# LIGHTING DESIGN

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## DATA COLLECTION

Office data collection is the first step in designing lighting. Collecting data, base mapping (obtaining or developing a base plan) and field review apply to any type of lighting. This is the time when the designer gathers information, collects existing data from outside sources, visits the project site and looks at potential design options.

### Office Data Collection and Preparation

Before preparing a design, the Designer should collect preliminary data and research existing records to develop the base plan and subsequently proceed with a conceptual design. For example, the Designer can research MSHA files for as-built plans, highway design plans, right-of-way plats and utility plans. Although all of the as-built information may not be available or completely accurate, the Designer should do this research to gain information on the history of the location. The designer could also check with the District for existing plans.

The District office should initiate the Design Request (DR) for lighting design projects, and thus may have some background information on the project. Again, although this information is shown in the DR, the Designer can gain insight on the location, history, problems and recommendations by contacting the preparer of the DR.

Another element for collecting office data is any proposed work being done. If the project is an insert job to a highway project, then the proposed geometrics and area improvements should be obtained. This may be acquired through the MSHA lead division or a local authority.

### Base Plan

The base plan is a key to the field work and design of lighting. It must be accurate and able to be used as a base for construction. In order to properly design the lighting, the designer needs a base plan showing existing topography, roadway geometrics, utilities, etc. The base plan should be in electronic format. One place to start is with the TEDD Archives. Often there may be an existing electronic file with this information that can then be field verified. The designer should verify within TEDD that the obtained plan is the latest version. For an insert job the electronic base plan may be obtained from the lead division, usually Highway Division. Other options may include a professional survey or extensive field work to obtain all of the mapping information.

### Photometric Concept Layout

Preliminary photometric calculations should be performed taking into account the existing conditions, base plan and design criteria as specified in the DR. The photometric calculations should be used to develop a preliminary concept layout with proposed pole locations and luminaire types. This concept will not typically be submitted to TEDD but will be brought to the field PI for discussion and verification.

### Information to Collect in the Field

#### Initial Site Visit

Most of the necessary information should be obtained during the initial site visit. This is the time to collect new information, verify existing information and prepare for the proposed and/or modified lighting design.

1. Collect existing information. This should include at a minimum:

    - Existing lighting – If there is any existing lighting then the control equipment, pole layout, pole types, luminaire types and sizes, etc. should all be gathered to be included with the plans. Determine what may be reused and what needs to be replaced.

NEMA identification decals are placed on the outside of the ballast housing of each roadway luminaire. The color indicates the type of light source and the number indicates the lamp wattage:

- Yellow = High Pressure Sodium
- Red = Metal Halide
- Light Blue = Mercury Vapor, this lamp type is no longer used in new installations due to environmental reasons.
- Green = Light Emitting Diode (LED)
- The number multiplied by 10 designates the wattage. For example, a black on yellow “25” = 250 Watts HPS

- Road geometrics (including diverging lanes, converging lanes, interchanges, intersections, structures, lane widths, etc.)
- Drainage elements (structures and ditches)
- Roadway alignment, vertical and horizontal
- Light level readings of existing lighting system and/or ambient levels to gauge offsite issues or future light trespass concerns.
- Driveways and entrances
- Utilities, overhead and underground
- Trees and vegetation
- Existing power service (location and size)
- Existing manholes, junction boxes, cable, and connector kits

2. Verify the proposed pole locations from the approved photometric concept plan. Decide what areas will and will not be lit. Locate potential power feeds for service. Identify if there are any constraints to be considered for planning conduit and manhole locations.

3. Confirm existing circuitry where needed.

4. Locate and measure the heights of overhead utilities, particularly at potential conflict locations. This will allow for meeting the NESC requirements of utility clearance and avoiding any conflicts between the proposed lighting and existing utilities. These measurements shall be documented.

5. Transmission line should be reviewed by the power company for required clearances/easements.

6. Always take photographs while in the field. This may save another trip to the site.

### Subsequent Site Visits

For most projects it will be necessary to do at least one subsequent site visit. This should include the verification of all proposed work. Things may change frequently in the field without prior notice so it is important to verify that the design is constructible and optimal for the given location under current conditions.

Field Data Collection Methods

The limits of the site review are usually determined by the limits of roadway or sign lighting. The methods used to collect field information may vary from a professional survey to simple tape and wheel techniques. The method will also vary dependent of the information required. Some or the following methodologies are explained further.

- Professional Survey – A professional survey is the hiring of an outside company or MSHA survey forces to collect the field information and mapping. A professional topographically survey may be needed on a case-by-case basis. This is the most accurate, all-encompassing method to collect field data, but is typically the most expensive.

- Tape and Wheel – The designer or designated person does a tape and wheel survey. This is the simple method of visiting the project site and using tape measures, wheels or other measuring devices to collect critical information. Using this method information may be collected on lane widths, distance between existing light poles, pole size, etc. All data collected shall be documented.

- Utility Heights – Measuring overhead utility heights is a critical element in the site visit, but it is also the most hazardous. Measuring the height of utilities is commonly done using an overhead cable measuring rod made of fiberglass. The rod is then used to measure the height of the different overhead utilities from the ground. DO NOT measure the primary electric lines with the rod due to hazardous high voltage. Further, do not attempt to measure any lines with the rod unless with someone who is trained and experienced.

- Photographs – Although photographs are not necessarily a formal method of collecting data, a picture can say a thousand words. Taking photographs will put the project site at arm's length once back in the office. Photos can be used to check lighting equipment locations, signal configurations, signs, intersection layout, roadside features, potential conflicts, etc.

- Notes – Taking good field notes is key when at the site. There are many things that a tape and wheel cannot measure. Taking notes to describe what is at the site is an excellent method of data collection. For example it is necessary to know the utility pole number for a potential power drop service, taking note of this number is the best way to communicate this information with the utility company to request location of a power source.

## LIGHTING CONCEPT

Developing a Concept

The conceptual plan is developed before the final lighting plan is designed. It is the first milestone in which input is received from the parties involved including the designer, project manager, team leader and district traffic office at a minimum.

Prior to the conceptual plan being developed, the base mapping should have been obtained and verified in the field. All field information should be shown on the base mapping including utilities, intersection geometrics, pavement markings, etc.

The conceptual lighting design process can be broken down into several steps as follows:

1. Determine Function of Lighting

2. Determine Classification of Roadway

3. Select Luminaire and Light Source
4. Select Structure
5. Preliminary Calculations
6. Define Design Criteria
7. Develop a Preliminary Layout

This is sometimes referred to as a post-it plan for lighting. The key is selecting the hardware, defining design criteria and developing a preliminary layout. Each of these steps will be discussed further in depth.

## Function of Lighting

Lighting for MSHA projects serves several different functions. At the beginning of the project the function of the lighting should be defined and agreed upon by all parties. On any given project there may be more than one function and all of these should be identified.

The most common application is roadway lighting. Other lighting functions include pedestrian/bicyclist lighting, sign lighting, and parking lot lighting. These four functions have similar design methods, but vary with criteria and function. Defining the function of the lighting allows the designer to determine the criteria to use for design. For example, lighting a freeway will have different criteria than parking lot lighting.

### Roadway Lighting

The purpose of roadway lighting is to promote safety at night by providing illumination of the highway, vehicles, pedestrians and roadside objects.

#### *Interchange Lighting*

It is current MSHA policy that all new projects which require lighting implement partial interchange lighting per the MSHA Lighting Guidelines. Full interchange lighting does also exist in some locations throughout Maryland and is described below for specific situations.

#### *Partial Interchange*

Partial interchange lighting involves lighting the conflict point(s) of an interchange, i.e. merge-diverge areas of ramp connections, ramp splits/ramp merges, intersections and critical roadway features such as sharp curves, reverse curves etc., and when the following is true:

- Generally works well for interchanges that can be readily visualized by motorists by viewing the critical decision points.
- Additional lights other than those minimally required shall be considered per the MSHA Lighting Guideline or at the discretion of the Administration.

#### *Full Interchange*

Full interchange lighting is the lighting of all roadways and ramps within an interchange and the following:

- Generally supplements continuous lighting along the mainline roadway.
- Also applied where substantial lighted commercial or industrial developments are located in the immediate vicinity of the interchange and where the crossroad is lit for at least ½ mile on each side of the interchange.

