

**Chapter Thirteen**  
**HIGHWAY LIGHTING DESIGN**

**Table of Contents**

<b><u>Section</u></b>	<b><u>Page</u></b>
13.1 GENERAL .....	13.1(1)
13.1.1 Adherence to Design Criteria .....	13.1(1)
13.1.1.1 Design Exceptions .....	13.1(1)
13.1.1.2 Documentation.....	13.1(1)
13.1.1.3 Procedure .....	13.1(2)
13.1.2 References .....	13.1(2)
13.1.3 Project/Plan Development Responsibilities .....	13.1(3)
13.1.4 Definition of Terms .....	13.1(4)
13.2 GUIDELINES FOR JUSTIFYING HIGHWAY LIGHTING .....	13.2(1)
13.2.1 Analyzing Highway Lighting Needs .....	13.2(1)
13.2.2 Freeways.....	13.2(1)
13.2.2.1 Continuous Freeway Lighting .....	13.2(1)
13.2.2.2 Complete Interchange Lighting.....	13.2(2)
13.2.2.3 Partial Interchange Lighting.....	13.2(2)
13.2.2.4 Crossroad Ramp Terminal Lighting .....	13.2(3)
13.2.3 Streets and Highways Other Than Freeways .....	13.2(3)
13.2.4 Rest Areas.....	13.2(5)
13.2.5 Weigh Stations .....	13.2(5)
13.2.6 Underpasses .....	13.2(5)
13.2.7 Tunnels.....	13.2(6)
13.2.8 Other Locations .....	13.2(6)
13.2.9 Roadway Reconstruction.....	13.2(7)
13.3 LIGHTING EQUIPMENT .....	13.3(1)
13.3.1 Foundations.....	13.3(1)
13.3.2 Light Standards (Poles).....	13.3(1)
13.3.3 Mast Arms .....	13.3(4)
13.3.4 Luminaires.....	13.3(5)

**Table of Contents**

(Continued)

<b><u>Section</u></b>	<b><u>Page</u></b>
13.3.4.1	Light Sources .....13.3(5)
13.3.4.2	Optical System.....13.3(6)
13.3.4.3	Ballasts .....13.3(6)
13.3.4.4	Housing Units .....13.3(7)
13.3.5	Other Equipment .....13.3(7)
13.4	LIGHTING DESIGN METHODOLOGIES .....13.4(1)
13.4.1	Illuminance Methodology .....13.4(1)
13.4.2	Luminance Methodology .....13.4(1)
13.4.3	Small-Target-Visibility (STV) Methodology .....13.4(2)
13.5	DESIGN PROCEDURES .....13.5(1)
13.5.1	Computerized Design .....13.5(1)
13.5.2	Design Process .....13.5(1)
13.6	DESIGN CONSIDERATIONS.....13.6(1)
13.6.1	Classifications .....13.6(1)
13.6.1.1	Roadway Classification.....13.6(2)
13.6.1.2	Area Classification .....13.6(3)
13.6.1.3	Pavement Classification .....13.6(3)
13.6.2	Design Criteria.....13.6(4)
13.6.3	Equipment Considerations .....13.6(6)
13.6.3.1	Light Distribution .....13.6(6)
13.6.3.2	Mounting Heights.....13.6(13)
13.6.3.3	Coefficient of Utilization .....13.6(13)
13.6.3.4	Light Loss Factors .....13.6(13)
13.6.4	Luminaire Arrangement .....13.6(15)
13.6.5	Roadside Safety Considerations .....13.6(19)
13.6.6	Other Considerations.....13.6(21)
13.6.7	Voltage Drop Determination .....13.6(22)
13.7	HIGH-MAST LIGHTING DESIGN.....13.7(1)

## Chapter Thirteen

# HIGHWAY LIGHTING DESIGN

### 13.1 GENERAL

The purpose of highway lighting is to provide a safe and comfortable environment for the nighttime driver. Due to the volume of highway lighting system design information, it would be impractical for this chapter to present a complete highway lighting design guide. For additional design information, the designer is encouraged to review the latest edition of the references listed in [Section 13.1.2](#). The intent of this chapter is to provide the user with a synopsis of the highway lighting design process and to present MDT's criteria, policies and procedures on these issues.

#### 13.1.1 Adherence to Design Criteria

Chapter Thirteen presents the design criteria for the application of highway lighting on individual projects. In general, the designer is responsible for making every reasonable effort to meet these criteria. However, recognizing that this will not always be practical, the following sections discuss the Department's procedures for identifying, justifying and processing exceptions to the governing highway lighting design criteria.

##### 13.1.1.1 Design Exceptions

The designer must seek an internal MDT design exception when the proposed highway lighting design criteria does not meet the following:

1. [Chapter Six, "Roadside Safety," MDT Traffic Engineering Manual](#); and
2. MDT Policies from the Chief Engineer or Director.

##### 13.1.1.2 Documentation

The type and detail of documentation needed to justify a design exception will vary on a case-by-case basis. The following is a list of potential items which may need to be documented for a specific design exception:

1. crash data,
2. environmental impacts,
3. right-of-way impacts,

4. construction costs, and
5. serviceability impacts.

### **13.1.1.3 Procedure**

The following procedure will be used to process an identified design exception:

1. Project Engineer. The Project Engineer will assemble the documentation for the design exception request. See Section 8.8 of the MDT Road Design Manual. This package will be submitted to the Traffic Engineer.
2. Traffic Engineer. The Traffic Engineer will review the design exception package and, if in agreement, will sign the request. In rare cases where the Traffic Engineer believes necessary, the design exception request may be submitted to the Traffic and Safety Bureau Chief.

### **13.1.2 References**

For information applicable to MDT highway lighting design projects, see the following publications:

1. Roadway Lighting Design Guide, AASHTO;
2. American National Standard Practice for Roadway Lighting, RP-8, Illuminating Engineering Society of North America;
3. Recommended Practice for Tunnel Lighting, Illuminating Engineering Society of North America;
4. Recommended Lighting for Walkways and Class 1 Bikeways, Illuminating Engineering Society of North America;
5. Standard Specifications for Structural Supports for Highway Signs, Luminaires and Traffic Signals, AASHTO;
6. Roadside Design Guide, AASHTO;
7. Standard Specifications for Road and Bridge Construction, MDT;
8. MDT Detailed Drawings, MDT;
9. MDT Electrical Detailed Drawings, MDT;
10. [Chapter Six, "Roadside Safety,"](#) MDT Traffic Engineering Manual;

11. Chapter Fourteen, "Roadside Safety," MDT Road Design Manual;
12. [Chapter Eight, "Project Development Process,"](#) MDT Traffic Engineering Manual;
13. [Chapter Nine, "Project Coordination,"](#) MDT Traffic Engineering Manual;
14. [Chapter Ten, "Plan Preparation,"](#) MDT Traffic Engineering Manual;
15. ALADAN — A GE Lighting Application Design and Analysis Computer Program, General Electric Lighting Systems;
16. Lighting Design Guide for Use with ALADAN, General Electric Lighting Systems;
17. Roadway Lighting Handbook, FHWA;
18. Warrants for Highway Lighting, NCHRP Report No. 152, TRB;
19. Partial Lighting of Interchanges, NCHRP Report No. 256, TRB;
20. A Guide to Standardized Highway Lighting Pole Hardware, AASHTO; and
21. National, state, and local electrical codes.

### **13.1.3 Project/Plan Development Responsibilities**

The following list provides information on highway lighting project and plan development responsibilities:

1. Project Development. [Chapter Eight](#) presents a network which describes the project development sequence when highway lighting is a part of the construction project.
2. Project Coordination. During the development of a highway lighting project, the designer must coordinate with many units internal and external to the Electrical Unit. [Chapter Nine](#) discusses specific coordination responsibilities between the designer and other units and applies both to a project for which the Electrical Unit is serving as the lead unit and to a project for which the Electrical Unit is providing project support when another unit is project lead (e.g., the Road Design Section).
3. Plan Development. [Chapter Ten](#) presents the Department's criteria for developing a set of plans applicable to highway lighting projects. Chapter Ten contains information on scale sizes, CADD requirements, plan sheet requirements, quantities, etc.

### 13.1.4 Definition of Terms

The following defines the more commonly used terms in highway lighting design:

1. Average Initial Illuminance. The average level of horizontal illuminance on the pavement area of a traveled way at the time the lighting system is installed when lamps are new and luminaires are clean; expressed in average footcandles (fc) (lux) for the pavement area. See definition of illuminance, footcandle and lux.
2. Average Maintained Illuminance ( $E_h$ ). The average level of horizontal illuminance on the roadway pavement when the output of the lamp and luminaire is diminished by the maintenance factors (LLD and LDD); expressed in average footcandles (fc) (lux) for the pavement area.
3. Ballast. A device used with an electric-discharge lamp to obtain the necessary circuit conditions (voltage, current and wave form) for starting and operating. It limits the current through the lamp and may also transform voltage.
4. Blinding Glare. Glare so intense that for an appreciable length of time no object can be seen.
5. Candela (cd). A measure of the luminous intensity of a light source as seen by the eye. For example, because the eye is less sensitive to blue light than to green light, a blue light source must radiate more power in watts (W) than must a green light source if the two are to have the same luminous intensity. Most light sources have different luminous intensities when viewed from different directions and so the luminous intensity for a light source may vary with the angle at which it is viewed.
6. Candela per Square Meter ( $\text{cd}/\text{m}^2$ ). The International System (SI) unit of luminance (photometric brightness) equal to the uniform luminance of a perfectly diffusing surface emitting or reflecting light at the rate of one lumen per square meter ( $\text{lm}/\text{m}^2$ ) or the average luminance of any surface emitting or reflecting light at that rate. One candela per square meter equals 0.2919 footlambert.
7. Candle (cd). The unit of luminous intensity. See Candela.
8. Candlepower (cp). The luminous intensity in a specific direction; expressed in candelas (cd). It is not an indication of the total light output.
9. Coefficient of Utilization (CU). The ratio of the luminous flux ( $\text{lm}$ ) from a luminaire received on the surface of the roadway to the lumens emitted by the luminaire's lamps alone.

10. Direct Glare. Glare resulting from high luminances or insufficiently shielded light sources in the field of view or from reflecting areas of high luminance. It is usually associated with bright areas (e.g., luminaires), that are outside the visual task or region being viewed.
11. Disability Glare. Glare resulting in reduced visual performance and visibility. It often is accompanied by discomfort. See Veiling Luminance.
12. Discomfort Glare. Glare producing discomfort. It does not necessarily interfere with visual performance or visibility. See Glare.
13. Equipment Factor. A factor used in illuminance or luminance calculations to compensate for light losses due to normal production tolerances of commercially available luminaires when compared with laboratory photometric test models.
14. Footcandle (fc). The unit of illumination when the foot is taken as the unit of length. It is the illumination on a surface one square foot in area on which there is a uniformly distributed flux of one lumen, or the illumination produced on a surface, all points of which are at a distance of one foot from a directionally uniform point source of one candela.
15. Footlambert (fL). A unit of luminance (photometric brightness) equal to  $1/\pi$  candela per square foot, or to the uniform luminance of a perfectly diffusing surface emitting or reflecting light at the rate of one lumen per square foot, or to the average luminance of any surface emitting or reflecting light at that rate.
16. Glare. The sensation produced by luminance within the visual field that is sufficiently greater than the luminance to which the eyes are adapted to cause annoyance, discomfort or loss in visual performance and visibility. See Blinding Glare, Direct Glare, Disability Glare and Discomfort Glare.
17. House Side. The horizontal direction which is away from the roadway or behind the nadir of the luminaire. See Street Side.
18. Isofootcandle (Isolux) Diagram. A diagram plotted on any appropriate set of coordinates to show all points on a surface for which the illuminance is the same, as represented by a series of isofootcandle (isolux) line curves.
19. Illuminance. The density of the luminous flux incident on a surface. It is the quotient of the luminous flux (lumen) by the area of the surface ( $\text{ft}^2$  ( $\text{m}^2$ )), when the latter is uniformly illuminated. See definition of Footcandle and Lux.
20. Lamp. A generic term for a man-made source of light produced either by incandescence or luminescence.

