requiring lighting. 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. Do not place light towers on the end of long tangents.
  - **Signs:** Locate light towers so that they are not within the driver's direct line of sight to highway signs.

- **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. The total illumination at a point is determined by the sum of the contributions of illumination from all mast assemblies within the effective range of the point. Due to the numerous calculations, computer software may be used to make these determinations. The template methodology uses isolux templates to determine the appropriate locations for light towers. The templates may be moved around to ensure that the minimum maintained illumination is provided and the uniformity ratio has been satisfied. TDOT recommends the use of the point-by-point method. Consideration should be given to adjacent land use during the design analysis.

➢ **Navigable Airspace:** Where lighting projects are being considered in close proximity to an active airfield or airport, consider the impact the height of the light tower has on navigable airspace. For additional information, 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 Engineering Office.

15.4.7 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. Underpass lighting generally is installed to enhance driver visibility after daylight hours. 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. Favorable positioning of conventional highway luminaires adjacent to a relatively short underpass often can provide adequate illumination within the underpass without a need to provide supplemental lighting. If this action is considered, ensure that shadows cast by the conventional luminaires do not become a visibility problem within the underpass.

15.4.8 TDOT Bridge Lighting Plan

- **General Information:** Luminaires mounted on the bridge supports and bridge piers shall be approved by the TDOT Structures Division to verify that the roadway lighting installations can be adequately supported by the bridge structure. Luminaires mounted 45 feet above the pavement on bridges often become inoperable because of excessive vibration from traffic. Therefore, the mounting height for bridge lighting may vary. 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. A Bridge Layout Sheet must be prepared for inclusion in the bridge plans when lighting elements either cross or are installed on a bridge. The information may be provided in electronic format or marked up on a bridge layout sheet and given to the appropriate structural designer for his use in completing the bridge plans. 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.

  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). The quantity of individual materials is to be footnoted on the sheet along with instructions to seal any open conduit to prevent moisture from entering. Pole foundation locations are to be noted in the bridge plan. The cost of the foundations will be included in other bridge items and described by a Bridge Standard Drawing. Elements such as supports, wiring and luminaries will be installed later by the lighting contractor and are included in the lighting plans in the appropriate item for each.

- **Bridge Lighting for Structures Submittal:** For overpass and underpass bridge lighting, the lighting designer shall submit the following to structures for inclusion in the bridge plans (See Figures 15.9 and 15.10 for details):

  - Bridge name, site location, and log mile;
  - Structural lighting quantities for each bridge;
  - Locations of all conduit, junction boxes, footings, etc.

- **Bridge Lighting for Lighting Plans:** 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 Figure 15.11 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 Figure 15.12 for details):
    - 1” = 50‘ scale;
    - Number and luminaire location on 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.