MSHA does not install full interchange lighting.

#### *Intersection Lighting*

Intersection lighting involves lighting only an intersection. It is Administration policy to light all signalized or ICB controlled intersections. Other intersections may be lit after an engineering study warrants it due to safety concerns, high crash history, complex geometrics, etc.

*Continuous Lighting*

Continuous lighting illuminates a straight stretch of roadway between interchanges and/or intersections.

Per the MSHA Lighting Guidelines, continuous roadway lighting shall not be installed along any state highway unless justified by an engineering study AND approved in advance by the Director of the Office of Traffic and Safety.

In general the Administration's practice is not to light continuous sections of the highway. However, sections of highways may be lit where combinations of sight distance, horizontal or vertical curvature, channelization or other factors contributing to a confusing or unsatisfactory condition exists.

*Roundabout Lighting*

It is the Administration's policy to light all roundabouts. See the MSHA *Lighting Guidelines* for more information. Lighting a roundabout follows the same process as lighting a roadway.

*Tunnel Lighting*

Tunnel lighting shall be considered where normal daytime illumination of a roadway section is restricted such that the driver's visibility is substantially diminished. Tunnel lighting shall be designed in accordance with the most recent version of the Illuminating Engineering Society RP-22, American National Standard of Tunnel Lighting.

*Underpass Lighting*

Underpass lighting can be considered critical during the daytime or nighttime to mitigate "dark spots". Underpass lighting during the daytime is considered where sidewalks are present. For nighttime it can be considered for pedestrian safety and to supplement for dark spots created by a structure's obstruction of light emitted by the adjacent light pole(s). Underpass lighting shall be designed per the MSHA Lighting Guideline and when length to height ratios of the structure exceed 10:1.

*Transition Lighting*

Transition lighting gradually takes a driver from a high level of lighting to little or no roadway lighting. Generally, MSHA doesn't use transition lighting for nighttime use, but uses transition lighting as needed for daytime use when entering and exit tunnels or underpasses.

Pedestrian Lighting

The Maryland Department of Transportation is committed to planning and constructing alternate forms of transportation i.e. walking and bicycle paths. Sidewalks that are located adjacent to the lighted roadways often do not have separate lighting provided for the safety and comfortable use by pedestrians and bicyclists. The incidental house side distribution of roadside luminaires is the only lighting afforded for the comfort of the pedestrian. Where a better quality of lighting for pedestrians is desired, the illumination design for the roadway can be modified to correct any deficiencies or supplemental lighting can be provided. The MSHA Pedestrian Lighting Policy as outlined in the MSHA Lighting Guidelines should be used for specifics on criteria for eligibility, financial responsibility and design standards.

When specific lighting is provided for pedestrians, the quality of lighting provided is dependent on whether the lighting is installed for illuminating the sidewalk or walkway, or if there is an additional requirement for special pedestrian security. Lighting for security purposes has an additional requirement for providing the specified vertical illumination 5' above the walkway to allow pedestrian identification at a distance.

Pedestrian characteristics are usually classified into three levels: high, medium and low.

- High: This is high nighttime pedestrian volume, over 100 pedestrians per hour, with expected crosswalks and sidewalks such as downtown retail areas, near theaters, stadiums, transit terminals, etc.

- Medium: This is a lower nighttime pedestrian volume, 11 to 100 pedestrians per hour, such as near office buildings, libraries, apartments, industry, etc.

- Low: This is a very low nighttime pedestrian volume, fewer than 10 pedestrians per hour, such as rural areas, low density residential areas, etc.

### Sign Lighting

Refer to the Sign Lighting Section of the Maryland MSHA Lighting Guidelines, 2017 for information regarding locations that require sign lighting. When sign lighting is required, LED light sources shall be used.

If a signing upgrade project is upgrading a sign that has sign lighting because it is not Type XI sheeting, the new sign should be made of Type XI sheeting and sign lighting should be eliminated where possible. When sign lighting is required, individual luminaires and supports should be used.

Sign lighting is usually accomplished by lighting the signs from the bottom for the following reasons:

- By having the lights pointed in an upward direction, any light which misses the sign, tends to shine into the sky and not provide a severe glare source for the drivers.

- Having the light point up tends to reduce the amount of light shining on adjacent properties and reduces the light trespass; although control of the light spilling upwards should still be considered to minimize sky glow.

### Parking Lot Lighting

Typically any given parking lot will be lit. For MSHA the most common application will be for Park & Ride facilities. Lighting for a parking lot will utilize different criteria for illuminance, but the design process is the same.

### Aesthetic Lighting

Aesthetic lighting is lighting designed to enhance existing or proposed surrounding features such as buildings, landscaping, structures, community signs etc. This is becoming more common with streetscape projects. For a typical roadway, aesthetic lighting will not be used.

## Classification of Roadway

The roadway classification will help determine the photometrics required for lighting as well as assist in selecting the proper lighting. These are basically the same as any other roadway classification for highway projects. The classifications are defined in the *MSHA Lighting Guidelines.*

## Luminaire and Light Source

The luminaire is the housing unit for the light source, along with the distribution and power elements such as reflectors, refractors, drivers, socket, wiring terminals, etc. Selecting a luminaire and light source is a key element in the illumination design of lighting.

There are several variables within the luminaire to be determined: shape, distribution, light source, ballast and depreciation.

## Distribution

Roadway luminaires are classified by the way they transmit and distribute light. The use of various types of reflectors and refractors permits the lighting designer to produce an efficient and aesthetic design. Luminaire classifications are defined in terms of vertical light distribution, lateral light distribution, and the control of distribution above nadir, known as cutoff.

### *Vertical Distribution*

The vertical distribution of light is divided into three categories; short, medium and long. Vertical distributions are classified by the candlepower along the transverse roadway lines (TRL) measured in lengths of the pole mounting height (MH). A shorter vertical distribution will reduce glare, but will require a tighter spacing to maintain uniformity. A longer vertical distribution will increase glare, but increase spacing. MSHA commonly uses a medium vertical distribution.

### *Horizontal/Lateral Distribution*

The lateral distribution of lighting is essentially the shape that the luminaire distributes on the pavement. There are five basic types of horizontal distribution, Type I through Type V. Types I and II have two subgroups for two-way and four-way distribution. Figure LT.1 illustrates Types I-IV. MSHA typically uses Type III distribution.

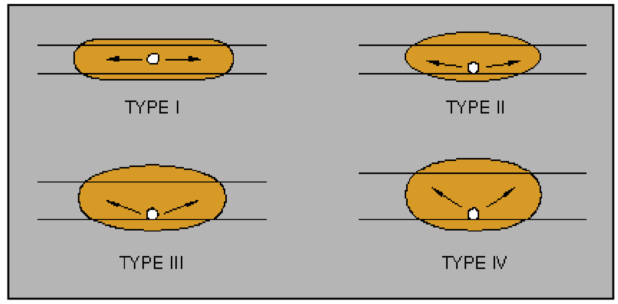


**Figure LT.1 - Horizontal Distribution**

### *Control of Distribution above Nadir*

The control of lighting distribution above nadir is known as cutoff. (The nadir is a reference of point in the line of the pole.) Lighting 90° above nadir leads to “sky glow,” glare and often an overflow of light where no light is needed.

#### Full Cutoff

A full cutoff luminaire allows no light above an angle 90° above nadir. For an angle 80° above nadir, the intensity can be no more than 10% of the total lumens. It has become common practice on highway projects to use the full cutoff luminaries.

#### Cutoff

A cutoff luminaire allows less than 2.5% of the total lumens above an angle 90° above nadir. For an angle 80° above nadir, the intensity can be no more than 10% of the total lumens.

#### Semicutoff

A semicutoff luminaire allows less than 5% of the total lumens above an angle 90° above nadir. For an angle 80° above nadir, the intensity can be no more than 20% of the total lumens.

#### Noncutoff

A noncutoff roadway fixture, as pictured below, typically has a dropped lens (a refractor). This allows the light to be easily distributed from the fixture to an area larger than the section being lighted. This type of fixture may be appropriate for area lighting such as wide intersections along divided highways, at grade railroad crossings, parking lots, maintenance yards, and urban streets where some house-side lighting is desirable for pedestrians. There are no intensity limits for a noncutoff luminaire. The Administration typically does not use these types of luminaries.