20. Lamp. A generic term for a man-made source of light produced either by incandescence or luminescence.
21. Lamp Lumen Depreciation Factor (LLD). A depreciation factor that indicates the decrease in a lamp's initial lumen output over time. For design calculations, the initial lamp lumen value is reduced by LLD to compensate for the anticipated lumen reduction. This multiplier is to be used in illumination calculations to relate the initial rated output of light sources to the anticipated minimum rated output based on the relamping program to be used.
22. Light Loss Factor. A depreciation factor applied to the calculated initial average luminance or illuminance.
23. Light Standard (Pole). A pole provided with the necessary internal attachments for wiring and the external attachments for the bracket and luminaire.
24. Longitudinal Roadway Line (LRL). Any line along the roadway parallel to the curb or shoulder line.
25. Lumen (lm). The unit of luminous flux. It is equal to the flux through a unit solid angle (steradian), from a uniform point source of one candela (cd), or to the flux on a unit surface all points of which are at unit distance from a uniform point source of one candela.
26. Luminaire. A complete lighting unit consisting of a lamp or lamps together with the parts designed to distribute the light, to position and protect the lamps and to connect the lamps to the power supply.
27. Luminaire Dirt Depreciation Factor (LDD). A depreciation factor that indicates the expected reduction of a lamp's initial lumen output due to the accumulation of dirt on or within the luminaire over time.
28. Luminance (Photometric Brightness). The luminous intensity (candela) of any surface in a given direction per unit of projected area ( $\text{ft}^2$  ( $\text{m}^2$ )) of the surface as viewed from that direction.
29. Luminous Efficacy (lm/W). The quotient of the luminous flux (lumen) emitted by the total lamp power input (watt). It is expressed in lumens per watt (lm/W).
30. Luminous Efficiency (%). The ratio of the total luminous flux emitted by a luminaire to that emitted by the bare lamp.
31. Luminous Intensity. See definition of candela.



- at a distance of one meter from a uniform point source of one candela. ( $1 \text{ lx} = 1 \text{ lm/m}^2$ ).
33. Maintenance Factor (MF). A combination of light loss factors used to denote the reduction of the illumination for a given area after a period of time compared to the initial illumination on the same area ( $\text{MF} = \text{LLD} \cdot \text{LDD}$ ).
  34. Mounting Height (MH). The vertical distance between the roadway surface and the center of the light source in the luminaire.
  35. Nadir. The vertical axis which passes through the center of the luminaire light source.
  36. Offset. The horizontal distance between the face of a light standard and the edge of traveled way.
  37. Overhang. The horizontal distance between a vertical line through the nadir of a luminaire and the edge of traveled way or edge of the area to be illuminated.
  38. Spacing. For roadway lighting the distance between successive lighting units, measured along the centerline of the street.
  39. Street Side. The horizontal direction that is toward the roadway from the nadir of the luminaire. See house side.
  40. Transverse Roadway Line (TRL). Any line across the roadway that is perpendicular to the curb or shoulder line.
  41. Uniformity Ratio ( $E_h/E_{\min}$ ). The ratio of average maintained horizontal illuminance ( $E_h$ ) to the maintained horizontal illuminance ( $E_{\min}$ ) at the point of minimum illumination on the pavement. A uniformity ratio of 3:1 means that the average footcandle (lux) value ( $E_h$ ) is three times the footcandle (lux) value ( $E_{\min}$ ) at the point of least illuminance on the pavement.
  42. Utilization Efficiency. A plot of the quantity of light falling on the horizontal plane both in front (street side) of and behind (house side) the luminaire. It shows only the percent of bare lamp lumens that fall on the horizontal surface and is plotted as a ratio of width of area to mounting height of the luminaire.
  43. Veiling Luminance. A luminance superimposed on the retinal image that reduces its contrast. It is this veiling effect produced by bright sources or areas in the visual field that results in decreased visual reflected glare.



## **13.2 GUIDELINES FOR JUSTIFYING HIGHWAY LIGHTING**

Providing lighting for all highway facilities is not practical nor cost effective. It is generally MDT's practice to only provide highway-facility lighting where justified based on sound engineering judgment and on the criteria, recommendations and principles presented in the AASHTO publication Roadway Lighting Design Guide.

A location that appears to justify lighting does not necessarily obligate the Department to provide funding for a lighting project. The Department will determine the economic feasibility and identify candidate locations for lighting projects. Local agencies may determine the feasibility of providing lighting within their respective municipalities.

For a highway facility to be considered for lighting, the lighting system must be both economically feasible and justified based on the applicable criteria presented in the following sections. The impacts of local conditions (e.g., frequent fog, ice, snow, roadway geometry, ambient lighting, sight distance, signing) also should be considered when analyzing highway lighting needs.

### **13.2.1 Analyzing Highway Lighting Needs**

The AASHTO publication Roadway Lighting Design Guide presents an empirical approach to analyzing highway lighting needs with application primarily to freeway-type facilities. The principal considerations are vehicular traffic volume, interchange spacing (i.e., an indicator of the relative frequency of vehicular traffic maneuvers), land development and artificial lighting conditions in the area surrounding the freeway, and the night-to-day crash ratio. The affect of these factors on driver visibility should be considered in the lighting needs analysis. The FHWA publication Roadway Lighting Handbook provides additional guidance.

### **13.2.2 Freeways**

Use the criteria presented in the following sections when analyzing lighting needs for State-maintained freeway-type facilities. See the AASHTO publication Roadway Lighting Design Guide for additional information.

#### **13.2.2.1 Continuous Freeway Lighting**

A continuous lighting system provides relatively uniform lighting on all main lanes and direct connections, and complete interchange lighting of all interchanges within the section. Frontage roads are not normally continuously lighted. The lighting units may

be conventional luminaires or high mast assemblies or both. Continuous freeway lighting is generally not justified nor provided by the Department.

### 13.2.2.2 Complete Interchange Lighting

Complete interchange lighting is defined as a lighting system that provides relative uniform lighting within the limits of the interchange, including:

1. main lanes,
2. direct connections,
3. ramp terminals, and
4. frontage road or crossroad intersections.

Complete interchange lighting is generally not justified nor provided by the Department.

### 13.2.2.3 Partial Interchange Lighting

Partial interchange lighting is defined as a lighting system that provides illumination only of decision-making areas of roadway including:

1. acceleration and deceleration lanes,
2. ramp terminals,
3. crossroads at frontage road or ramp intersections, and
4. other areas of nighttime hazard.

Partial interchange lighting is considered the Department's preferred method for interchange lighting. Consider providing partial interchange lighting for interchanges under the following conditions:

1. Ramp Volume. Where the total current ADT ramp traffic entering and leaving the freeway within the interchange area exceeds 5000 for urban conditions, 3000 for suburban conditions or 1000 for rural conditions.
2. Freeway Volume. Where the current ADT on the freeway through traffic lanes exceeds 25,000 for urban conditions, 20,000 for suburban conditions or 10,000 for rural conditions.
3. Night-To-Day Crash Ratio. Where the night-to-day ratio of crash rates within the interchange area is at least 1.25 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 should also be evaluated.

4. Continuous Freeway Lighting. 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 mi (2.5 km) or less with adjacent areas outside the right-of-way being substantially urban in character.

#### **13.2.2.4 Additional Interchange or Freeway Lighting**

Additional interchange or freeway lighting may be considered for facilities in which an engineering study indicates a need. Some of the characteristics that may be considered and should be documented in the engineering study are:

1. ramps, interchange alignments or grades that are complex or unusual;
2. high levels of pedestrian or bicycle volumes during times of darkness;
3. important decision point(s) or existing roadside hazard areas that would not be covered with partial interchange lighting;
4. an operational analysis indicates the need for lighting. Volume and crash data should be used to support the analysis; and/or
5. local agency needs. Where the local agency find sufficient benefit in the forms of convenience, safety, policing, community promotion, public relations, etc., to pay an appreciable percentage of the cost of, or wholly finance, the installation, maintenance and operation of the lighting facilities.

#### **13.2.2.5 Crossroad Ramp Terminal Lighting**

Where the crossroad ramp terminal design incorporates raised channelizing or divisional islands or there exists less than desirable sight distance, lighting of the crossroad ramp terminal is justified regardless of traffic volume.

#### **13.2.3 Streets and Highways Other Than Freeways**

Urban and rural conditions, traffic volumes (both vehicular and pedestrian), intersections, turning movements, signalization, channelization and varying geometrics are some of the factors that should be considered when determining the lighting needs of streets and highways other than freeways. See the AASHTO publication Roadway

Lighting Design Guide and consider the following when assessing the lighting needs of State-maintained facilities:

1. Facilities With Raised Medians. The Department requires that lighting be provided along State-maintained facilities with raised medians.
2. Major Urban Arterials. Lighting should be considered for all major arterials in urbanized areas.
3. Intersections. Consider the installation of lighting at intersections where one or more of the following conditions exist:
  - a. the intersection design incorporates raised channelization;
  - b. within a three-year period, the intersection exhibits five or more correctable crashes attributable to a lack of lighting during the hours of darkness;
  - c. the intersection meets at least one-half of the requirements necessary to warrant signalization (At intersections where signalization is warranted, the lighting installation is normally performed in conjunction with the signal installation.); or
  - d. the intersection is located in an unlighted area within 1000 ft (300 m) of an existing lighted area.
4. High Conflict Locations. Consider lighting locations with high vehicle-to-vehicle interactions (e.g., sections with numerous driveways, significant commercial or residential development, high percentage of trucks). Lighting generally improves the efficiency and safety at these locations.
5. Complex Roadway Geometry. Consider providing lighting at spot locations in rural areas where the driver is required to pass through a section with complex geometry.
6. Night-To-Day Crash Ratio. Consider providing lighting 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 should also be evaluated.
7. Local Agency Needs. Lighting should be provided where the local agency finds sufficient benefit in the forms of convenience, safety, policing, community promotion, public relations, etc., to pay an appreciable percentage of the cost of,

or wholly finance, the installation, maintenance and operation of the lighting facilities.

#### **13.2.4 Rest Areas**

Provide lighting for rest areas that offer complete rest facilities (e.g., comfort station, information kiosk, picnic areas). Illuminate all areas within the rest area that have pedestrian activities (e.g., parking areas, immediate area of building). Lighting at rest area ramps, gore areas and other decision points should be considered on a case-by-case basis. See the AASHTO publication Roadway Lighting Design Guide for additional information.

#### **13.2.5 Weigh Stations**

Provide lighting at all permanent truck weigh stations where weighing will occur after daylight hours. Illuminate the weighing areas, parking areas, speed change lanes, ramps and gore areas. Coordinate luminaire placement with the Motor Carrier Service. Overheight detectors are also the Electrical Unit's responsibility, at weigh stations and at "bailout" points prior to structures with low overhead clearance. See the AASHTO publication Roadway Lighting Design Guide for additional information.

#### **13.2.6 Underpasses**

Because of their typical configuration and length-to-height ratio, underpasses generally have good daylight penetration and do not require supplemental daytime lighting. If justified, underpass lighting is generally installed to enhance driver visibility after daylight hours. However, when the length-to-height ratio of the underpass exceeds approximately 10:1, it is usually necessary to analyze specific geometry and roadway conditions, including vehicular and pedestrian activity, to determine the need for daytime lighting. See [Section 13.2.7](#) for information on tunnel lighting.

On highways that are not continuously lighted, consider providing underpass lighting in areas having frequent nighttime pedestrian traffic through the underpass or where unusual or critical geometry occurs under or adjacent to the underpass area.

Provide underpass lighting on all highways that are continuously lighted. Favorable positioning of luminaires adjacent to the underpass can often provide adequate lighting of relatively short underpass areas without the need for supplemental lighting within the underpass.

See the AASHTO publication Roadway Lighting Design Guide and the ANSI/IESNA RP-22-96 publication Recommended Practice for Tunnel Lighting for additional information.

### **13.2.7 Tunnels**

A tunnel is defined as a structure of any type surrounding a vehicular roadway which requires the use of artificial lighting or equivalent means to provide adequate roadway visibility necessary for safe and efficient traffic operation. Daytime tunnel lighting is justified when driver visibility requirements are not satisfied without the use of a lighting system to supplement natural sunlight. Overall tunnel visibility varies considerably with such items as:

1. portal to portal length of the tunnel (i.e., short or long);
2. tunnel portal design;
3. geometry of the tunnel and its approaches;
4. vehicular and pedestrian traffic characteristics;
5. treatment of pavement, portal, interior, and environmental reflective surfaces;
6. climate and orientation of the tunnel; and
7. visibility objectives to provide for safe and efficient tunnel operation.

The lighting of tunnels should be provided in accordance with the criteria presented in the AASHTO publication Roadway Lighting Design Guide. See the ANSI/IESNA RP-22-96 publication Recommended Practice for Tunnel Lighting for additional information.

### **13.2.8 Other Locations**

Provide lighting for all pedestrian underpass and tunnel facilities. In addition, evaluate the need to provide lighting for the following facilities on a case-by-case basis:

1. roundabouts,
2. chain-up areas,
3. commuter park-and-ride lots,
4. bike paths,
5. pedestrian walkways, and
6. pedestrian overpasses.