Figure 15.9 – Detail of Overpass Bridge Lighting for Submittal to Structures

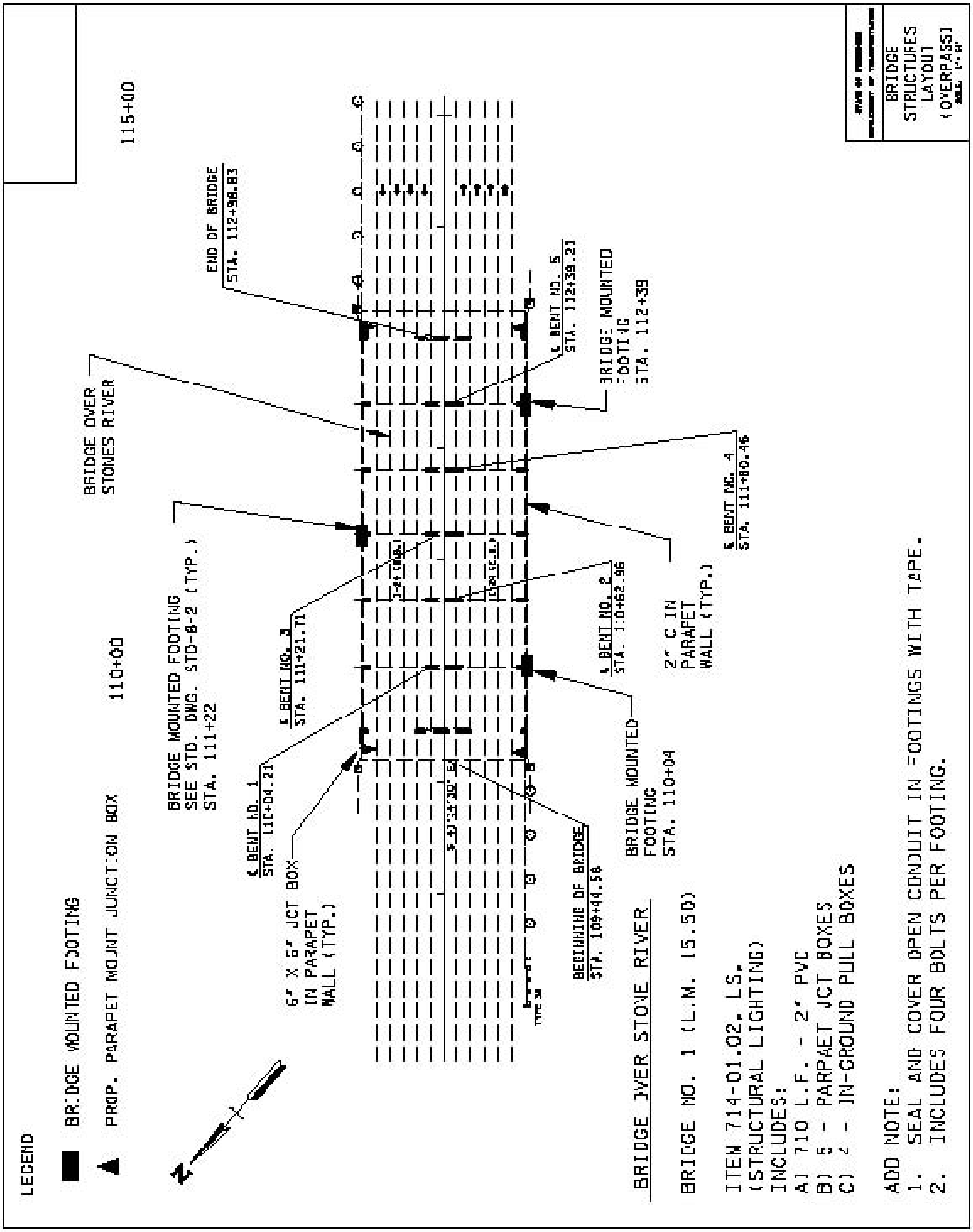


Figure 15.10 – Detail of Underpass Bridge