**Figure LT.2 - Noncutoff Roadway Lighting Fixture**

## Backlight, Uplight, and Glare (BUG) Ratings

Addendum A for IESNA TM-15-07 contains tables that list BUG ratings that may be used to evaluate luminaire optical performance related to light trespass, sky glow, and high angle brightness control.

Roadway lighting systems are under increasing scrutiny from various sectors of the public. While the general public is not usually aware of specific design requirements of roadway lighting systems, glare, sky-glow, and aesthetic elements are widely perceived and open to criticism. The lighting designer should become familiar with these issues and be prepared to design a lighting system that meets the needs of the owner. An increasing number of communities are adopting lighting ordinances meant to reduce sky-glow.

## Light Sources

The light source is housed inside the luminaire and is the artificial source of light. There are many different types of light sources. Light sources may be selected based on their efficiency, depreciation, color, life, cost and/or restrike time. There are three basic categories for light sources, low pressure sodium lamps, high intensity discharge lamps, and LEDs. These may be found in existing conditions, but the only category that is currently used by MSHA is LEDs.

### *Low Pressure Sodium*

Low pressure sodium (LPS) lamps are monochromatic and have no color rendition. They have good initial efficiency, however the efficiency decreases and the current draw increases with aging. The lamps also tend to be much larger and require larger fixtures making them prohibitive for roadway lighting applications. LPS lamps are not used on MSHA projects.

### *High Intensity Discharge*

High pressure sodium (HPS) lamps were the standard light source for the Administration's roadway lighting. HPS was used because they give the optimum mix of a long life and low maintenance with a high efficiency (lumen output per watt). The primary draw- backs are that it has a pinkish orange color, which some people find objectionable and tends to mute some colors.

### *Mercury Vapor*

Mercury vapor lamps have formerly been used in sign lighting and may still be in use, but they are no longer used for new installations.

### *Metal Halide*

Metal halide lamps have a blue-white color that provides a very good color rendition. They have a good energy efficiency, however also have a relatively shorter service life.

They are primarily used for old high mast lighting applications and by local jurisdictions that need a better color rendition with their pedestrian or roadway lighting. All new metal halide lamps are Pulse Start. Pulse Start metal halide lamps have a longer lamp life, are more efficient, and have a quicker start up.

*LED*
LED is the standard light source for MSHA for all lighting except for high mast. An LED light source is a semiconductor diode. It consists of a chip of semiconducting material treated to create a structure called a p-n (positive-negative) junction. When connected to power source, current flows from the p-side or anode to the n-side, or cathode, but not in the reverse direction. Charge-carriers (electrons and electron holes) flow into the junction from electrodes. When an electron meets a hole, it falls into a lower energy level, and releases energy in the form of a photon (light).

LED light sources are available in a variety of colors. They are very energy efficient and have a long service life. The LED technology continues to develop making the light source more efficient, have a longer life, and cheaper.

*Inductive*
Inductive lamps are light sources in which the power required to generate light is transferred from outside the lamp envelope to inside via electromagnetic fields. This differs from a typical electrical lamp that uses electrical connections through the lamp envelope to transfer power.

Inductive lamps are amongst the most efficient light sources. They offer energy savings, long life spans, high scotopic output and high color rendering index. The inductive lighting technology continues to develop making the light source more efficient and have a longer life.

*Ballasts*
Ballasts are used for high intensity discharge light sources. The ballast is an interface between the electric current and the light source. It allows the light source to obtain the necessary circuit conditions for starting and operating. For application with MSHA projects, a high power factor ballast is housed in the luminaire.

*Drivers*
Drivers are used for LED light sources. The driver converts line power to the appropriate voltage (typically between 2 and 4 volts DC for high-brightness LEDs) and current (generally 200-1000 milliamps or mA), and may also include dimming and/or color correction controls.

Depreciation
Another factor in the selection of a luminaire and light source is depreciation. The depreciation of the luminaire and light source directly affect the illuminance calculations. Depreciation is measured as a light loss factor and is a combination of several factors. The two main factors are maintenance and equipment. Both of these elements combine to form a total light loss factor. Depreciation is defined by a percentage of loss. The factor will vary greatly depending on the elements discussed below.

*Light Loss Factor*
In most cases, measured values are less than the calculated values of the new, clean lamp and luminaire. Any lighting parameter, including luminance and veiling luminance, can be calculated in terms of either an initial or a maintained value. Any compensation for system aging is part of the “light loss factor” (LLF). LLF is the overall factor used to link calculated to measured levels. LLF must be incorporated into lighting design calculations. A LLF of 0.64 should be used for all MSHA lighting projects, but designers should confirm

the current LLF with TEDD before establishing design parameters.

*Equipment Factor*
Equipment factors are not time dependent, but are related to the specific equipment in use. These include ambient temperature, voltage, ballast and lamp factor, luminaire component depreciation and change in physical surroundings.

<u>Lighting Structures</u>
The light structure is the support of the luminaire. Most commonly the luminaire is attached to a bracket arm in turn connected to a pole that sits on a base. Luminaires can also be attached to walls and bridges. It includes the pole, base and typically the bracket arm.

Pole Assembly

*Low Level Lighting*
Low level lighting is most commonly used in Maryland. It refers to poles that are 50' and lower in height.

*Bracket Arm*
The bracket arm connects the pole to the luminaire. The arm may range in size from none to 35'. The bracket arm length is dependent on the offset of the pole from the edgeline, with the luminaire preferably installed over the edge of travelway.

*Bases*
The first element to define for the base is the use of a breakaway base versus an anchor base. A breakaway base is a safety feature that breaks the pole from its foundation when impacted. An anchor base does not offer this safety feature and can be a hazard if not protected. Breakaway bases should be used when the structure is not protected from errant vehicles such as with w-beam traffic barrier or barrier wall.

High Mast Lighting
High mast lighting is typically installed at large complex interchanges within predominantly business or industrial areas. It is associated with mounting heights that require special lowering gears to maintain the lights. The lights typically require higher wattage lamps to produce the desired illumination levels on the pavement. The light output usually provides an improved visual field negating the tunnel effect usually associated with low-level lighting, improved uniformity and reduced veiling glare. The poles can be placed further away from the travel lanes, which decrease the possibility of off-the-road crashes. Light trespass into surrounding neighborhoods however, is a usual source of complaints associated with high mast lighting. High mast lighting will not be installed along state roadways unless required lighting levels cannot be achieved with low level lighting and justified by an engineering study, per the MSHA Lighting Guideline.

Underpass Lighting
Underpass lighting is installed for tunnel and underpass lighting applications. MSHA prefers that underpass lighting be mounted on the substructure. The method of strapping on metal plates to the pier caps is the most common method of mounting underpass lights to existing piers.

Roadside Placement
During the conceptual plan it may not be necessary to finalize an offset location of the lighting structures, but it should be considered. Lighting structures are like any other roadside hazard and should be placed based on AASHTO's Roadside Design Guide. Look for obstacles that may limit placement such as bridges, signs, signals, utilities, etc.

Some of these elements may help to define where poles may or may not be placed.

### Other Structures

In addition to simple pole structures, luminaries may be attached to walls, bridges, or other special features. These often require a special design.

## Preliminary Calculations

After selecting the luminaire, light source and structure to be used, the process of designing the layout begins. Placing the lights is an iterative process that depends heavily on several factors such as roadway geometrics, roadway classification, and pavement surface. Some of the other factors that are considered when determining the design are traffic crash history, severe grades and curves, type and location of high use driveways, underpasses, overpasses, trees and zoning of surrounding areas.

The prevailing photometric design criteria for highway lighting can be found in the latest approved version of the *MSHA Lighting Guidelines*. Currently the Administration design practice utilizes illuminance for roadway lighting and veiling luminance for glare reduction. The calculations involve an iterative process for predicting the quality of lighting and are usually performed using commercially available software.