As appropriate, the lighting of these facilities should be provided in accordance with the criteria presented in the AASHTO publication Roadway Lighting Design Guide. See the IESNA publication Recommended Lighting for Walkways and Class I Bikeways for additional information.



**13.2.9 Roadway Reconstruction**

For roadway reconstruction projects, existing lighting should be evaluated and upgraded, if necessary, to meet current highway lighting design criteria.



### 13.3 LIGHTING EQUIPMENT

A variety of options are available to the designer when selecting luminaire equipment to satisfy the desired design criteria. [Figure 13.3A](#) illustrates the various parts of the light standard and luminaire. Ensure that the selected equipment meets MDT standard hardware designs. Specialized equipment can significantly increase installation and maintenance costs, thereby reducing the cost effectiveness of the lighting system. In addition to the MDT electrical detailed drawings and the MDT Standard Specifications for Road and Bridge Construction, the following sections provide guidance on MDT's preferred lighting equipment.

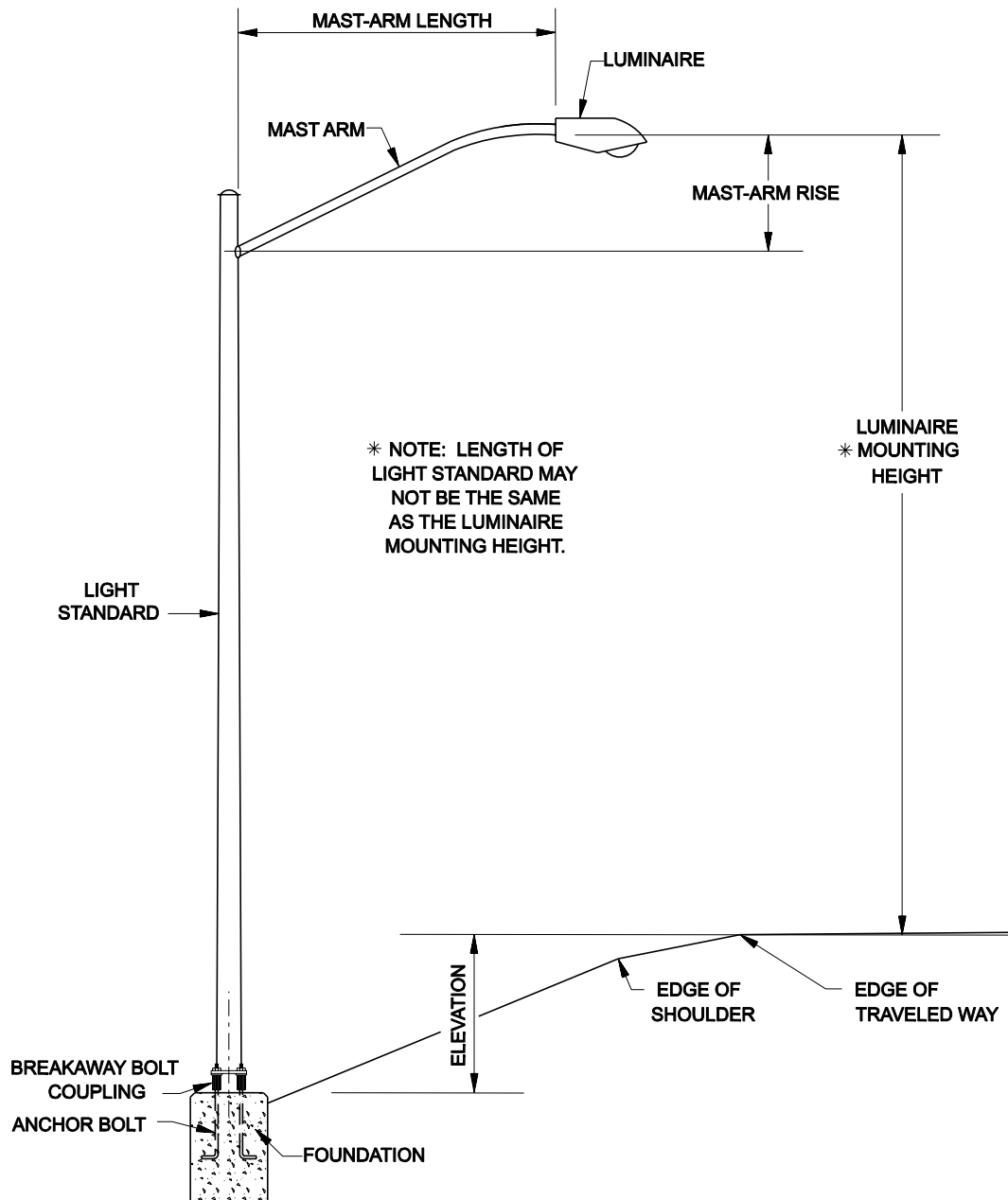
#### 13.3.1 Foundations

When determining the foundation design, consider the following:

1. Material. All foundations for permanent installations should be made with Class "DD" Portland cement concrete. See the MDT Standard Specifications for additional information.
2. Design. The MDT electrical detailed drawings and the MDT Standard Specifications provide the design details for foundation depth, width, reinforcing, etc., for conventional light standards. If high-mast lighting is used, foundations typically require specialized designs and soil surveys be performed to ensure adequate support. Check with the Geotechnical Section for additional guidance.
3. Placement. [Section 13.6.5](#) provides the Department's criteria for the placement of light standards relative to the roadway.

#### 13.3.2 Light Standards (Poles)

A major factor in highway lighting design is the selection of the luminaire and the mounting height. Higher mounting heights usually reduce the number of light standards required and enhance illumination uniformity. The MDT Standard Specifications, the MDT electrical detailed drawings, and the latest edition of the AASHTO publication Standard Specifications for Structural Supports for Highway Signs, Luminaires and Traffic Signals provide the Department's criteria for light standards. The following describes the light standards commonly used by the Department:



**TYPICAL LUMINAIRE**

**Figure 13.3A**

1. Conventional. The conventional light standard is commonly used in highway lighting applications. Depending on their application, conventional light standards will accommodate luminaire mounting heights ranging from 20 ft to 50 ft (6 m to 15 m). MDT's typical practice is to use a light standard that will accommodate a luminaire mounting height between 35 ft (10.5 m) and 45 ft (13.5 m). The most common mounting height is 40 ft (12 m) or 45 ft (13.5 m) on wide roadways. The recommended minimum mounting height is 35 ft (10.5 m). The 35 ft (10.5 m) mounting height may be considered where maintenance of higher heights may be an issue. Luminaires are typically mounted on either light standards or combination signal and luminaire standards. See the MDT electrical detailed drawings for additional information.
2. High Mast. High-mast poles can range from 80 ft to 200 ft (24 m to 60 m). This pole is an excellent choice where there is a large area that requires lighting (e.g., interchanges). The use of high-mast lighting and higher wattage lamps greatly reduces the number of poles and provides quality lighting by enhancing illumination uniformity.
3. Materials. Light standards for permanent installations recommended by the Department are typically made of galvanized steel. In special cases, fiberglass luminaire poles have been used. Wood poles are normally used for service poles or for temporary lighting (e.g., in construction zones). The MDT Standard Specifications provide the material specifications for all light standards used by the Department.
4. Bases. Unless otherwise protected, a breakaway base should be provided for all light standards within the clear zone along rural and high-speed urban highways. However, in areas where pedestrians, bicyclists or building structures and windows may be struck by falling poles and mast arms after a crash, evaluate the relative risks of mounting the light standard on a breakaway base. [Section 13.6.5](#) provides additional criteria on the appropriate application of breakaway or non-breakaway bases. All breakaway bases will meet the breakaway criteria set forth in the AASHTO publication Standard Specifications for Structural Supports for Highway Signs, Luminaires and Traffic Signals. Typical luminaire bases used by the Department include:
  - a. Breakaway Bolt Couplings. Breakaway bolt couplings are aluminum connectors or sleeves that are designed to shear when the pole is hit. The bottom of the coupling is threaded onto the foundation anchor bolts, and the light standard is attached to the top of the coupling. Four couplings are used with each light standard. Where breakaway supports are required, use the breakaway bolt coupling unless it will not function

with the approved light standard. Connections for all wiring at the base must have fused watertight breakaway connectors.

- b. **Frangible Transformer Base.** The frangible transformer base consists of a cast aluminum apron between the concrete foundation and the base of the pole. It is designed to deform and break away when hit by a vehicle bumper. Use the frangible transfer base where a breakaway base is justified but breakaway bolt couplings cannot be used. Connections for all wiring inside the base must have fused watertight breakaway connectors.
  - c. **Non-Breakaway Anchor Base.** A non-breakaway anchor base consists primarily of a metal plate that is welded to the bottom of the light standard. The plate allows the light standard to be bolted directly to the foundation without an intermediate breakaway device. It does not meet AASHTO breakaway-base criteria. Connections for all wiring inside the base must have fused watertight connectors.
5. **Structural Design.** All light standards must meet the structural design criteria presented in the AASHTO publication Standard Specifications for Structural Supports for Highway Signs, Luminaires and Traffic Signals including the criteria for wind loading, maximum horizontal deflection, maximum stresses, luminaire loads, material strengths, bolts, etc. Welding for steel poles must meet the criteria called for in the current edition of the American Welding Society Specifications for Structural Welding Code — Steel, AWS D-1.1.
6. **Mounting Height.** The lengths of light standards must be specified so that they accommodate the required luminaire mounting height above the roadway pavement. After determining the required luminaire mounting height, the appropriate pole length can then be determined.

### **13.3.3 Mast Arms**

Mast arms allow placement of the light source near the edge of the traveled way. The use of longer mast arms is recommended, although the initial costs may be higher. Longer mast arms allow the poles to be placed farther from the traveled way, thus providing a safer roadside environment. On the other hand, the use of longer mast arms may have a negative effect on the loading capabilities of the base. Typical luminaire mast arm lengths are 10 ft (3.0 m) and 15 ft (4.5 m). For additional information on mast arms, see the MDT Standard Specifications and the MDT electrical detailed drawings.

### 13.3.4 Luminaires

A luminaire is defined as a complete lighting unit consisting of a lamp or lamps together with the parts designed to distribute the light. The following sections, the MDT Standard Specifications and the MDT electrical detailed drawings provide the Department's criteria for luminaire hardware. [Section 13.6.3.1](#) discusses the various types of light distribution for luminaires.

#### 13.3.4.1 **Light Sources**

There are numerous light sources for highway lighting. However, there are only a few practical choices when considering availability, size, power requirements and cost effectiveness. Only high-intensity discharge light sources should be used. The following provides information on the high-intensity light sources that are available:

1. High Pressure Sodium (HPS). Due to its excellent luminous efficiency, power usage and long life, HPS is commonly used in installations of conventional and high-mast highway lighting. The HPS lamp produces a soft, pinkish-yellow light by passing an electric current through a combination of sodium and mercury vapor. Use of the HPS lamps is preferred by the Department.
2. Low Pressure Sodium (LPS). Low pressure sodium is considered one of the most efficient light sources on the market. Its disadvantage is that it requires very long tubes and has poor color quality. MDT does not typically specify the use of LPS on State-maintained facilities. However, local agencies may consider the use of LPS lamps. The LPS lamp produces a yellow light by passing an electrical current through a sodium vapor.
3. Mercury Vapor (MV). Prior to the introduction of HPS, mercury vapor was the most commonly used light source. However, MDT does not typically specify MV lamps for conventional or high-mast highway lighting. If used, MV is usually limited to overhead sign lighting applications. The mercury vapor lamp produces a bluish-white light.
4. Metal Halide. Metal halide lamps produce better color at higher efficiency than mercury lamps. However, life expectancy for metal halide lamps is shorter than for HPS or MV. They are also more sensitive to lamp orientation than other light sources. Metal halide lamps are commonly used for lighting sports arenas, major sports stadiums, high-mast highway lighting, downtown areas and parks. Metal halide produces good color rendition. Light is produced by passing a current through a combination of metallic vapors.

The lamps commonly used in highway lighting are 200 W, 250 W and 400 W.