Lighting for Submittal to Structures

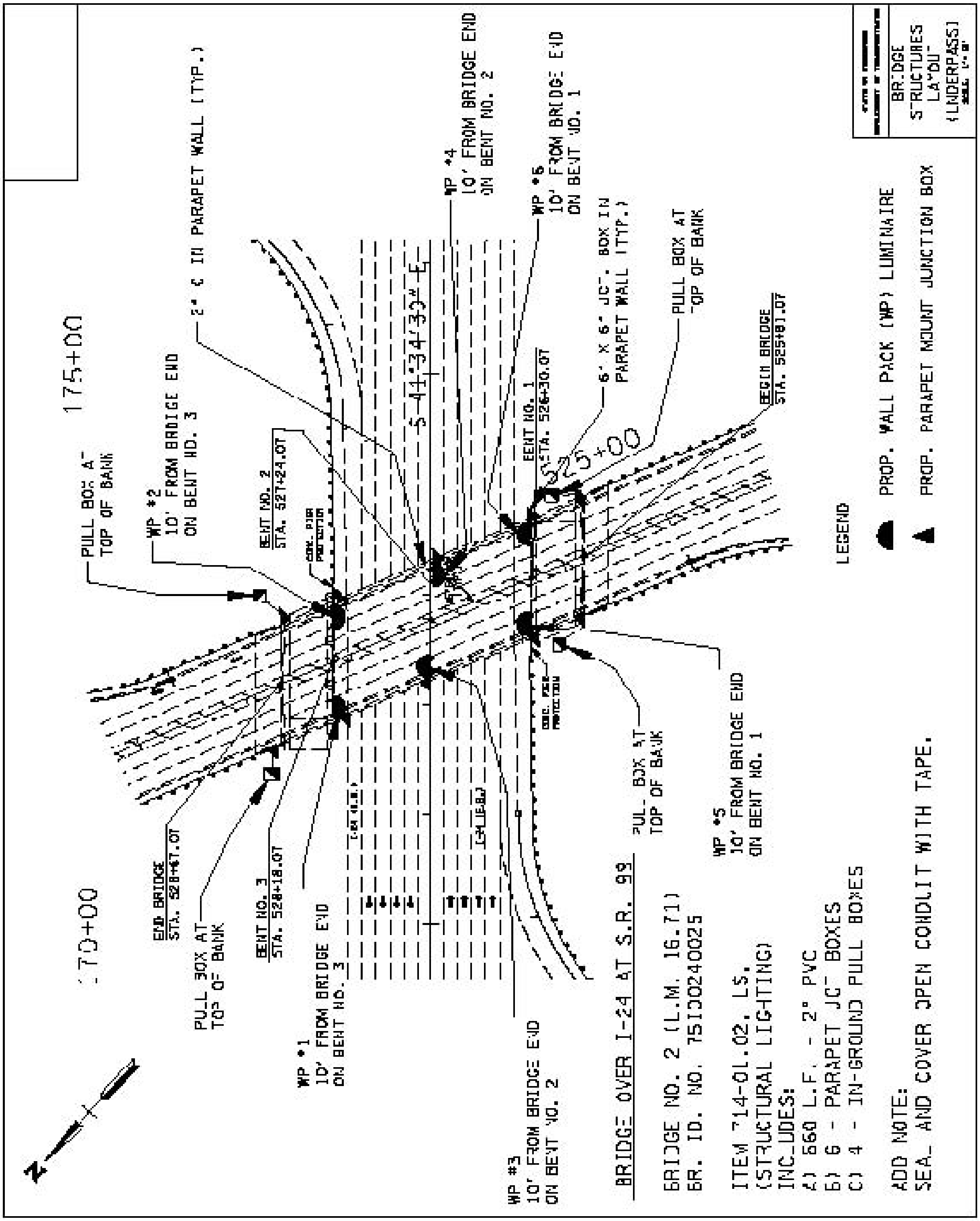


Figure 15.11 – Detail of Proposed Lighting Layout at Bridge Overpass (NTS)