### Design Software and Establishing Lighting Criteria

There are numerous design software programs available to use when calculating lighting photometrics. They allow for ease and efficiency of computations. Most software packages require several inputs from the user. This may vary with the software, but below is a general list of inputs that should be established during preliminary design:

- Roadway geometrics
- Luminaire selected
- Light Source
- Depreciation factors
- Orientation
- Distribution
- Mounting height
- Bracket arm length
- Pavement classification

It is required that the consulting engineer complete lighting calculations, not the manufacturer.

### Illuminance

Illuminance is generally described as the amount of light falling on a surface or as “incident light” and is measured in footcandles (fc) (or lux (lx) in the metric system). This method is the simplest to calculate using an integration of all the light falling on a spot on the pavement surface from all adjacent light point sources. An additional calculation is done to determine the uniformity of lighting based on the ratio of the average and minimum illumination.

The recommended values of illuminance and veiling luminance (described below) for various roadway classifications and pedestrian classifications are found in the *MSHA Lighting Guidelines*.

### Luminance

Luminance is a method of predicting effective brightness of an object that a driver sees based on light, which is reflected back to the eye after having struck the surface. The luminance of the object depends on its material characteristic and reflectance. Luminance is usually expressed in candelas per square meter (cd/m2). Additional calculations are done to determine the uniformity of lighting and the veiling luminance (glare) to determine the comforting level of lighting.

### *Veiling Luminance*

Also known as disability glare, veiling luminance is a stray light that is produced within the eye. The veiling luminance ratio is the ratio of the maximum veiling luminance from a system divided by the average pavement luminance.

### *Pavement Classification*

Pavement classifications for the purpose of pavement luminance and lighting design are classified as follows (Source is the *Roadway Lighting Design Guide* by AASHTO):

- R1: Portland cement concrete road surface. Asphalt road surface with minimum of 12 percent of the aggregates composed of artificial brightener aggregates.
- R2: Asphalt road surface with an aggregate composed of a minimum 60 percent gravel. Asphalt road surface with 10 to 15 percent artificial brightener in aggregate mix.
- R3: Asphalt road surface with dark aggregates; rough texture after some months of use.
- R4: Asphalt road surface with very smooth texture.

MSHA uses the R3 classification for all roads.

### Defining the Design Criteria

Defining the design criteria is the most critical step in the design process for lighting. During this step it is essential to put in writing each piece of the design. This should include at a minimum:

- Lighting Function
- Classification of Roadway/Ped Conflict
- Luminaire
- Lens
- Vertical Distribution
- Lateral Distribution
- Cut-Off
- Light Source Type
- Light Source Wattage
- Mounting Height
- Bracket Arm Type
- Type of Pole
- Pole Base
- Average Maintained Illuminance
- Uniformity Ratio
- Veiling Luminance
- Operating Voltage
- BUG Rating

Figure LT.3 shows an example of a list of design criteria definitions.

## Preliminary Layout

The preliminary layout is the first opportunity to start to layout structure locations. This may be based on:

- Preliminary analysis with design software
- Previous experiences
- Engineering judgment

Many software programs for lighting design incorporate a "pre" program to allow for preliminary layout. Software programs which aid in photometric analysis are useful for developing initial light structure locations.

Previous experience can also aid in preliminary layout design. If using the same luminaire, light source, mounting height, and design criteria it may be possible to use previous experience to assist in layout design. Experience also allows the designer to be familiar with certain types of luminaire distribution and the designer becomes familiar with specific capabilities.

Engineering judgment and studies is a last way to develop a preliminary layout of luminaires. The preliminary layout will determine if luminaries will be placed on one side of the road, both sides of the road, in the median, or staggered. This layout should also define a preliminary spacing of the luminaries.

## Reviewing the Concept

The conceptual plan is the time for all interested parties to agree and finalize the major decision making components of the lighting design. It is recommended to prepare a memorandum to accompany the concept plans. The memorandum should summarize the lighting analysis and concept design and should document all criteria and assumptions used to create the preliminary layout and concept. At this point the designer should receive input from the Project Manager and the Team Leader. This conceptual plan will govern the other elements of design to follow. Resolving any conflicts or issues at this point will eliminate the need for change after final design.

A reviewer should consider the following items when viewing a conceptual lighting plan:

1. Check that the lighting meets the requirements of the Design Request.
2. Check for any special design considerations such as underpasses, roundabouts, signing, and pedestrians.
3. Check that the design criteria is well defined and that the criteria is met within the design.
4. Check for overall concurrence with Federal and MSHA standards.

**Design Criteria for Lighting**

**US 29 / MD 216**

*Highway Lighting Assumptions and Conditions*

Lighting Function
- Partial interchange lighting
- Lighting for both roundabouts
- Add lighting to expanded Park & Ride
- Complete lighting of loop ramps

Luminaire and Light Source
- High pressure sodium lamps
- Flat glass lens
- Full cut off
- Medium vertical distribution
  Type III lateral distribution
  Light loss factor = 0.64
  HPF rector or lag ballast
  GE luminaire (M250A2)

Lighting Structure
- 40 Ft poles
- Galvanized steel poles
- Galvanized steel bracket arm
- Breakaway transformer base

Illuminance
- Uniformity ratio (avg:min): 3:1
- Minimum maintained illuminance: > 0.2 fc
- US 29, Freeway classification; average maintained illumination between 0.6 fc and 0.8 fc
- MD 216, Expressway classification; average maintained illumination between 0.8 fc and 1.2 fc
- Use AGI software to calculate illumination

Electrical
- 277/480 operating voltage
- Three phase, four wire
- Duct cable

Sign Lighting Assumptions and Conditions
- All overhead signs will be lighted
- LED luminaires
- Die-cast aluminum housing
- Standard light mounting with individual I-beam supports

**Figure LT.3 - Example of Design Criteria**

## ROADWAY LIGHTING DESIGN

Once the lighting concept plan has been developed, reviewed, and approved the next step is to formally evaluate the photometrics and finalize the layout. By now all criteria to be used, pole selection, luminaire and lamp selection and a preliminary layout have been determined.

### Lighting Calculations

A lighting calculation is a complex process. Most designers use computer software to evaluate the photometrics and design the lighting layout. This is typically the most efficient and effective method of computation. The lighting calculations should be prepared as part of the conceptual plan. For roadway lighting, the average maintained illuminance, uniformity, and veiling luminance should be computed.

### Using Design Software

At this time, MSHA doesn't require a specific type of software. Since most manufacturers of luminaries and lamps have their own design software, the results of any given software will vary. For this reason, the software used should be specified to allow for quality review and comparison to other software applications.

Some applications will only consider straight line roadways and the designer will need to apply general engineering practices to account for special geometrics such as curves. Other applications have preliminary calculations, which allow the user to develop a preliminary spacing.

The approved roadway LED luminaires and lamps can be found on the MSHA list of qualified products. IES files shall be obtained from the various luminaire manufacturers.

### Interchanges

Partial interchange lighting is the illumination of only the parts of the interchange that are most critical to the night driver, which are the merge-diverge areas of the ramp connections, intersections, and other critical roadway features.

Partial interchange/ramp intersection required lighting analysis areas include:

- Acceleration and deceleration lanes
- Ramp terminals
- Intersections

Partial interchange/intersection additional lighting areas beyond the analysis areas include:

- Horizontal curves
- Crest Curves
- Other areas of geometric and traffic complexity
- Crossroads at frontage road or ramp intersections
- Other areas of nighttime hazard.

The following guidance is provided for locating lighting poles. Diagrams are provided in the MSHA Lighting Guideline to indicate the typical configuration for partial interchange lighting through diagrammatic scenarios. The exact locations of lighting poles should be adjusted to avoid obstructions and must provide adequate lighting levels per the MSHA Lighting Guideline and the photometric results.

Refer to the *MSHA Lighting Guidelines* for information regarding the lighting of ramps and acceleration and deceleration lanes.

Where there is a split in the ramp lighting shall be provided. Intersections at the end of a ramp shall be lit based on intersection warranting conditions prescribed in the IESNA RP-8 Roadway Lighting Manual.

Transition Lighting is a technique intended to provide the driver with a gradual reduction in lighting levels and glare when leaving a lighting system. Some factors that may influence the justification for a transition lighting area are:

- Radical reduction in roadway cross section
- Severe horizontal or vertical curvature of the roadway.
- Change from a very high lighting level.