#### **13.3.4.2 Optical System**

The optical system consists of a light source, a reflector and usually a refractor. The following discusses the optical system of a luminaire:

1. Light Source. [Section 13.3.4.1](#) discusses the high-intensity light sources that are available. HPS lamps are preferred by the Department.
2. Reflector. The reflector is one of the devices used in optical control to change the direction of the light rays. Its purpose is to take that portion of light emitted by the lamp that otherwise would be lost or poorly utilized and redirect it to a more desirable distribution pattern. Reflectors are designed to work either alone or with a refractor. Reflectors can be classified into two types — specular and diffused. Specular reflectors are made from a glossy material that provides a mirror-like surface. Diffuse reflectors are used where the intent is to spread the light over a wider area.
3. Refractor. The refractor is another means in optical control to change the direction of the light. Refractors are made of a transparent, clear material, usually high-strength glass or plastic. Plastic is used in high-vandalism areas. However, plastic may yellow over time due to heat and ultraviolet exposure. The refractor, through its prismatic construction, controls and redirects both the light emitted by the lamp and the light redirected by the reflector. It can also be used to control the brightness of the lamp source. Glass refractors are commonly used by the Department.
4. Glare Shield. In applications where additional glare control is necessary, consider the use of a glare shield. The glare shield has a conical shape and is attached under the luminaire housing for additional control of light direction and distribution.

#### **13.3.4.3 Ballasts**

All luminaires must include a built-in ballast. Ballasts are used to regulate the voltage to the lamp to ensure that the lamp is operating within its design parameters. It also provides the proper open circuit voltage to start the lamp. MDT typically specifies integral ballasts and luminaires with the ballast providing -20°F (-29°C) starting capacity. Multiple ballasts must be 240 V regulated lag type, 0.90 power factor, with an operating



operating range of  $\pm 10\%$ . [Figure 13.5A](#) provides the approximate expected operating wattage for various ballasts based on the lamp wattage.

#### 13.3.4.4 Housing Units

Luminaire housing requirements are dependent upon the application type. When selecting luminaire housings, consider the following:

1. Roadway Lighting Luminaire. Roadway lighting luminaire housings and specular reflector holders are typically made of aluminum with a weatherproof finish. The housing unit should allow access from the street side and allow for adjustments to the light. The luminaire is usually equipped with a high-impact, glass, prismatic refractor. The unit should be sealed to ensure that dust, moisture and/or insects will not be able to enter the inside of the luminaire.
2. Underpass Luminaires. Underpass luminaires typically are specified with the same housing requirements as roadway lighting luminaires except that they also are specified with a durable, plastic, vandal-resistant shield. Care should be exercised when specifying ballast placement. Underpass luminaires may be attached to the vertical side surface of bridge bent structures or may be suspended by the use of pendants.
3. High-Mast Luminaires. High-mast luminaires typically are enclosed aluminum units with a reflector and a borsilicate glass refractor. The unit should be sealed to ensure that dust, moisture and/or insects will not be able to enter the inside of the luminaire. The luminaires are attached to the mast ring. The mounting attachment is adjustable to allow for directing the light.

#### 13.3.5 Other Equipment

In developing a highway lighting system, there are numerous other components that can influence the design. Many of these components are presented and/or discussed in the MDT Standard Specifications, the MDT electrical detailed drawings, and the manufacturer's product literature. Some of these components include:

1. Electrical Components. The above sources discuss many electrical components, including ballasts, fuses, photoelectric controls, wiring, conduit, pullboxes, connections, breaker boxes, circuit breakers, lightning arrestors, relay switches, ground rods, etc. All wiring between poles should be placed underground. Because cable runs are much longer and roadway crossings are less frequent, the Department typically specifies plastic conduit due to its cost effectiveness.

2. High-Mast Lighting Systems. Some of the additional components for high-mast lighting systems include luminaire ring assemblies for attaching luminaires, head frame assemblies, winch assemblies, external drive systems used to lower the luminaires for maintenance, cable terminators and lightning rods.

## 13.4 LIGHTING DESIGN METHODOLOGIES

There are three lighting design methodologies — illuminance methodology, luminance methodology and small-target-visibility methodology. For the most part, the Illuminating Engineering Society of North America (IESNA) has been the leader in the development of these procedures. The following sections briefly describe each methodology. The Department uses the illuminance methodology in its design of highway lighting systems. For additional information on these procedures, review the references in [Section 13.1.2](#).

### 13.4.1 Illuminance Methodology

The illuminance methodology is the oldest and simplest to use of the three methodologies. Experience has shown this design methodology to be very effective. Illuminance is defined as the density of the luminous flux, lumen (lm), incident on a surface area ( $\text{ft}^2$  ( $\text{m}^2$ )) and is measured in footcandle ( $\text{fc} = \text{lm}/\text{ft}^2$ ) ( $\text{lux}$  ( $\text{lx} = \text{lm}/\text{m}^2$ )). The illuminance methodology is used to determine the combined amount of luminous flux reaching critical pavement locations from contributing luminaires (i.e., a measure of light quantity) and assess how uniformly the luminaires' combined luminous flux is horizontally distributed over the pavement surface (i.e., a measure of light quality). The brightest spot will normally occur directly under the luminaire and diminishes the farther the driver is away from the source. The disadvantage of this methodology is that one does not “see” incident light, but instead sees reflected light from an object or surface. This sensation 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. See [Section 13.4.2](#).

The design factors used in illuminance designs are the average maintained horizontal illumination ( $E_h$ ), or quantity of light, and the uniformity ratio (i.e., the ratio of the average maintained illuminance to the minimum maintained illuminance), or quality of light.

### 13.4.2 Luminance Methodology

Luminance is defined as the luminous intensity, candela (cd), of any surface in a given direction per unit of projected area ( $\text{ft}^2$  ( $\text{m}^2$ )) of the surface as viewed from that direction. It is measured in units of candela per square foot (candela per square meter). 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. Assumptions are made regarding the spatial positioning of the driver's eye, and luminance values are calculated at grid points over the pavement surface. 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. 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.

The design factors in luminance design include average maintained luminance ( $L_{avg}$ ), minimum luminance ( $L_{min}$ ), maximum luminance ( $L_{max}$ ), maximum veiling luminance ( $L_v$ ) and ratios of  $L_{avg}$  to  $L_{min}$ ,  $L_{max}$  to  $L_{min}$ , and  $L_v$  to  $L_{avg}$ . The Department is presently not using the luminance methodology for highway lighting design.

### **13.4.3 Small-Target-Visibility (STV) Methodology**

The Illuminating Engineering Society of North America has proposed the STV methodology in an effort to better define actual driver visibility requirements. Both the luminance and STV methodologies require the designer to consider factors not required by the illuminance methodology. The luminance methodology depends upon pavement reflectance characteristics, observer position and luminaire location and performance. STV depends on these same characteristics plus the addition of an array of 7 in (180 mm), flat targets (each with 20% diffuse reflectance) 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 lighting system design. While theoretical analyses and laboratory experiments indicate that the STV methodology closely approximates actual driver visibility, there is not yet sufficient field experience to verify the STV concept. It is recognized that the STV methodology requires measurements and computer calculations that are considerably more complex than either the illuminance or luminance methodologies. The Department does not use the STV methodology for highway lighting design.

## 13.5 DESIGN PROCEDURES

The following sections provide guidelines on the highway lighting design procedures used by MDT. For additional design information, review the references in [Section 13.1.2](#).

Lighting system design often requires several iterations to produce acceptable results. If after the first run the design criteria are not satisfied, it will be necessary to change the initial parameters (e.g., pole spacing, mounting height, luminaire wattage) and recheck the design for acceptability. This process is repeated until the design is optimized and all criteria are satisfied.

### 13.5.1 Computerized Design

Determining an acceptable lighting system design requires numerous iterations of calculations based on numerous variables. The designer is encouraged to use a computer software package for lighting design purposes. The Department is currently using the PC-based program "ALADAN", developed by General Electric, for its highway lighting calculations. ALADAN is used to generate templates for design and to check illuminance level and uniformity.

For lighting projects prepared by outside consultants, the consultant shall provide the Electrical Unit with the design data (inputs and reports) in both a hard copy format and on an electronic media.

### 13.5.2 Design Process

Use the following procedural steps when designing a highway lighting system for the Department:

1. Assemble Information. Assemble all necessary information. This includes:
  - a. an approved scope-of-work report for the project;
  - b. contacting the Electrical Unit in the Traffic Engineering Section for the current design policies and procedures applicable to the project and the latest copies of sample plans, schedules, pay quantities, plan notes and example calculations;
  - c. gathering roadway and bridge plans including plan and profile sheets and special detail sheets (e.g., overhead signs);

- d. determining existing and expected utility locations;
  - e. discussing any special considerations with the highway or bridge designer;
  - f. conducting field reviews; and
  - g. contacting local officials for local projects.
2. Determine Classifications. If not already included in the project report, determine the roadway classification, area classification, pavement classification and environmental conditions. Classifications for lighting purposes are defined in [Section 13.6.1](#).
  3. Select Design Criteria. Based on the above information, select the pertinent design methodology (see [Section 13.4](#)) and the appropriate criteria based on the classification selected in Step #2; see [Section 13.6.2](#). For MDT lighting projects, use the illuminance design methodology.
  4. Select Equipment. In the preliminary design, it will be necessary to make some initial assumptions on the equipment and design parameters. This includes mounting height, pole setback distance, light source, mast-arm length, lamp wattage, etc. Commonly used mounting heights are 35 ft (10.5 m), 40 ft (12 m) and 45 ft (13.5 m). Typical lamps used for highway lighting include 200 W, 250 W and 400 W HPS. [Figure 13.5A](#) provides information on lighting levels for various lighting sources. See Sections 13.3 and 13.6.3 for additional details on equipment selection. After selecting the luminaire equipment, obtain the manufacturer's photometric data for each luminaire selected.
  5. Select Layout Arrangement. [Section 13.6.4](#) provides information on the commonly used lighting arrangements. The selection of the appropriate layout design depends upon local site conditions and engineering judgment. [Section 13.6.5](#) presents the roadside safety considerations when selecting the lighting arrangements. [Section 13.6.6](#) provides other layout considerations.
  6. Luminaire Spacing. For MDT roadway lighting projects, use the illuminance methodology to determine the appropriate luminaire spacing. Typically, luminaire spacing is calculated by computer software. For manual calculations, [Equation 13.5-1](#) should be used. [Sections 13.1.4](#) and [13.6.3](#) define the various factors used in the equation.

LAMP WATTAGE <sup>①</sup>	APPROXIMATE BALLAST WATTAGE <sup>②</sup>	TOTAL WATTAGE	INITIAL LUMENS	MEAN LUMENS	AVERAGE LIFE (hours)
<b>Mercury Vapor</b>					
100	35	135	4040	3415	24000+
100 DX	35	135	4425	3620	24000+
175	35	205	7975	7430	24000+
175 DX	35	205	8600	7640	24000+
250 <sup>③</sup>	35	285	11825	10625	24000+
250 DX	35	285	12775	10790	24000+
400	55	455	21000	19150	24000+
400 DX	55	455	23125	19840	24000+
700	65	765	40500	36250	24000+
700 DX	65	765	42750	36045	24000+
1000	90	1090	56150	48400	24000+
1000 DX	90	1090	63000	48380	24000+
<b>High Pressure Sodium</b>					
50	18	68	3650	3285	24000
70	20	90	5800	5220	24000
100	35	135	9500	8550	24000
150 <sup>④</sup>	45	195	16000	14400	24000
200 <sup>⑤</sup>	50	250	22000	19800	24000
250 <sup>⑤</sup>	60	310	27500	24750	24000
250S	60	310	30000	27000	24000
310	70	380	37000	33300	24000
400 <sup>⑤</sup>	85	485	50000	45000	24000
1000 <sup>⑥</sup>	—	1100	140000	126000	28500
<b>Low Pressure Sodium</b>					
18	14	32	1800	1720	10000
35	25	60	4800	4570	18000
55	30	85	8000	7610	18000
90	35	125	13500	12850	18000
135	40	175	22500	21400	18000
180	50	230	33000	31400	18000

**Notes:**

1. Typical lamps are shown. For others, see the IESNA publication *RP-8 Roadway Lighting*.
2. Typically the highest loss found for commonly used ballast types.
3. Typically used for signing illumination.
4. Typically used for highway underpasses.
5. Typically used for conventional highway lighting.
6. Typically used for high-mast lighting.