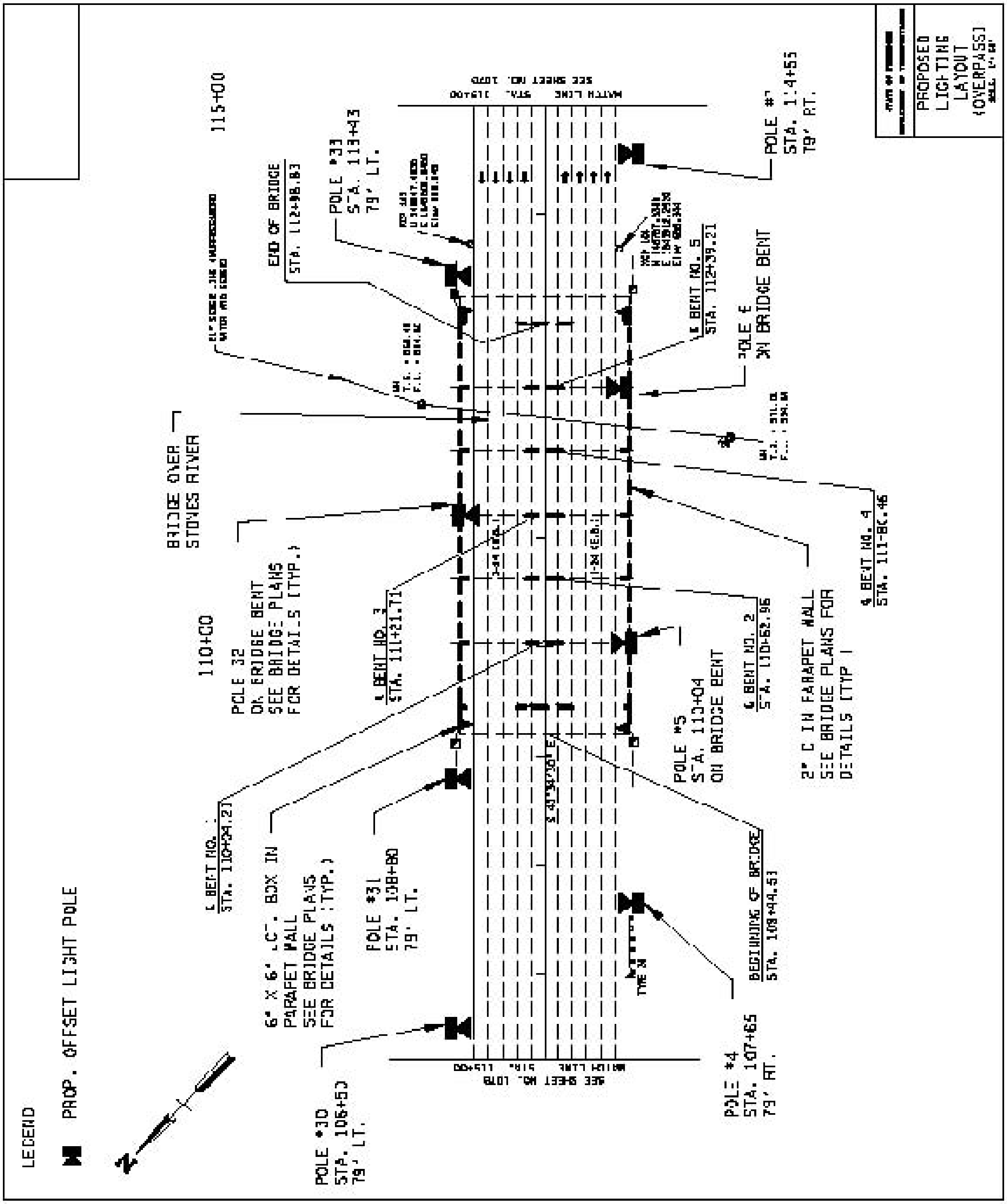
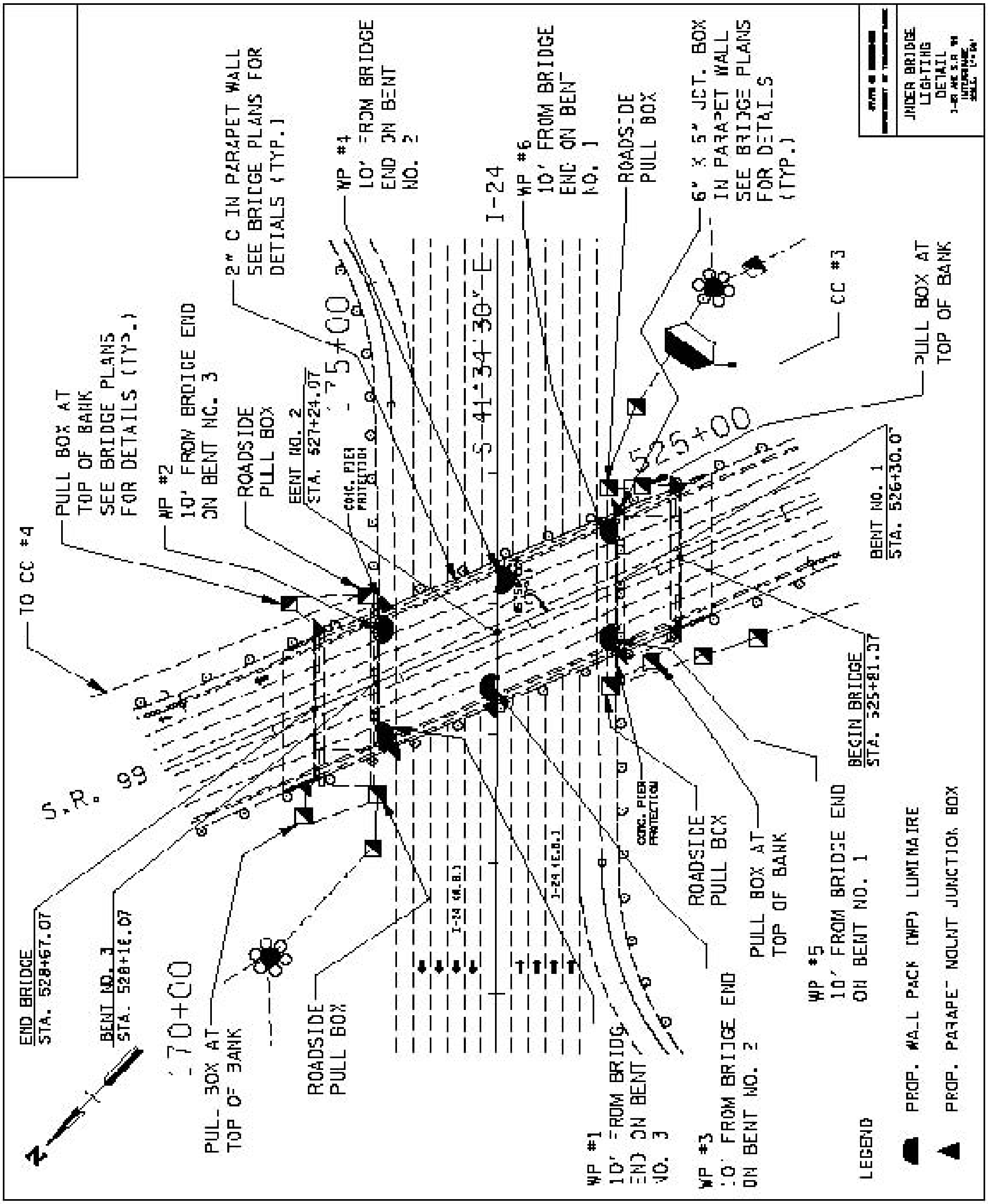