Transition Lighting is recommended at the option of the designer after a study of the conditions at a specific location.

Aesthetically pleasing lighting structures and pole colors may be required under some projects to coordinate with existing structures or other special design applications. Usually, these requirements are defined by MSHA and are documented in the Design Request.

### Intersections

There are three types of at grade intersections: unrestricted traffic flow on both roadways, restriction by means of stop signs on one or both of the roadways, and control by traffic signals. Some are complicated by pedestrian activities as well as vehicular traffic. The lighting task on all of these, however, is fundamentally the same. The luminance level in these areas should generally be higher than the level of either intersecting road.

Luminaires should be located so that lighting will be provided on vehicles and pedestrians in the intersection area, on the pedestrian walkways, and on the adjacent roadway areas. Of particular importance is the amount of light falling on the vertical surfaces of such objects that differentiate them from the pavement background they are seen against.

With channelized intersections, the Designer should examine the frequency and location of nighttime crashes so that an adequate design can be prepared to address the problem.

### Underpasses vs. Tunnels

Structures considered to be underpasses are those in which the length and physical configuration of the structure do not substantially limit the drivers' ability to see objects ahead.

A tunnel is defined as a structure over a roadway which restricts the normal "daytime" illumination of a "roadway" section such that the driver's visibility is substantially diminished. Tunnel lighting may be considered where an underpass exceeds 80 ft in length and has a length to height ratio of up to 10:1. Tunnel lighting shall be considered when the portal to portal length is greater than the minimum wet pavement stopping distance.

Underpass lighting shall be designed for "nighttime" hours. The need for "daytime" lighting shall be based on an engineering study. Typically, MSHA installs underpass lighting for walkway and bikeway safety or vehicular safety. Underpass lighting may also be installed as a part of partial interchange lighting where the acceleration/deceleration lane limits extend underneath of a structure. See the MSHA Lighting Guidelines for details.

Underpasses of multiple highway structures, where the space between these structures permits good penetration of daylight on the underpass roadways, will normally be treated separately, rather than as one single, composite length. Where direct daylight reaches the roadway beneath the overhead structure of considerable length, on one or more sides, daytime lighting may not be required.

When the length of an underpass exceeds 80ft, it is necessary to analyze the specific geometry and roadway conditions, including vehicular and pedestrian activity, to determine the need for daytime lighting or tunnel lighting.

Long underpasses, where adequate lighting from the street luminaires cannot be accomplished, require special treatment. Long underpasses also greatly reduce the entrance of daylight and, therefore, may warrant lighting during the daytime.

For nighttime lighting, luminaires on the lower roadway should be positioned so that there are not large dark spots in the pavement lighting from that on either side of the overpass. These luminaires should also provide adequate vertical illumination on the supporting structures.

A roadway which is not continuously lighted may warrant underpass lighting in areas having frequent nighttime pedestrian traffic through the underpass, or where unusual or critical roadway geometry occurs under or adjacent to the underpass area.

Roadways having continuous lighting will generally warrant the use of underpass illumination. Favorable positioning of luminaires adjacent to the underpass can often provide adequate lighting of relatively short underpass areas without the need for supplemental lighting.

Underpass lighting levels and uniformities should duplicate, to the extent practical, the lighting values on the adjacent roadways. Because of luminaire mounting height and spacing limitations in an underpass, it may be necessary to provide somewhat higher levels of lighting in the underpass to achieve the required underpass uniformity values. Such increased levels should not exceed approximately twice that of the roadways adjacent to the underpass.

For further information of tunnels and underpasses lighting see IES's *RP-22 American National Standard for Tunnel Lighting*. Design approach based on photometric calculations and required lighting limits should be approved by MSHA before advancing the concept to detailed design.

## Special Geometrics

Depending on the software used to complete the lighting calculations, special consideration may need to be given to some situations. For example, a horizontal curve may need the spacing of the poles tightened to compensate for the effect that the curve has on the illumination.

### *Horizontal Curves*

The visual problems of driving increase on horizontal curves. In general, gradual, large radius curves and gently sloping grades when lighted, are treated as straight level roadway surfaces. Sharper radius curves require closer spacing of luminaires in order to provide higher pavement luminance and improved uniformities. The spacing ratio between poles may vary from 0.55 to 0.90 to provide adequate and uniform levels of lighting. Spacing shall be appropriate for site conditions in addition to recommended illuminance requirements.

The geometry of abrupt horizontal curves, such as those found at interchanges and many roadway areas, also requires special consideration. Headlighting is not as effective in these situations and silhouette seeing cannot be provided in some instances.

Luminaires should be located to provide light on vehicles, road, curbs, traffic barriers and other fixed objects. It is generally found in national guidelines that poles are more likely to be involved in fixed object type crashes if placed on the outside of curves. Many vehicle operators may be unfamiliar with these areas and lighting the surroundings greatly helps their discernment of the roadway path.

Proper horizontal orientation of luminaire supports and poles on curves is important to assure balanced distribution of the light flux on the pavement. Furthermore, when luminaires are located on steep grades, it is desirable to orient the luminaire so that the light beams reach the pavement equidistant from the luminaire. This assures maximum uniformity of light distribution and keeps glare to a minimum.

*Acceleration and Deceleration Lanes*

Acceleration lanes refer to entrance ramps and frequently have all the challenges of abrupt curves. Light from vehicle head lights in acceleration lanes may be ineffective. It is thus desirable to provide good direct side lighting on the vehicles entering the main traffic lanes. Generally, lighting is provided starting within 100 feet prior to the physical gore along the ramp, and ending at a point where the full width acceleration lane begins to taper.

Deceleration lanes warrant careful consideration because these are areas where motorists are reducing speeds and looking for exit/turn information. Luminaires should be placed to provide illumination on curbs, abutments, traffic barriers and vehicles in the area of traffic divergence. Poles should be located based on the Roadside Design Guide best practices to protect against vehicles that may cross the gore area. Install partial lighting in the deceleration zone. Starting at the full width lane and ending approximately 100 feet past the gore area, i.e. the safety clearance.

*Roundabouts*

When illuminating roundabouts, MSHA's Roundabout Design Guidelines (also found in the MSHA Lighting Guideline) should be used as a reference. This guide emphasizes the following recommendations:

- Lights should be located so that they provide good illumination on the approach nose of splitter islands, the conflict area where traffic enters the circulating stream and at places where traffic streams separate at points of exit.

- Particular attention should be given to the lighting of the pedestrian crossing areas at sites where the pedestrian/bicycle/vehicle conflicts are likely to be significant.

- Poles should not be placed within splitter islands, on the central island directly opposite an entry roadway, or on the left-hand perimeter immediately downstream of an entry point.

Lighting of roundabouts in local streets should be individually designed to suit site considerations. Aesthetic lighting may be a consideration for the type and placement of poles in roundabouts. As a general guide MSHA lights each leg of a roundabout.

The risk of an errant vehicle colliding with a pole should always be considered when designing the lighting system, and the use of breakaway type poles should be encouraged.

## Final Pole Layout

After the photometric computations have been completed the final layout should be designed. Using the results of the photometrics as well as good engineering judgment the poles should be located in their final location.

### Placement of Poles

The horizontal placement of the pole is the placement in relation to the roadway. Most horizontal placements are defined by an offset distance from the baseline, face of curb or edge of pavement. Lighting structures should be placed based on AASHTO's Roadside Design Guide.

The physical roadside conditions may restrict the placement of lighting poles. Therefore, it is important that the Designer consider limitations in the design to provide for constructability. Sign structures, overpasses, traffic barriers, roadway curvature, roadside slopes, gore clearances and lighting equipment limitations are factors which must be taken into account during design. The Designer must evaluate all judgment factors including safety, aesthetics, economics and environmental impact while accounting for the physical limitations.

Some safety considerations for lighting pole locations include the following:

- It is desirable to place poles outside the roadside clear zone, but this isn't often possible in order to meet the photometric needs. When placed inside the clear zone, breakaway bases should be used.

- Pole locations should consider the hazards and convenience in servicing the lighting equipment.

- Poles should be located to provide adequate safety clearance in the gore areas of exit and entrance ramps. For exit ramps it shall be at least 100' from the physical gore.