**LAMP DATA****Figure 13.5A**

$$S = \frac{LL \cdot CU \cdot LLD \cdot LDD}{E_h \cdot W} \quad (\text{Equation 13.5-1})$$

Where:

S	=	luminaire spacing (ft (m))
LL	=	initial lamp lumens (lm)
CU	=	coefficient of utilization
LLD	=	lamp lumen depreciation factor
LDD	=	lamp dirt depreciation factor
$E_h$	=	average maintained horizontal illumination (footcandle (lux))
W	=	width of lighted roadway (ft (m))

7. Check Uniformity. Once the spacing has been determined, check the uniformity of light distribution and compare this to the criteria selected in Step #3. Use Equation 13.5-2 to determine the uniformity ratio.

$$\text{Uniformity Ratio} = \frac{\text{Average Maintained Illumination Value}}{\text{Minimum Maintained Illumination Value}} \quad (\text{Equation 13.5-2})$$

8. Select Optimum Design. Because lighting design by computer is relatively quick and easy, develop and test several alternative designs even if one design is found to initially satisfy the criteria. There are often several alternatives that will work. Select the most cost-effective design.
9. Electrical Design. Once the number, size and location of the luminaires are determined, determine the electric voltage drop for the system. [Section 13.6.7](#) provides information on how to determine voltage drop for the lighting system.
10. Prepare Plans. Once the final design has been selected, prepare the plan sheets, quantities and notes, cost estimate, voltage drop calculations, circuit schematic layouts, and any special provisions that are required for review.



## 13.6 DESIGN CONSIDERATIONS

In designing a lighting system, there are many elements and factors the designer must consider. To help the designer in this process, IESNA and AASHTO have standardized many of these elements. [Figure 13.6A](#) presents typical design values used by the Department. The AASHTO publication [Roadway Lighting Design Guide](#), the IESNA publication RP-8 [Roadway Lighting](#) and the following sections discuss these factors and other design considerations.

### 13.6.1 Classifications

When selecting the design criteria for a lighting project, it is necessary to determine the classifications (Step #2 in [Section 13.5.2](#)) 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.

<b>HIGHWAY LIGHTING DESIGN PARAMETERS</b>	
Lamp Lumen Depreciation Factor (LLD)	0.80
Luminaire Dirt Depreciation Factor (LDD)	0.85
Percent of Voltage Drop Allowed	5%
Typical Conventional Luminaire Mounting Heights	35 ft, 40 ft, 45 ft (10.5 m, 12 m, 13.5 m)
Typical Lamp Sizes	150 W HPS (Underpasses) 200 W HPS (Conventional) 250 W HPS (Conventional) 400 W HPS (Conventional) 1000 W HPS (High Mast)
Typical Pavement Classification	Class R3
Typical IESNA Luminaire Classification Specification	Type II, Type III or Type IV Medium Distribution (M) Full-Cutoff (Flat Lens)
Typical Luminaire Arrangement	Staggered, Both Sides (Conventional)

### **MDT HIGHWAY LIGHTING DESIGN PARAMETERS**

**Figure 13.6A**

### 13.6.1.1 Roadway Classification

Use the following definitions to classify roadway facilities for MDT lighting projects:

1. Freeway. A divided major highway with full control of access and with no crossings at grade.
2. 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 are generally known as parkways.
3. Urban Principal Arterials. The urban major roadway system that serves the major centers of activities of urbanized areas containing the corridors with the highest traffic volumes.
4. Urban Minor Arterials. The roadway system that interconnects with and augments the urban principal arterial system. It accommodates trips of moderate length at a somewhat lower level of travel mobility than do principal arterials.
5. Collector. The distributor and collector roadways serving traffic between arterials and local roadways. These are roadways used mainly for traffic movements within residential, commercial and industrial areas.
6. 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 will generally be divided into short sections by the collector roadway system.
7. Alley. A narrow public right-of-way within a block, generally used for vehicular access to the side or rear of abutting properties.
8. Sidewalk. Paved or otherwise improved facility designated for pedestrian traffic that is located within public street right-of-way of a roadway used for vehicular traffic.
9. Pedestrian Way. Public facility for pedestrian traffic that may or may not be within the public right-of-way for vehicular traffic roadways. Included are skywalks (pedestrian overpasses), subwalks (pedestrian tunnels), walkways giving access to park or block interiors and crossings near centers of long blocks.
10. Bikeway. Any road, street, path or otherwise improved facility specifically designated as being open to bicycle travel, regardless of whether the facilities

are designed for the exclusive use of bicycles or are to be shared with other transportation modes.

### 13.6.1.2 Area Classification

For MDT lighting projects, use the following definitions to classify the area in which the roadway traverses:

1. 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.
2. 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.
3. 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 are also included.

### 13.6.1.3 Pavement Classification

For MDT lighting projects, use the following definitions to classify the pavement type of the roadway facility:

1. Class R1. Class R1 pavement has a mostly diffuse mode of reflectance. R1 pavements include Portland cement concrete road surfaces and asphalt road surfaces with a minimum of 12% of the aggregates composed of artificial brightener (e.g., Synopal) aggregates (e.g., labradorite, quartzite).
2. Class R2. Class R2 pavement has a mixed diffuse and specular mode of reflectance. R2 pavements include asphalt road surfaces with an aggregate composed of a minimum 60% gravel with a size greater than 0.375 in (10 mm), and 10% to 15% artificial brightener in aggregate mix.

3. Class R3. Class R3 has a slightly specular mode of reflectance. R3 pavements include asphalt road surfaces, both regular and carpet seal, with dark aggregates (e.g., trap rock, blast furnace slag) and exhibit a rough texture after some months of use. Class R3 pavement represents typical asphalt highways and is used on most highway lighting projects.
4. Class R4. Class R4 pavement has a mostly specular mode of reflectance. R4 includes asphalt road surfaces with a very smooth texture.

### 13.6.2 Design Criteria

Design criteria for highway lighting projects vary according to the roadway classification, area classification, and pavement type. [Figure 13.6B](#) presents the illuminance design criteria used by the Department. In addition to [Figure 13.6B](#), consider the following:

1. Crossroads at Interchanges. Lighting levels on the crossroad approaches should not be reduced through the interchange area. If existing crossroad illuminance currently is deemed inadequate, it should be considered for upgrading to ensure safe and efficient traffic operation on the crossroad.
2. Partial Interchange Lighting. 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. The design controls of basic level of lighting and uniformity should be subordinated to overall lighting of the roadway area at these locations. [Section 13.6.4](#) provides information on partial interchange lighting; see [Figure 13.6J](#).
3. Underpasses. Where justified, underpass lighting level and uniformity ratios should duplicate, to the extent practical, the lighting values on the adjacent facility.
4. Bridges and Overpasses. On continuously lighted freeways and lighted interchanges, the lighting of bridges and overpasses should be at the same level and uniformity as the roadway.
5. Transition Lighting. Transition lighting is a technique intended to provide the driver with a gradual reduction in lighting levels and glare when leaving a lighting system. The designer may consider transition lighting after a study of the conditions at a specific location. Typical transition lighting design should extend the lighting system a sufficient distance beyond the normal limits of illumination.

Roadway Class ②	Area Class ②	Average Maintained Horizontal Illuminance ( $E_h$ ) ① footcandle (lux)						Uniformity Ratio (Ave/Min)
		Pavement Classification②						
		R1		R2 & R3		R4		
Interstate	Commercial	0.7-1.1 (8-12)						3:1 to 4:1
	Intermediate	0.7-0.9 (8-10)						
	Residential	0.6-0.7 (6-8)						
Other Freeways	Commercial	0.9 (10)	1.3 (14)	1.2 (13)				3:1
	Intermediate	0.7 (8)	1.1 (12)	0.9 (10)				
	Residential	0.6 (6)	0.8 (9)	0.7 (8)				
Other Principal Urban Arterials ③	Commercial	1.1 (12)	1.6 (17)	1.4 (15)				3:1
	Intermediate	0.8 (9)	1.2 (13)	1.0 (11)				
	Residential	0.6 (6)	0.8 (9)	0.7 (8)				
Urban Minor Arterials	Commercial	0.9 (10)	1.4 (15)	1.0 (11)				4:1
	Intermediate	0.7 (8)	1.0 (11)	0.9 (10)				
	Residential	0.5 (5)	0.7 (7)	0.7 (7)				
Collectors	Commercial	0.7 (8)	1.1 (12)	0.9 (10)				4:1
	Intermediate	0.6 (6)	0.8 (9)	0.7 (8)				
	Residential	0.4 (4)	0.5 (5)	0.5 (5)				
Local	Commercial	0.6 (6)	0.8 (9)	0.7 (8)				6:1
	Intermediate	0.5 (5)	0.7 (7)	0.6 (6)				
	Residential	0.3 (3)	0.4 (4)	0.4 (4)				
Alleys	Commercial	0.4 (4)	0.6 (6)	0.5 (5)				6:1
	Intermediate	0.3 (3)	0.4 (4)	0.4 (4)				
	Residential	0.2 (2)	0.3 (3)	0.3 (3)				
Sidewalks	Commercial	0.9 (10)	1.3 (14)	1.2 (13)				3:1 4:1 6:1
	Intermediate	0.6 (6)	0.8 (9)	0.7 (8)				
	Residential	0.3 (3)	0.4 (4)	0.4 (4)				
Pedestrian & Bicycle Ways④	All	1.4 (15)	2.0 (22)	1.8 (19)				3:1
<b>REST AREAS AND WEIGH STATIONS</b>								
Ramp Gores & Interior Roadways	All	0.4 (4)	0.6 (6)	0.5 (5)				3:1 to 4:1
Parking & Major Activity Areas	All	0.7 (7)	1.0 (11)	0.8 (9)				
Minor Activity Areas	All	0.4 (4)	0.5 (5)	0.5 (5)				6:1

**Notes:**

1. Average illuminance on the traveled way or on the pavement area between curb lines of curbed facilities. See [Section 13.1.4](#) for definition of average maintained illuminance and uniformity ratio.
2. See [Section 13.6.1](#) for definitions of roadway facility, area and pavement classifications.
3. Partial or no-control of access.
4. This assumes a separate facility. Facilities adjacent to a vehicular roadway should use the illuminance levels and uniformity ratios for the roadway. Use R3 requirements for other surface materials not shown.

**MDT ILLUMINANCE DESIGN CRITERIA****Figure 13.6B**

6. Navigable Airspace. Where lighting projects are being considered in close proximity to an active airfield or airport, the designer should consider the impact luminaire height has on navigable airspace. For additional information, consult the FAA Advisory Circular AC 70/7460-2I Proposed Construction or Alteration of Objects That May Affect the Navigable Airspace.

Where illumination is justified for tunnels, overhead signing, chain-up areas and other facilities not covered under this section, review the AASHTO publication Roadway Lighting Design Guide, the IESNA publication RP-8 Roadway Lighting and/or contact the Electrical Unit for the appropriate illuminance design criteria.

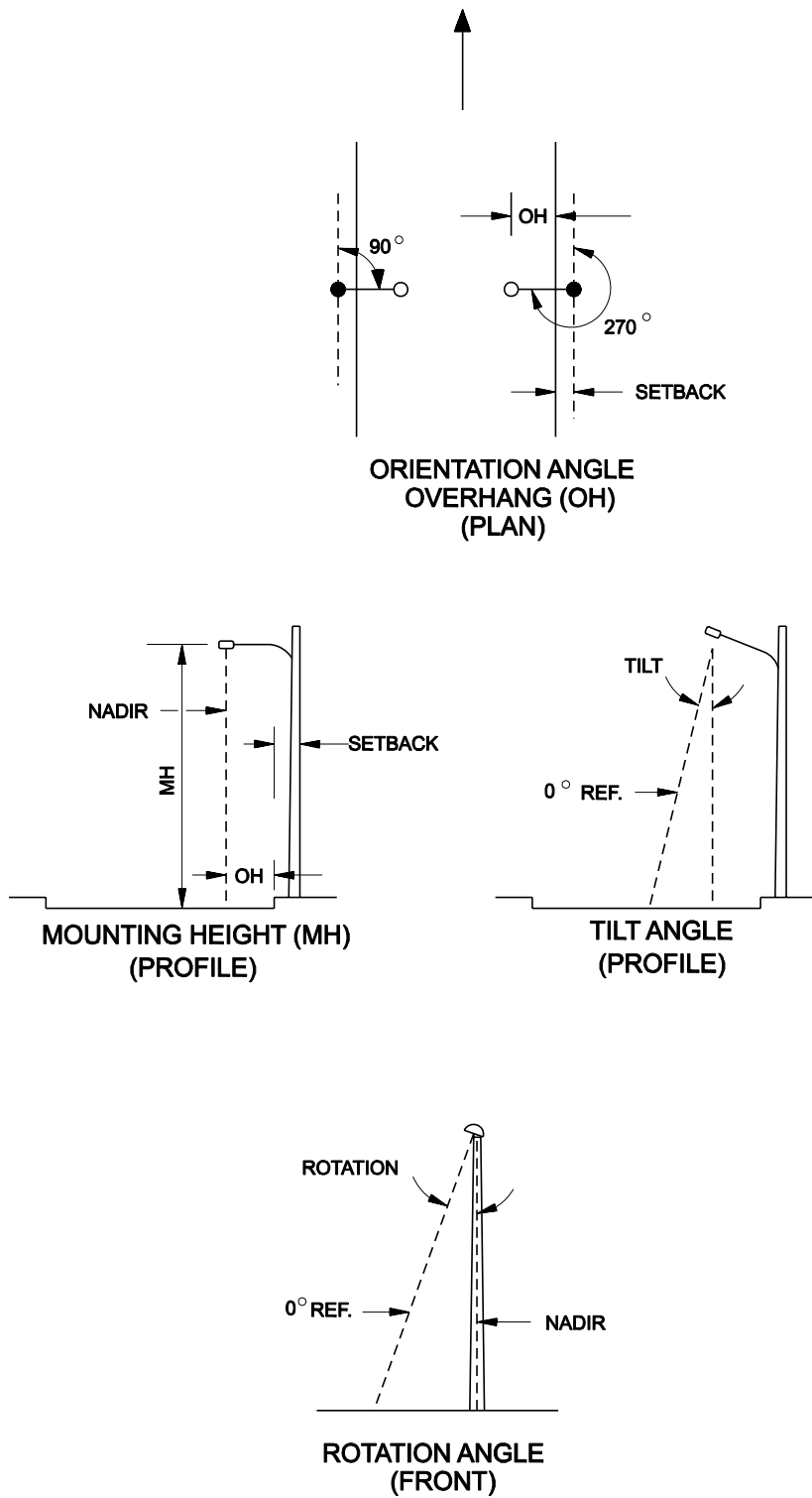
### 13.6.3 Equipment Considerations

Figure 13.6C illustrates the common terms used in defining and designing luminaires (e.g., mounting height, overhang). The following sections discuss other equipment considerations for design.