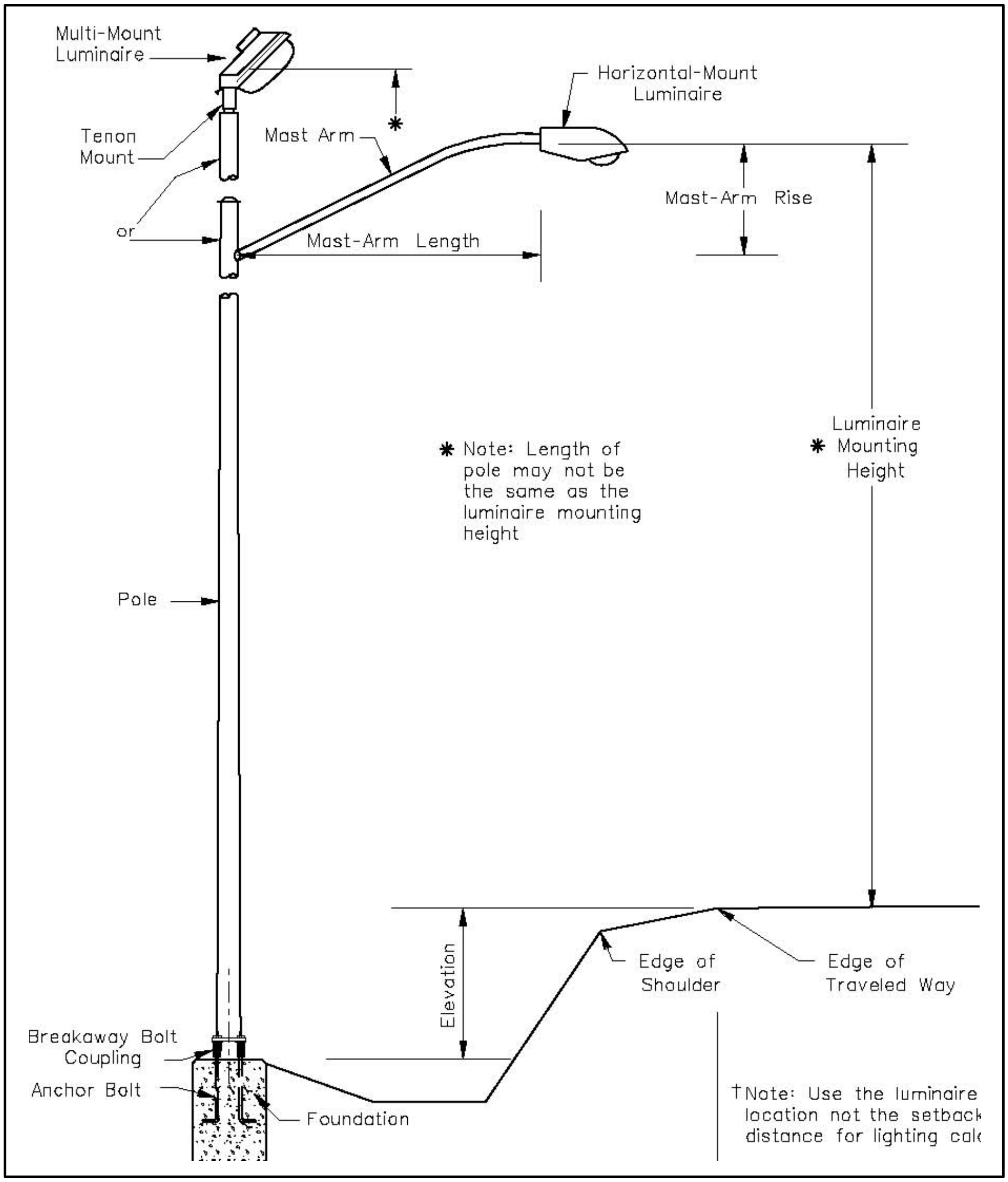
Figure 15.12 – Detail of Proposed Lighting Layout at Bridge Underpass (NTS)