- Breakaway bases can only be used for forty and fifty foot poles with certain arm lengths. Forty foot poles with arm lengths of up to 25 feet may be installed on a breakaway transformer base. Fifty foot poles with arm lengths up to 15 feet may be installed on a breakaway transformer base. Any forty or fifty foot poles with greater arm lengths must be protected or placed beyond the clear zone.

- Poles should not be placed within 50 feet of an overhead sign. Violating this could cast distracting shadows on the roadway surface at night and/or wash out the message on the sign.

- Poles on the inside radius of superelevated roadways should have sufficient clearance to avoid susceptibility of being struck by trucks.

- Poles should not be placed on the traffic side of traffic barrier or any natural or man-made deflecting barrier without permission

- Where poles are located in exposed areas, they should be designed to have a suitable breakaway or yielding feature. The safety feature shall comply with all applicable AASHTO requirements for structural supports.

- Poles behind traffic barriers should be so located to provide the necessary clear distance for the railing or barrier deflection as defined in the MSHA *Book of Standards for Highway and Incidental Structures* and the MSHA *Guidelines for Traffic Barrier Placement and End Treatment Design*.

- Poles should be placed to avoid conflict with utilities, inlets and other underground or overhead items that must be cleared. Any pole placement near overhead transmission lines requires the power company's approval.

- Median pole locations should be considered where the width is appropriate on open roadways or median barriers are to be used. Median pole locations provide several lighting and economic advantages. The number of poles necessary may be reduced to approximately one-half, the amount of cable may be reduced, the house side lighting could be utilized, and the visibility on the high speed lanes also may be improved.

- Other design considerations also include:

- Provisions for present or future lighting may be included with the roadway and structural work. Such provisions include under pavement conduit, junction boxes and conduit, and pole anchorage in structures.

- Annual cost of energy and maintenance, maintenance capability, and responsibility for the maintenance of the lighting system are some of the items, which should be considered as part of the system design. All items should be weighed for their importance on any specific design.

## SPECIAL LIGHTING DESIGN

### Rest Areas

Rest areas incorporate both vehicular and pedestrian usage, and constitute an important highway feature to the traveling public. They are available for use at night as well as by day, and their general appearance should generate a feeling of safety and security. This condition can exist only if the facility is adequately lit for nighttime use. According to AASHTO, any rest area offering complete rest facilities should be lit.

Properly designed lighting, conventional or high mast, will enhance the architectural and landscape features of the facility, promote safety by easing the task of policing, and contribute to the rest and relaxation of the motorist by completely delineating the driving, parking and walking areas of the facility.

One of the prime concerns in consideration of rest area lighting is that the motorists traveling along an unlighted main highway do not have their vision adversely affected by glare or by spill light from luminaires placed adjacent to the roadway within the rest area. Adverse glare within all interior areas should also be given consideration. As the motorist on the main roadway traverses the entire length of the adjacent rest area, the motorist should be able to discern any vehicle leaving the rest area, as well as the traffic traveling along the main roadway.

The overall design of the lighting is divided into four general areas as follows:

- Entrance and exit

- Interior roadways

- Parking areas

- Activity areas

### Parking Facilities

Parking facility lighting is vital for traffic safety, for protection against assault, theft and vandalism, and for convenience and comfort to the user. Typical parking facilities include park-n-ride lots, train stations, building parking lots and other types of commuter lots.

The illumination requirements of an open parking facility depend on the amount of usage it receives. According to the IES three levels of activity have been established and are designated as *high, medium* and *low*. For MSHA projects, the design of lighting for parking lots is for transportation parking such as airports, commuter lots, train station lots, etc. This is considered a medium activity. The *IESNA Lighting Handbook* and *RP-20 Lighting for Parking Facilities* should be used as a guide for the photometric design of these facilities.

If the level of nighttime activity involves a large number of vehicles, then the designation of the specific facility, like the ones mentioned above, for low and medium activity properly belongs in the next higher level.

In open parking facilities, a general parking and pedestrian area is defined as one where pedestrian conflicts with vehicles are likely to occur. A vehicular use area (only) is defined as one where conflicts with pedestrians are not likely to occur. These are areas such as service areas or access roads.

Special consideration should be given to lighting of access roads to all types of parking facilities and lighting levels should match the local highway lighting, as much as possible. The average maintained illuminance should be compatible with local conditions. Refer to the *MSHA Lighting Guidelines* for the average-to-minimum uniformity ratio requirements. In all parking facilities, consideration should be given to color rendition, uniformity of lighting and minimizing glare. Users sometimes have trouble identifying their cars under light sources with poor color rendering characteristics. Uniformities less than recommended can detract from safety and security. Glare can affect the ability to perceive objects or obstructions clearly.

Vandalism is an important consideration with open parking facilities. Damage can generally be reduced by mounting luminaires at least 3 m (10 ft) above grade. However, greater mounting heights are recommended and MSHA typically uses 40’ poles.

## Pedestrian Lighting

When properly designed and installed, pedestrian lighting has benefits that include enhancing revitalization projects, increasing nighttime pedestrian use and commerce, increasing safety and security, improving aesthetics, and adding to the sense of pride of a community. In some instances, it may be preferable not to install pedestrian lighting due to environmental, financial, or other considerations including glare, light trespass, increased energy consumption and sky glow.

Maryland SHA’s Pedestrian Lighting Policy provides the following specific criteria for eligibility:

- Within ½ mile of a transit center or ¼ mile of a major transit stop or along connection between two or more transit centers
- Within a designated urban revitalization area
- Within ½ mile of an educational or similar facility that generates significant pedestrian traffic during hours of darkness
- High volume of pedestrians and/or bicyclists within any one-hour period of darkness
- Within a commercial area with significant nighttime activity
- Pedestrian safety and security issues

See the MSHA Pedestrian Lighting Policy for specifics on warranting, funding, design, construction, and maintenance of pedestrian lighting systems in which the Administration will be involved.

## Sign Lighting

Motorists may stop or reduce their speed at roadway signs that are difficult to read, and thus create a hazardous condition. Proper sign visibility, including sign lighting, can aid rapid and accurate recognition of the sign shape, color and message. To determine which signs require lighting, refer to the Maryland SHA Lighting Guidelines, 2017.

Lighting for roadway signs becomes more significant as the volume of traffic increases, the complexity of highway design increases, the likelihood of adverse weather increases, and the ambient luminance increases.

The background luminance against which a motorist will view a sign is called its ambient luminance. Three categories of ambient luminance (high, medium and low) can be identified:

- High: Areas with high street lighting levels and brightly lighted advertising signs
- Medium: Areas with small commercial developments and lighted roadways and interchanges
- Low: Rural areas without lighting or areas with very low levels of lighting

MSHA illuminates overhead signs from the bottom of the sign rather than the top due to provide easier maintenance and better uniformity of lighting.

MSHA only uses LED sign lighting on all new installations, however older sign lighting typically consists of mercury vapor.

There are three types of lighted signs: externally lighted signs, internally lighted signs, and luminous source message signs (where the message is formed by lamps).

## High Mast Lighting

High mast lighting is only considered when photometrics cannot be met with 40’ or 50’ poles and employs an area type of lighting with groups of luminaires mounted on free standing poles or towers, at mounting heights varying from approximately 80 feet to 180 feet or more. At these mounting heights, several high output luminaires develop a highly uniform light distribution. High mast lighting is used principally on interchange lighting, lighting of toll plazas, rest areas and parking areas, general area lighting and for continuous lighting on highways having wide cross sections and a large number of traffic lanes, such as Interstate 95.

The principal benefits of high mast lighting applications are the ability to provide excellent uniformity of illumination and reduce glare with a substantially smaller number of pole locations. This is especially true in interchange and other complex road areas.

While utilization efficiency is low on individual roadways, several roadways can usually be illuminated from the luminaires on a single pole. The off-road surrounding areas receive sufficient illumination to provide the motorist with an exceptionally wide illuminated field of vision compared to the “tunnel of light” effect provided by the conventional system. Performance of the system under adverse weather conditions such as rain, fog, etc., is good.

High mast lighting generally provides its own adaptation (transition) lighting to and from unlighted roadways.