#### 13.6.3.1 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 may be obtained from the luminaire manufacturer. Manufacturers typically classify their luminaire products based on the IESNA luminaire classification system. Figure 13.6D presents the IESNA luminaire classification system as it relates to typical highway applications. The following briefly describes the IESNA classification system:

1. Vertical Light Distribution. There are three IESNA 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:
  - a. Short Distribution (S). The maximum candlepower strikes the roadway surface between 1 and 2.25 mounting heights from the luminaire. The theoretical maximum luminaire spacing, using the short distribution, is 4.5 mounting heights.
  - b. Medium Distribution (M). 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 by the Department.



**LUMINAIRE GEOMETRY**

**Figure 13.6C**

IESNA CLASSIFICATION <sup>②⑤</sup>		TYPICAL APPLICATION <sup>①③</sup>	
Vertical Light Distribution		Luminaire Placement	Roadway Width
Type I <sup>⑧</sup>		Center Mounting	≤ 2.0 MH <sup>④</sup>
Type II <sup>⑦</sup>	Side Mounting	One Side	≤ 1.0 MH
		Both Sides	≤ 2.0 MH
Type III <sup>⑦</sup>	Side Mounting	One Side	≤ 1.5 MH
		Both Sides	≤ 3.0 MH
Type IV <sup>⑦</sup>	Side Mounting	One Side	≤ 2.0 MH
		Both Sides	≤ 4.0 MH
Type V <sup>⑧</sup>		Center Mounting	≤ 4.0 MH
Lateral Light Distribution		Luminaire Spacing <sup>⑥</sup>	
S <sup>⑧</sup>	Short	≤ 4.0 MH	
M <sup>⑦</sup>	Medium	≤ 5.0 MH	
L <sup>⑧</sup>	Long	≤ 5.0 MH	
Light Distribution Control		Glare Control above 80° Vertical from Nadir <sup>⑨</sup>	
C <sup>⑧</sup>	Cutoff	Strict	
S	Semi-Cutoff	Medium	
N <sup>⑧</sup>	Non-Cutoff	None	
⑦	Full-Cutoff		

## Notes:

1. Source: *Addendum to Chapter Six of the Roadway Lighting Handbook, FHWA.*
2. The complete luminaire classification consists of three terms in sequence (e.g., Type III-M-S).
3. The above information is for guidance only. There is no assurance that illuminance criteria will be satisfied by a luminaire classification used as shown above.
4. MH = mounting height of luminaire.
5. For additional information of the IESNA luminaire classification system, see *ANSI/IESNA RP-8 Roadway Lighting.*
6. See [Figure 13.6F](#) for theoretical maximum lateral and transverse light distribution coverage.
7. Typically used by the Department in conventional highway lighting systems.
8. Generally not used by the Department.
9. See [Figure 13.6C](#).

## IES LUMINAIRE CLASSIFICATION SYSTEM

Figure 13.6D



- c. Long Distribution (L). 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 practice, and the spacing of luminaires normally does not exceed 5 to 6 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.

2. Lateral Light Distribution. IESNA has developed seven classifications for lateral light distribution. The following provides application guidelines for each luminaire type:

- a. 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 also considered a modified form of Type I. The Department does not generally use the Type I luminaire.
- b. Type I - 4-Way. This luminaire type is placed in the center of the intersection and distributes the lighting along the four legs of the intersection. This type generally applies to high-mast lighting. The Department does not generally use the Type I - 4-way luminaire.
- c. 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.
- d. 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. The Department does not generally use the Type II-4-way luminaire.
- e. 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.
- f. 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.
- g. Type V. The Type V luminaire is placed in the center of the roadway, intersection or area where lighting is required. It produces a circular,

lighted area. Type V often applies to high-mast lighting. The Department does not generally use the Type V luminaire.

3. Control of Distribution. As the vertical light angle increases, disability and discomfort glare also increase. To distinguish the glare effects on the driver generated by the light source, IESNA has defined the vertical control of light distribution as follows:
  - a. **Cutoff (C)**. A luminaire light distribution is designated as cutoff (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. Cutoff luminaires are generally not specified by the Department.
  - b. **Full-Cutoff (F)**. “Cutoff” optics are characterized by a shallow glass globe where as the lens type used for “Full-Cutoff” is simply a flat glass. The difference between the two is the amount of light that is allowed to pass vertically above a certain line around the luminaire (the difference is only about 2%).
  - c. **Semi-Cutoff (S)**. A luminaire light distribution is designated as semi-cutoff (S) 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. The Department will consider semi-cutoff luminaires on a case-by-case basis.
  - d. **Non-Cutoff (N)**. This classification is where there is no limitation on the zone above the maximum candlepower. Non-cutoff luminaires are rarely used by the Department.

Guidelines for placement and arrangement of the various types of IESNA luminaires are presented in [Figure 13.6E](#). A plan view of the theoretical light distribution (i.e., roadway coverage) and schematics of the intended application of each type of IESNA luminaire are illustrated in [Figure 13.6F](#).

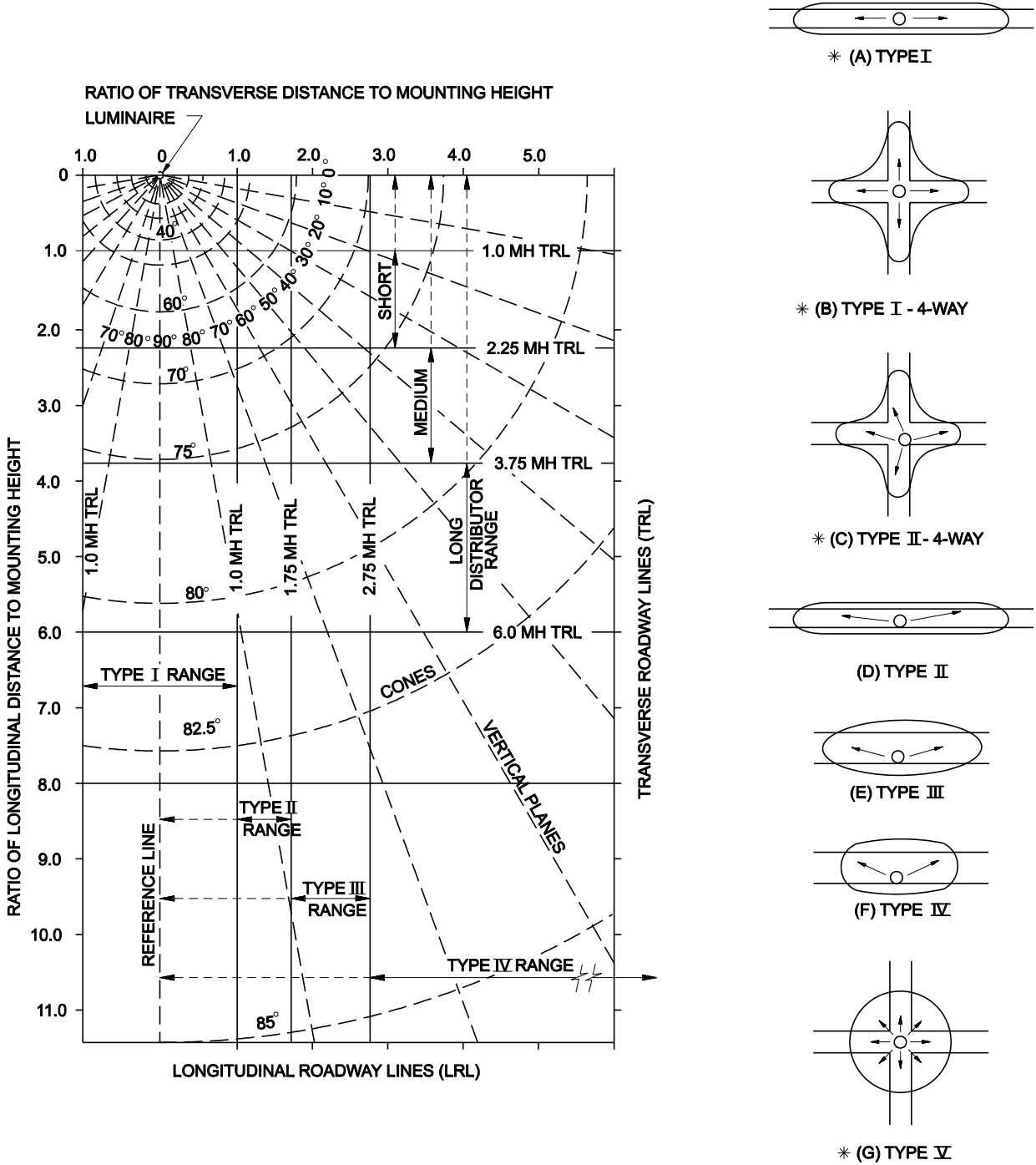
LUMINAIRE PLACEMENT AND ARRANGEMENT <sup>①②</sup>	ROADWAY WIDTH <sup>⑤</sup>	APPLICABLE <sup>④</sup> IES LUMINAIRES
One-Side Mounting	$\leq 1.5$ MH <sup>③</sup>	Type II Type III Type IV
Both Sides, Staggered Arrangement <sup>⑦</sup>		
Both Sides, Opposite Arrangement	$> 1.5$ MH	Type III Type IV
Side Mounting at Grade Intersection (Local Street) <sup>⑥</sup>	$\leq 1.5$ MH	Type II-4-Way
Center Mounting on Single Roadway <sup>⑥</sup>	$\leq 2.0$ MH	Type I <sup>⑥</sup>
Median Mounting on Dual Roadway <sup>⑥</sup>	$\leq 1.5$ MH (Each Pavement)	Type II Type III
Center Mounting at Grade <sup>⑥</sup> Intersection (Local Street)	$\leq 2.0$ MH	Type I 4-Way <sup>⑥</sup> Type VVV <sup>⑥</sup>

## Notes:

1. Source: *Roadway Lighting Handbook*, FHWA.
2. The above information is for guidance only. There is no assurance that illuminance criteria will be satisfied by a luminaire classification used as shown above.
3. MH = mounting height of luminaire.
4. For additional information of the IESNA luminaire classification system, see *ANSI/IESNA RP-8 Roadway Lighting*.
5. See [Figure 13.6F](#) for theoretical maximum lateral and transverse light distribution coverage.
6. Generally not used by the Department.
7. Typically used by the Department in conventional highway lighting systems.

## GUIDELINES FOR IES LUMINAIRE PLACEMENT AND ARRANGEMENT

Figure 13.6E



\* NOTE: TYPICALLY NOT USED BY THE DEPARTMENT.