15.5 Materials and 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 *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 15.13 illustrates the various components of a typical highway lighting structure.

Figure 15.13 – Typical Highway Lighting Structure



Note: Single mast arm/multi-mount luminaire shown for illustrative purposes. For other luminaire mounting types, see the TDOT electric detail sheets, highway standards, and the standard specification.

15.5.1 Foundations and Mounting

In conventional highway lighting applications, luminaire assemblies generally are attached to poles mounted along the roadway either on ground foundations or atop bridge parapets. Supports for conventional light poles may be either reinforced concrete or steel helix foundations and are constructed from typical designs. However, concrete foundations for light towers in high-mast lighting applications require special designs and soil analyses to determine adequate depth and support. Depending on factors such as roadside location, most conventional light poles will be mounted on breakaway devices. Light poles that are 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 also may be mounted on a combination mast-arm assembly and pole. 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.

15.5.2 Pole Bases

Light poles may be mounted on one of several types of bases (e.g. stainless steel flair base, transformer base, breakaway coupling base, anchor base, butt base). Selection is governed by project need. A very important distinguishing characteristic of the pole base is whether or not it is classified by AASHTO and FHWA as an acceptable breakaway device. If the pole represents a roadside hazard, it will be mounted on a breakaway device (See Section 15.3.5). The following briefly describes the pole bases used by TDOT:

- **Breakaway Bolt Coupling:** Breakaway bolt couplings are connectors or sleeves that 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.

15.5.3 Poles

Light poles for conventional highway lighting applications support luminaire mounting heights ranging 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, stainless steel, weathering steel, fiberglass, and wood. Light towers for high-mast lighting applications generally range from 80 feet to 160 feet and are designed in multiple sections.

15.5.4 Luminaires

A luminaire is a complete lighting unit consisting of a lamp, or lamps, together with the parts necessary to regulate and distribute the light. The following sections provide some general information on the basic components of the luminaire.