High mast lighting makes a contribution to safety and aesthetics by reducing the number of poles that would be required for a conventional system and through locating poles out of the recovery area adjacent to the driving lanes. Also, their remote location eliminates the need for maintenance vehicles obstructing traffic on the roadway, or the requirement for maintenance personnel to be near the high speed traffic lanes.

While there are many benefits of high mast lighting, there are also several cons. High mast lighting can often lead to light trespass of non-roadway areas. It may also require access roads to reach pole locations further off the road. The lowering systems for high mast light poles also require maintenance. Additionally, high mast lighting may have higher costs. These factors should be considered when planning for high mast lighting on a project.

The design and installation of high mast lighting equipment is more complex than conventional lighting. Poles or towers, with lowering devices or other methods of luminaire servicing, require special design and maintenance considerations.

The most common type of luminaire used in high mast lighting is the area type, which is usually offered having symmetric or asymmetric distribution. Both types of distribution are frequently used to adequately fit the area to be lighted, and to minimize spill light.

Due to the lack of satisfactory experience in designing high mast installations to the luminance system, use of the luminance system is not encouraged when designing a high mast installation. Higher levels of illuminance on the roadway may be required after consideration of such factors as the complexity of the interchange, the existence of high brightness from competing light sources near the roadway, and the prevailing level of lighting on connecting roadways. In addition to the level of light on the roadway, the Designer must also consider objectionable spill light and discomfort glare beyond the right of way and the visibility of vertical surfaces of the roadway system, i.e., traffic barriers, bridge columns, abutments, drainage headwalls, and the like.

For the design of a high mast installation it may be assumed that all symmetric distribution luminaires on a given mast form a point source and have the same orientation and photometric display. All asymmetric distribution luminaires are usually oriented in groups with the principal axis of each luminaire in the group having the same orientation and having the same photometric pattern. Two methods available for formulating a design for high mast lighting are:

1. Utilized Lumens Method (Templates): By use of isofootcandle curve transparencies overlaid on drawings of the area to be lighting, pole locations are established and design values are then computed from standard utilized lumens formula. This method can also be accomplished by using direct calculations made from the coefficient of utilization charts.

2. Average Point Method: Readings are determined at points designated in an established grid pattern on the roadway and then averaged. Pole spacing, size of luminaire, and mounting height are usually determined by the Designer based on economics, illumination levels, and lighting area. Typically, the size of a luminaire may vary from 600W HPS to 1000W HPS and spacing of poles also may range from 400 to 600 feet.

## LIGHTING ELECTRICAL SYSTEM

This section presents guidelines and procedures that may assist the Designer in selecting the type and size of an electrical service for a lighting system. It also presents guidelines for sizing Traffic Control Device Cabinets and equipment (as described in Maryland SHA's *Standard Specifications for Construction and Materials*), determining the size of lighting cables, determining the voltage drop on lighting circuits, and determining the type and number of connector kits used.

The electrical system for lighting is designed after the lighting is fully designed. The luminaires are selected and the poles have been laid out in their final locations. Following is a list of the basic steps to follow when designing the electrical system for lighting:

1. Determine Power Source
    a. Location
    b. Size
2. Define Lighting Cabinet
    a. Location
    b. Size
3. Define Luminaire Electrical Requirements
4. Circuit Layout, Wire Size and Voltage Drop
5. Connector Kits

### Power Source

Power source refers to the power company's standard supply of electricity at secondary distribution systems, i.e. the system voltage supplied by the power company. Generally, a lighting system for an isolated intersection requires a single phase, 120/240 volts, 3-wire service. The first number, 120V, refers to the phase to neutral voltage in the transformer. The second number, 240 volts, refers to the phase-to-phase voltage. MSHA prefers to use the 120/240 volt service.

For larger projects such as interchanges and continuous roadway lighting, electrical services may be via either a single phase, 120/240 volts, 3-wire service or a 3-phase, 120/208 volts or 277/480 volts, 4-wire service. Three-phase circuits are composed of three single-phase circuits where the source voltages for each phase are 120° apart. MSHA prefers to split interchanges into smaller systems and use multiple 120/240 volts service if possible. Generally, interchanges are split in half preferably using the mainline roadway as the dividing line.

For information on the existing service, the Designer could obtain data on the service type, circuits, and cable sizes either from as-built plans, the MSHA District Office for Maintenance, or by coordinating a field visit to the electrical distribution cabinet.

### Selecting Power

Selecting the electrical service size and type is the responsibility of the Designer. Generally, a higher operating voltage will allow the design of a more efficient and cost effective system, but for simplicity and consistency MSHA's preference is to use the 120/240 voltage service with a 100 or 200 amp cabinet dictated by need.

Luminaires are generally supplied in two types: a multitap which can operate on 120, 208, 240, or 277 voltage systems and secondly a 480 volt luminaire. Most old systems operate at 277/480 volt. If a 480 volt luminaire is used in an area that historically uses a lower voltage, then maintenance personnel must have a larger inventory of spare parts, or may accidentally install an inappropriate luminaire. Historically, 480 volts luminaires have typically been used along I-495, while the rest of the State operates at a lower voltage, such as 120/240 volts. The Designer should always verify that a multitap luminaire is specified in order to avoid problems with wrong luminaires installed in wrong systems.

A Pepco 120/208 volt or 277/480 volt (used by most old services) 3-phase supply is generally considered an industrial service, and may not be available in a rural or suburban area. In these areas 120/240 volts, which is the standard for new systems, may be the only option.

Lighting associated with traffic signals is wired at 120 volts.

For servicing non-signalized intersections, an underground 120/240 volts, 3-wire, single phase service should be selected. An embedded metered service pedestal is normally specified for a project with less than 8 luminaires. This requires each luminaire to have its own photocell. However, there are exceptions to the use of an embedded metered service pedestal for projects with less than 8 luminaires which may be discussed and become apparent during the project review process.

A pole mounted lighting control cabinet with photocell, using a single phase 120/240 volts electrical service, is used where eight or more luminaires are installed and there is already existing service. The pole mounted lighting control cabinet has a 3-circuit panel and should be powered by a base mounted metered service pedestal with a photocell if there is no existing service. Separate photocells on each luminaire are not required with this type of control and distribution. When base mounted cabinets are used, the size of service should be dictated by the total load.

### Selecting the Service Connection

The Designer is responsible for the coordination with the power company on the availability of service within the proximity of the proposed installation location. Coordination with the power company should begin in the preliminary stages and should continue throughout the project. The Designer should initiate the coordination activity with a telephone call and a follow-up letter with a preliminary concept layout of the lighting design. Service must be confirmed prior to wiring circuits. It should be noted that coordination requirements may vary depending on the power company. Some companies, such as BGE, require an application to be completed and submitted by MSHA. All correspondence should be documented and kept for reference throughout the project.

### Determining Service Load

The electrical service required is dependent on several things, but the key item is the current required for the luminaires to operate. Each type of luminaire for each wattage size requires a different operating current at any given operating voltage. For example, a 250 watt high pressure sodium luminaire with a line voltage of 277 operates at a current of 1.2 amps.

Table LT.1 shows the operating currents at some of the standard operating voltages of commonly used luminaries in Maryland.

**Table LT.1 - Typical Operating Current for Common Lamps and Ballasts**

| Type of Lamp | Bulb Watts | Current (amp) | | | | Line Watts |
|---|---|---|---|---|---|---|
| | | 120 V | 240 V | 277 V | 480 V | |
| HPS | 100 | 1.2 | 0.6 | 0.5 | 0.3 | 127 |
| HPS | 150 | 1.6 | 0.9 | 0.7 | 0.5 | 189 |
| HPS | 200 | 2.1 | 1.0 | 0.9 | 0.8 | 253 |
| HPS | 250 | 2.6 | 1.3 | 1.2 | 0.7 | 312 |
| HPS | 400 | 3.9 | 2.0 | 1.7 | 1.0 | 475 |
| *LED | 96 | 0.8 | 0.4 | 0.4 | 0.2 | |
| *LED | 275 | 2.3 | 1.2 | 1.0 | 0.58 | |
| *LED | 280 | 2.4 | 1.17 | 1.0 | 0.6 | |

*The wattage of LED luminaires varies among manufacturers, and there are no standard values. The load information an LED luminaire must be obtained from the manufacturer.