PLAN VIEW OF ROADWAY COVERAGE FROM IESNA LUMINAIRES

Figure 13.6F

### 13.6.3.2 Mounting Heights

Higher mounting heights used in conjunction with higher wattage luminaires enhances lighting uniformity and typically reduces the number of light standards 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 the Department for conventional highway lighting purposes include 35 ft, 40 ft and 45 ft (10.5 m, 12 m and 13.5 m). For additional guidance on mounting heights, see [Section 13.3.2](#).

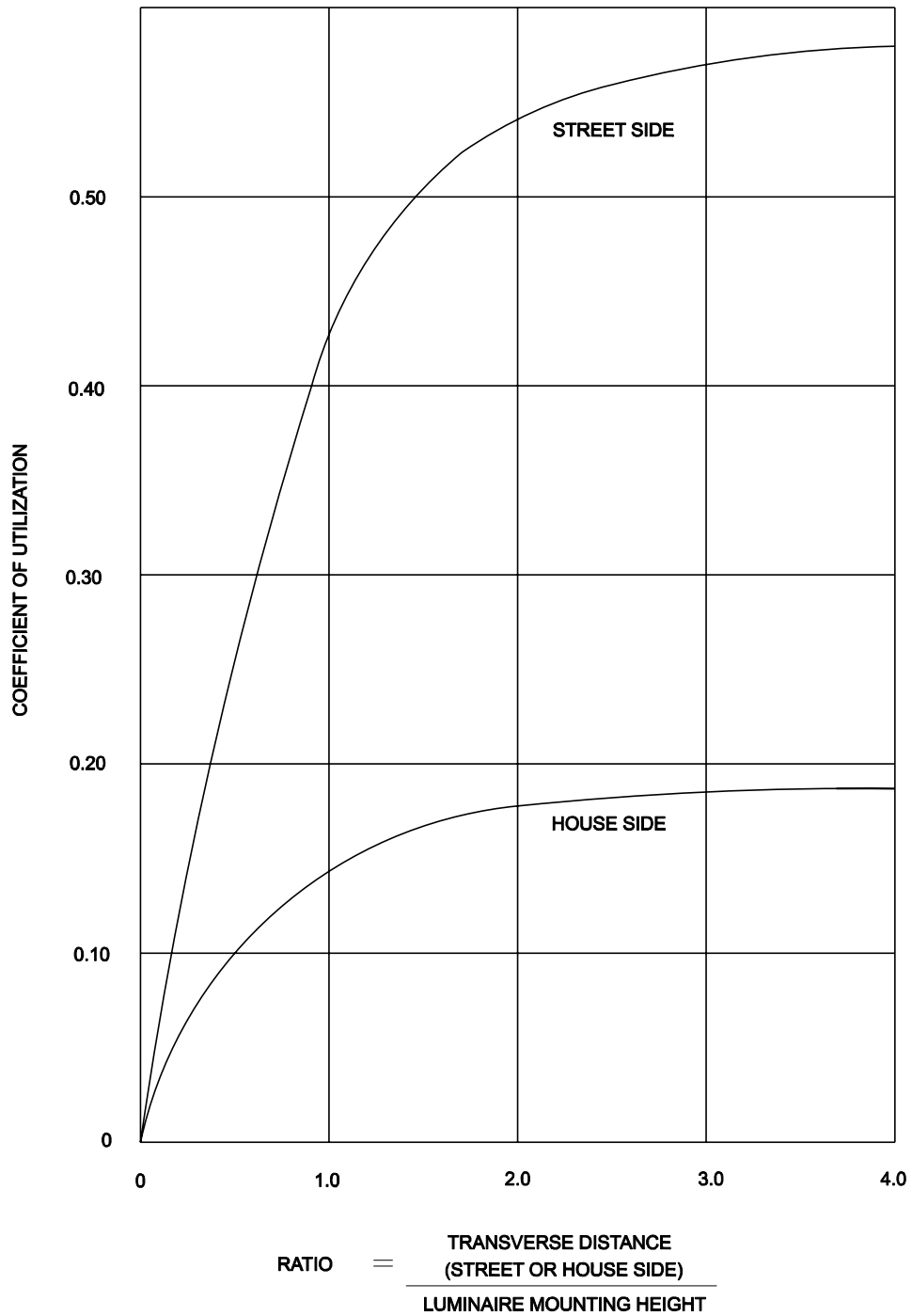
### 13.6.3.3 Coefficient of Utilization

A utilization curve is used to obtain a luminaire's coefficient of utilization (CU) that is used in illuminance design calculations. Manufacturers typically provide utilization curves and isolux diagrams with each of their respective luminaire products. [Figure 13.6G](#) 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 that are used 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.

### 13.6.3.4 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. [Figure 13.6A](#) presents the typical light loss factors used by MDT for highway lighting design. The following briefly discusses these factors:

1. Lamp Lumen Depreciation Factor (LLD). 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 ensures that a minimum level of illumination will be available at the end of the assumed lamp life, even though lamp lumen depreciation has occurred. This information is usually provided by the manufacturer. For design purposes, an LLD factor of 0.80 should be used. Other values may only be used if approved by the Electrical Unit.



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

### SAMPLE UTILIZATION CURVE

Figure 13.6G

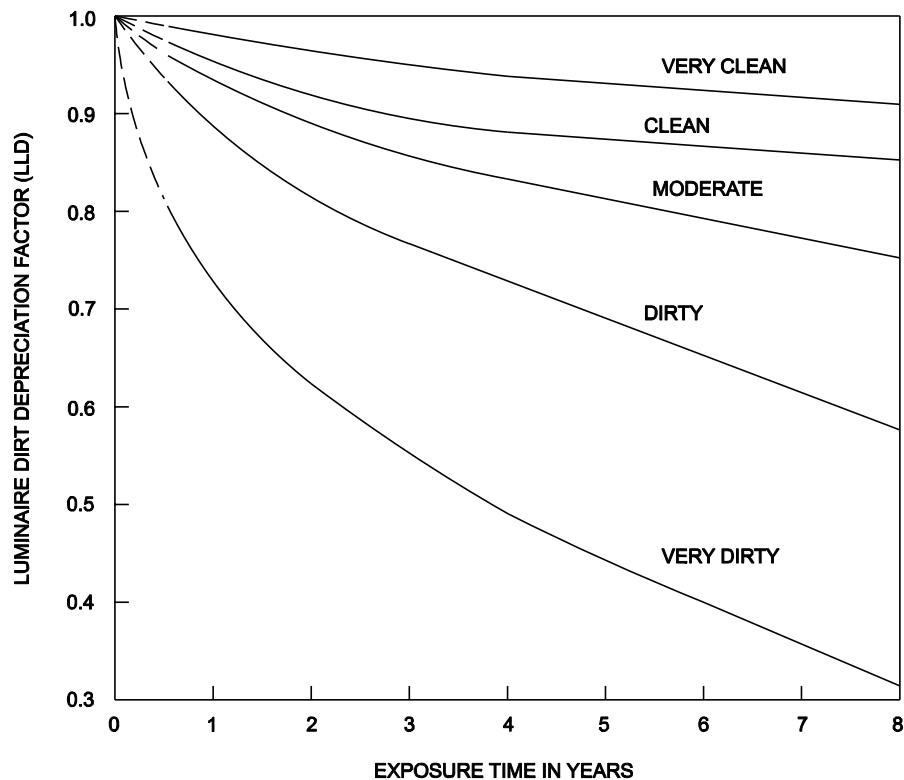
2. Luminaire Dirt Depreciation Factor (LDD). Dirt on the exterior and interior of the luminaire, and to some extent on the lamp itself, reduces the amount of light reaching the pavement. Various degrees of dirt accumulation may occur depending upon the area in which the luminaire is located. Industrial 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 illustrated in [Figure 13.6H](#). For MDT highway lighting design purposes, an LDD factor of 0.85 should be used. Other values may only be used if approved by the Electrical Unit.

#### **13.6.4 Luminaire Arrangement**

[Figure 13.6I](#) illustrates typical luminaire arrangements for conventional highway lighting designs. [Figure 13.6I](#) also illustrates the recommended illuminance calculation points for the various arrangements (Step #7 in [Section 13.5.2](#)). The Department prefers the use of staggered arrangement. MDT typically does not place light standards in the median for the following reasons:

1. In medians without barriers, the light standards can be struck by traffic in both directions.
2. In medians with concrete median barriers, the light standards are typically placed on the top of the barrier. Studies have shown that trucks and buses hitting the concrete median barrier will lean substantially over the barrier and may strike the light standard.
3. Maintenance of the luminaire in the median can be a safety concern for the maintenance crew and truck near the high-speed lanes.

[Figure 13.6J](#) illustrates a typical layout for partial lighting of an interchange.



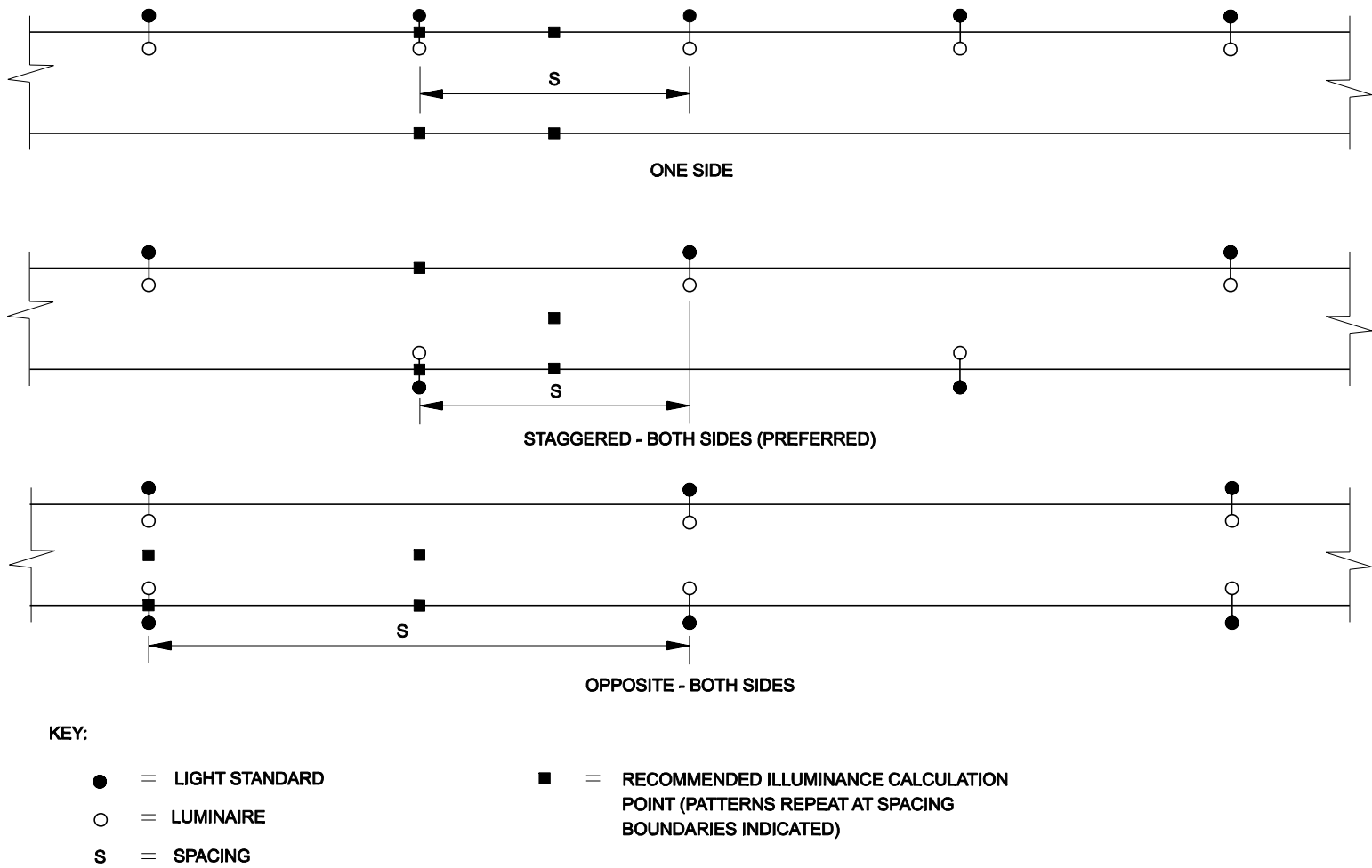
Notes:

1. 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.
2. 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.
3. Moderate. Moderate smoke or dust-generating activities nearby. The ambient particulate level is not more than 600 micrograms per cubic meter.
4. Dirty. Smoke or dust plumes generated by nearby activities may occasionally envelope the luminaires.
5. Very Dirty. As above, but the luminaires are commonly enveloped by smoke or dust plumes.