- **Optical System:** The optical system of the luminaire consists of a light source, a reflector, and usually a refractor. The following provides a general discussion on the optical system components:
    - **Light Sources:** There are numerous light sources for highway lighting applications. However, there are only a few practical choices when considering availability, size, power requirements, and cost effectiveness. LED and HID types are used in highway lighting applications. However, fluorescent lamps have been used to illuminate signs. The following provides information on some of the high-intensity light sources used in highway applications:
        - **LED:** LEDs have longer life, saves energy, requires less maintenance, and is environmentally friendly. LED can last for 10 years and longer. Currently, the Department requires a 10 year warranty for all LED luminaires (See Appendix E for LED specifications).
        - **High Pressure Sodium:** HPS lamps have excellent luminous efficiency, power usage, and long life. The HPS lamp produces a soft, pinkish-yellow light by passing an electric current through a combination of sodium and mercury vapors.
        - **Low Pressure Sodium:** LPS lamps are considered one of the most efficient light sources on the market. However, the LPS lamp is very long and produces a very pronounced yellow light. Light is produced by passing an electrical current through a sodium vapor.
        - **Metal Halide:** MH lamps produce better color at higher efficiency than MV lamps. However, life expectancy for MH lamps is shorter than for HPS or MV lamps. They also are more sensitive to lamp orientation (i.e. horizontal vs. vertical) than other light sources. MH lamps produce good color

rendition. Light is produced by passing a current through a combination of metallic vapors.MH can be comprised of either probe start or pulse start technologies.

- **Reflector:** The reflector is used to redirect the light rays emitted by the lamp. Its primary purpose is to redirect that portion of light emitted by the lamp that would otherwise be lost or poorly utilized. Reflectors are designed to function alone or, more commonly, with a refractor to redirect the poorly utilized portion of light to a more desirable distribution pattern. Reflectors are classified as either specular or diffused. Specular reflectors are made from a glossy material that provides a mirror-like surface. Diffuse reflectors are used where there is a need to spread light over a wider area.
- **Refractor:** The refractor is another means of optical control to change the direction of the light. 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. It also can be used to control the brightness of the lamp source.

➢ **Ballasts:** Some luminaires used in highway lighting applications have a built-in ballast. Ballasts are used to regulate the voltage to the lamp and to ensure that the lamp is operating within its design parameters. It also provides the proper open circuit voltage for starting the lamp. LED has a voltage regulator or driver (See Appendix E for LED specifications).

➢ **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. Air entering the housing for thermal breathing will typically pass through a filter to eliminate contaminates. Housing units are designed to accommodate access for lamp maintenance and adjustment (i.e., light direction and distribution).

15.5.5 Other Materials and Equipment

There are numerous other materials and equipment that are used in a highway lighting system such as quick disconnect fuse holders, controllers, photocells, surge arresters, raceways, ground rods, cabling, transformers, conduit, hand holes, and pull boxes. The use and specification of such ancillary items will depend on the particular highway lighting application and will vary on a project-by-project basis.

15.6 TDOT Lighting Plans Layouts

15.6.1 Plans Preparation

Photometric Plans, Right-Of-Way/Utility Plans, and Construction 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 and control centers included in the Roadway Right-Of-Way/Utility Plans submittal. Where it is not feasible, the lighting plans shall be submitted separately through the TDOT Traffic Engineering Office. The lighting designer shall coordinate efforts with the primary roadway designer. The designers shall work together with project scheduling, sheet numbering, 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 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 various circuits, control centers, location 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 the shall be included on one sheet. This sheet shall be submitted for inclusion with the roadway plan as a second sheet. For standalone lighting projects, the standard drawings, tabulated quantities, and notes shall be prepared on separate 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 mounting detail (pad or pole mounted).
- **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, 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.
- **Special Lighting Details:** This sheet shall include details of special fixtures or other non-standard TDOT items clearly identified and detailed.
- **Lighting Layout Sheets:** For large projects, a lighting layout sheet shall be included. This sheet 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 showing, but 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. Each standard shall be flagged to note the pole number, station, coordinates, offset, and pole height if it varies;
    - All conduits and wiring shall be shown and labeled as per the wire/conduit schedule. Special conduit for jack and bore, 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;
    - Under bridge lighting shall be shown with location of circuitry. A special detail sheet at a larger scale may be required to clarify the under bridge lighting system;
    - North arrow, legend and road names shall be on all layout sheets.
- **Underpass Lighting Details:** This sheet shall be done 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 Figure 15.12 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. The lighting designer shall provide the lighting design information to the TDOT Structures Division as depicted in Figure 15.9 and Figure 15.10. The bridge layout sheets shall be signed and sealed exclusively by the structural designer
- **Bore Locations and Geotechnical Notes:** For lighting designs that include high mast lighting, a bore location and geotechnical notes sheet shall be included in the lighting plans. This sheet shall depict the bore locations and numbers, geotechnical notes, and parameters used for the design of the high mast foundation.