**ROADWAY LUMINAIRE DIRT DEPRECIATION CURVE**

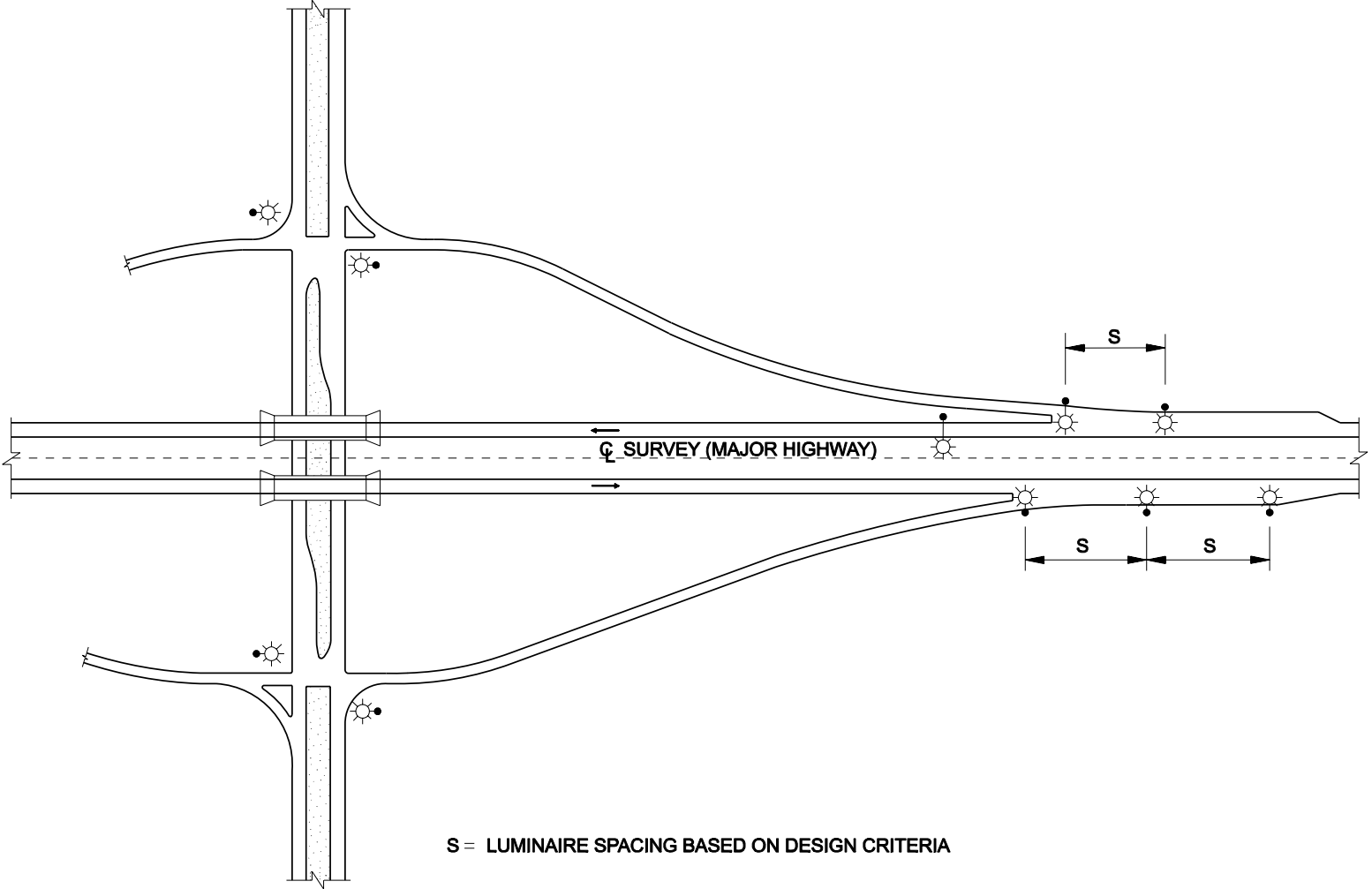
**Figure 13.6H**





TYPICAL LUMINAIRE ARRANGEMENTS FOR CONVENTIONAL HIGHWAY LIGHTING DESIGN

Figure 13.6I



S = LUMINAIRE SPACING BASED ON DESIGN CRITERIA

**PARTIAL INTERCHANGE LIGHTING**

Figure 13.6J

### 13.6.5 Roadside Safety Considerations

Light standards 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 standards. The designer also must consider other 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 to accommodate the safe placement of light standards. The designer should also consider the following when determining the location of light standards relative to roadside safety:

1. Clear Zone. See Chapter Fourteen “Roadside Safety” of the MDT Road Design Manual for the definition of clear zone. Light standards should be installed 10 feet from the edge of pavement where there is no curb and gutter or behind the sidewalk where there is curb and gutter.
2. Breakaway Supports. Unless located behind a roadside barrier or in consideration of special circumstances, all conventional light poles placed within the clear zone will be provided with a breakaway device. The designer must remain aware that falling poles may endanger bystanders (e.g., pedestrians, bicyclists, motorists). In addition, the designer should consider the following:
  - a. Pedestrians. In areas where pedestrians, bicyclists or building structures and windows may be struck by falling poles and mast arms after a crash, evaluate the relative risks of mounting the light standard on a breakaway base. Light standards located within rest areas should not be mounted on breakaway devices.
  - b. Breakaway Bases. All breakaway bases will comply with the applicable AASHTO requirements for breakaway structural supports. See Section 13.3 for those breakaway bases approved by the Department.
  - c. Breakaway Support Stub. Any substantial portion of the breakaway support that will remain after the light standard has been struck will have a maximum projection of 4 in (100 mm) in accordance with AASHTO criteria. See Chapter Six of the MDT Traffic Engineering Manual.
  - d. Wiring. All light standards that require a breakaway device should be served by underground wiring and should be designed with breakaway connections.

3. Gore Areas. Light Standards should be located outside the gore areas of the exit and entrance ramps.
4. Horizontal Curves. Light standards should desirably be placed on the inside of sharp curves and loops. Poles on the inside radius of superelevated roadways should have sufficient clearance to avoid susceptibility of being struck by trucks.
5. Maintenance. When determining pole locations, the designer should consider the hazard which will be encountered while performing future maintenance on the lighting equipment.
6. Barriers. The placement of light standards in conjunction with roadside barriers should be designed to meet the criteria provided in Chapter Fourteen "Roadside Safety" of the MDT Road Design Manual. In addition, the designer should consider the following:
  - a. Placement. Where a roadside barrier is provided, all light standards should be placed behind the barrier.
  - b. Deflection. Light standards placed behind a roadside barrier should be offset by at least the deflection distance of the barrier; see Chapter Fourteen "Roadside Safety" of the MDT Road Design Manual. 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, the rail should be stiffened. If the pole is located within the gaping portion of the approach end of the railing, the pole should be mounted on a breakaway base.
  - c. Concrete Barriers. Light standards that are shielded by a rigid or non-yielding barrier type do not require a breakaway device base.
  - d. Impact Attenuators. Light standards, either with or without a breakaway base, should be located so that they will not interfere with the functional operation of any impact attenuator or other safety breakaway device.
7. Protection Features. Special features (i.e., curbs or barriers) that are constructed primarily to protect a light standard should not be used.
8. Luminaire Mounting Height. Higher mounting heights may significantly reduce the total number of luminaire supports needed along a section of highway. For example, the use of high-mast lighting instead of conventional lighting at interchanges requires far fewer supports located much farther away from the roadway, thus reducing the number of fixed-object hazards.

### 13.6.6 Other Considerations

In addition to the considerations discussed in the previous section, the designer should review the following when determining the design of a highway lighting system:

1. Signs. Light standards should be placed to minimize interference with the driver's view of the roadway and highway signs. The luminaire brightness should not seriously detract from the legibility of the sign at night.
2. Structures. Light standards should be placed sufficiently far enough away from overhead bridges or overhead sign structures so that the light from the luminaire will not cast distracting shadows on the roadway surface or produce unnecessary glare toward the motorist.
3. Trees. Trees should be sufficiently pruned so that they do not cause shadows on the roadway surface or reduce the luminaire's efficiency. The luminaire should be designed with the proper height and mast-arm length to negate any adverse effects that trees will have on light distribution.
4. Retaining Walls. Luminaires may be located either on top of or behind retaining walls. Light standards mounted on top of retaining walls will require special consideration in the retaining wall design. Coordination with the Bridge Bureau will be necessary.
5. Bridge Railing. Luminaires may be located either on top of or behind bridge railing. Light standards mounted on top of bridge railing will require special consideration in the bridge rail design. Coordination with the Bridge Bureau will be necessary.
6. Medians. Although not desirable, light standards may be placed in median locations where the width of the median is adequate or if median barriers will be used. Where used, twin luminaires should have the same mast-arm length on each side.
7. Roundabouts. Experience has shown that roundabouts require special attention with respect to highway lighting. Motorists unfamiliar with the roundabout will need considerable more navigational information than typical intersections. Good lighting will improve driver confidence and performance in navigating through the roundabout. For additional guidance for providing lighting at roundabouts, see the AASHTO publication Roadway Lighting Design Guide.

### 13.6.7 Voltage Drop Determination

The typical highway lighting distribution circuit consists of two 120 V circuits provided by two conductors and a ground wire. Power supply to the lighting system is normally 120/240 V, single phase, 60-cycle alternating current. The lights are connected on both sides of the circuit to obtain 240 V at the luminaires. Use [Figure 13.6K](#) to determine the voltage drop between two adjacent luminaires. See [Figure 13.6A](#) for the maximum allowable voltage drop.

NOMINAL LAMP WATTAGE	AMPS	
	120 VOLTS	240 VOLTS
200 WATTS	2.0	1.0
250 WATTS	2.6	1.3
400 WATTS	4.0	2.0

Note: The amperage accounts for ballast loss.

AWG	FACTOR (R/ft (R/m))	AWG	FACTOR (R/ft (R/m))
10	2268 (7442)	2	352 (1155)
8	1435 (4707)	1	286 (938)
6	907 (2975)	1/0	227 (745)
4	575 (1886)	2/0	180 (590)

Note: Voltage Drop = Amps x Distance (ft (m)) x Factor x  $10^{-6}$

## VOLTAGE DROP BETWEEN LUMINAIRES

Figure 13.6K

### 13.7 HIGH-MAST LIGHTING DESIGN

In general, the design of high-mast lighting systems consists of the same design procedures as discussed in [Section 13.5.2](#). In addition, consider the following:

1. Light Source. Generally, a 1000 W high pressure sodium light source should be used. 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 100 ft (30 m) will require 400,000 lm, 600,000 lm for mounting heights of 115 ft to 130 ft (35 m to 40 m) and 800,000 lm for mounting heights of 150 ft (45 m). The number of luminaires per pole typically ranges from 4 to 6 luminaires.
2. Mounting Heights. High-mast lighting can range from 80 ft to 200 ft (24 m to 60 m). In general, heights of 100 ft to 160 ft (30 m to 50 m) have proved to be the most practical. Greater heights require more luminaires to maintain illumination levels. However, greater heights allow for fewer poles and provide better illuminance uniformity.
3. Location. In determining the location for high-mast poles, the designer should review the plan view of the area to determine the more critical areas requiring lighting. In selecting the appropriate luminaire supports for high-mast lighting, consider the following:
  - a. Critical Areas. Mast poles should be located so that the highest localized levels of illumination fall within the critical traffic areas (e.g., freeway/ramp junctions, ramp terminals, merge points).
  - b. Roadside Safety. Mast poles should be located a sufficient distance from the roadway so that the probability of a collision is virtually eliminated. They also should not be placed on the end of long tangents.
  - c. Signs. Masts should be located so that they are not within the driver's direct line of sight to highway signs.
4. Design. There are generally two methodologies for checking the adequacy of uniformity — the point-by-point method and the template method. The point-by-point method checks illumination by using the manufacturer's isofootcandle (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, a computer should be used to make these determinations. The template methodology uses isofootcandle (isolux) templates to determine the appropriate locations for mast supports. The templates may be moved around to ensure that the minimum maintained

illumination is provided and the uniformity ratio has been satisfied. Give consideration to adjacent land use during the analysis. The FHWA publication Roadway Lighting Handbook provides an example of using the template methodology for a high-mast lighting design.

5. Navigable Airspace. Where lighting projects are being considered in close proximity to an active airfield or airport, the designer should consider the impact luminaire height has on navigable airspace. For additional information, consult the FAA Advisory Circular AC 70/7460-2I Proposed Construction or Alteration of Objects That May Affect the Navigable Airspace.