- **Bore Log Details:** For lighting designs that include high mast lighting, a bore log details sheet shall be included in the lighting plans. This 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.
- **Foundation Details:** For lighting designs that include high mast lighting, a foundation details sheet shall be included in the lighting plans. This sheet shall include, but is not limited to, foundation design information such as footing dimensions, notes, materials description, and design criteria used for a complete foundation design. If the foundation can be constructed as per the standard drawings, this sheet may be eliminated.

15.6.2 Photometric/Preliminary Plans Preparation

The Designer shall prepare all components necessary for photometric/ preliminary plan submittal. The Designer shall submit, to the TDOT Design Manager, the plan sheets showing the overall project. Ensure that the photometric/preliminary plans include:

- Stationing at appropriate intervals and stationing of noses and tangent points of ramps which are formed by the roadway proper and not by the shoulder;
- Pavement, shoulder, and median widths at frequent intervals;
- All roadway features which may affect the stationing or setback of poles (e.g., guardrail, barrier median, barrier curb, signs exceeding 50 feet, driveways, culverts, railroads, pipelines);
- The approximate height of any power and telephone 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 a layout sheet 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 ten to 20 feet along the roadway length (e.g. for a 12-foot lane, the grid size should be six feet x ten 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 x 20 feet);

- The photometric/preliminary plans shall be designed to TDOT Survey and Design CADD Standards. Section 15.6.4 describes additional drafting standards;
- Plan preparation checklists are listed in Section 15.6.7;
- Plans and Work File submittals are discussed in Section 15.6.6.

15.6.3 Photometric/Preliminary Plan Review

Upon receipt of the photometric/preliminary plans, the TDOT Design 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) 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 Design Manager shall approve the photometric/preliminary plans. The TDOT Design 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 right-of-way/utility plans.

15.6.4 Lighting Computer-Aided Design Drafting Standards

Lighting plans shall follow the TDOT Survey and CADD Standards. The following details additional lighting design criteria that will aid to maintain 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 1, 2, etc.;
- High mast poles (i.e. tower poles) shall be numbered as HM1, HM2, etc.;
- Control centers shall be numbered as CC1, CC2, etc.

15.6.5 Site and Field Reviews

- **Site Reviews:** A very necessary, but sometimes overlooked, part of a complete lighting design is the need for site reviews. The number of site reviews will be dependent 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 select potential service point locations by identifying power sources 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 review to determine if proposed pole and luminaire locations will interfere with existing or proposed underground utilities, and at-grade and aerial roadway structures.

➢ **High Mast Lighting:** On high mast lighting design projects, it may be necessary for both the lighting designer and the geotechnical engineer to simultaneously conduct a field review to finalize pole locations. This will ensure that the lighting designer and geotechnical engineer are in agreement with the location at which the bores will be performed.

15.6.6 Photometric Plans and Work Files Submittal

For Photometric/Preliminary Plan, Utility Plan, Right-of-Way Plan, and Construction Plan submittal, the lighting designer is required to provide specific files such as the AGI32 and Visual electronic files to the TDOT Traffic Engineering Office. These files shall follow the naming convention set forth in the Survey and Design Computer-Aided Drafting Standards. In addition, the working units for all files shall coincide with the working units set forth in the Survey and Design Computer Aided Drafting Standards.

15.6.7 Lighting Design Checklists

In order to reduce plan revisions, errors, and standardize the preparation, format and content of plans, Lighting Design Checklists (See Appendix E) 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 particular stage of plans development; and
- These checklists are intended as a design aid.