In order to determine the required load of a proposed system, the Designer may follow two steps:

1. Identify the total number of luminaires and the types of lamp such as 250 High Pressure Sodium or LED. Include any luminaire within the system, signing and roadway.

2. Calculate the total load of the lighting system, based on the desired line voltage and operating current data as shown in Table LT.1. The total amperage may be determined as follows:

**Equation LT. 1 - Minimum Total Amperage**

$$\sum \left( {}^{\#lamps}\!\!\diagup\!_{type} \right) \times (current)$$

Given:

Operating Voltage: 277 V

Roadway Lighting Lamps: 12 luminaires with 250 Watt High Pressure Sodium Lamps

Sign Lighting: 4 luminaires with 100 Watt, LED Lamps

Based on the above given information the results are shown in Table LT.2**.**

**Table LT.2 - Example of Calculating Total Load of a Lighting System**

| No of Luminaires | Type of Lamp | Lamp Power (watts) | Operating Current (amp) | Total Load (amp) |
|---|---|---|---|---|
| 12 | HPS | 250 | 1.2 | 14.4 |
| 4 | LED | 100 | 0.5 | 2.0 |
| **TOTAL** | | | | **16.4** |

This example results in a total minimum load required of 16.4 amps. Under these circumstances, the Designer could either request a 60 amp service from the power company, or may consider future expansion of the lighting system and request either a 100 amp or 200 amp service.

In general, the MSHA uses a minimum of 100 amp service for a typical application of 15 to 20 lighting standards. A 277/480V service will be more expensive to provide than a 120/240V service.

Another consideration in selecting the power source and size is the voltage drop on the circuits. A typical circuit would have less of a voltage drop with the same number of lighting standards under a 277/480 volts service than with a 120/240 volts system because of the higher operating voltage with a 277/480 volt system.

## Base Mounted Lighting Control Cabinet

The lighting control cabinet is Base Mounted and refers to the control cabinet itself and the equipment within the cabinet including the meter socket, external disconnect switch and circuits panel. Control equipment is usually housed in an aluminum cabinet enclosure and is installed on the side of the road where it can be easily accessed for maintenance. It performs the following functions:

1. Distributes electrical energy (current) to individual luminaires via lighting circuits.

2. Powers on and powers off the lighting system via switching equipment such as photoelectric cells.

The number of circuits on a panel should not exceed 42 two pole circuits.

## Circuit Layout, Wire Size and Voltage Drop

After determining the service to be used for the lighting system, the next step is to layout the circuits, determine wire to be used, and calculate voltage drops. These three items are dependent upon each other, meaning that this process is an iterative process to achieve an optimal system. There are also several methodologies to determine the same results. This section is directed toward the NEC equations and applications of calculations.

### Circuit Layout

Circuits are run from the control and distribution equipment to the lights. Each circuit has a unique number in that panel. Following are some general guideline for laying out circuits in a lighting system:

- Odd circuit numbers run together and even circuit numbers run together.

- For a 120/240V single phase, 3 wire system circuits are run together in groups of two circuits (e.g. circuits 1 and 3 will run together or 2 and 4 will run together) See Figure LT.4.

- For a 277/480 V three phase, 4 wire system circuits are run together in groups of three circuits (e.g. circuits 1, 3, 5 will run together or 2, 4, 6 will run together) See Figure LT.4.

- Luminaires should always have alternating circuits so that if one circuit goes out, the one next to it will still be operating.

- For sign lighting, run dedicated circuits for only the sign lighting.

The maximum number of luminaires allowed per circuit is a function of the line voltage, voltage drop, operating current of luminaire, circuit breaker trip size, and the length of the circuit run. All of these variables are interrelated to each other.

As a matter of safety, the number of luminaires per circuit can preliminarily be determined such that the circuit should not be loaded to more than 80 percent of its capacity.

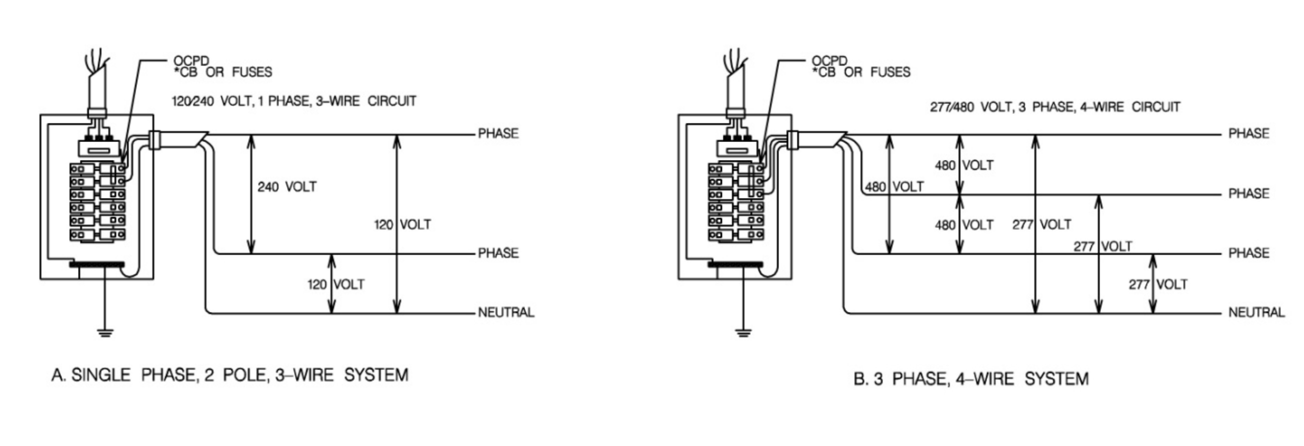


**Figure LT.4 - Wiring Schematic**

## Optimal Cable Size

Generally, underground wiring for lighting is either #6 AWG or #4 AWG. Number 4 AWG cables are used for larger installations with longer circuit runs that may have higher voltage drop. The resistance of a larger size cable is lower than the resistance of a smaller size cable and, therefore, will have a lower voltage drop.

Number 12 AWG cables are used for luminaires in conjunction with traffic signals. For intersections where few lights are anticipated and there is a potential for the intersection to be signalized, a #12 AWG cable may be used to ensure expandability for a future signal. Smaller size cables are more susceptible to damage during construction, and are more susceptible to damage from environmental causes when buried.

Generally only one size cable should be used on a project. Requiring multiple cable sizes leads to constructability problems and increases the potential for error. If a project requires #8 AWG cables in one area and #4 AWG cables in another area, then it is possible for the contractor to install the #8 cables where the #4 cables are required. This will cause improper system operation, and may lead to critical failures. The exception is when #4 cables are used underground and #6 cables are used in bridges and walls. The NEC has different requirements for cables that are #4 AWG or larger than it does for cables that are #6 AWG or smaller. Generally, #4 AWG cables should not be run through bridges or in barrier walls. In these applications, only #6 AWG cables should be used.

Theoretically, determining the optimum cable size depends largely on the luminaire operating secondary voltages and the anticipated load of the luminaires. Some things to remember when selecting the wiring:

- Use multiple 2 conductor duct cables instead of 4 or 6 conductor duct cables. This allows for circuits not being used in a given pole to bypass the pole underground instead of running into the pole with connector kits.

- For sign lighting, use the 4 or 6 conductor duct cable since sign lighting uses more than one circuit and it isn't possible to fit 2 duct cables into the 4 inch conduit in the sign foundation.

- For cable runs in bridges and/or parapets, the designer typically must use #6 AWG wiring. However, a larger cable may be able to be used dependent upon the size of the junction boxes. Refer to NEC 314.28 for more information.

- Ensure that all plans are clearly marked to the size of wiring, number of conductors, duct cable and/or conduit.

## Voltage Drop Calculations

In order to assure that the luminaires on the lighting system have the proper operating current delivered to them it is critical to determine the voltage drop on each circuit including all branches. A branch circuit is any subsection of a circuit that may be diverged in a non-linear path to service other lighting devices on the same circuit. Branch circuits begin at the splice point in electrical manholes.

Voltage drops should be computed at each lighting pole or sign luminaire in an incremental order. For planning, however, the Designer may also check the voltage drop at the last pole with the longest circuit run with the assumption that all loads occur at the last pole location. This procedure is only used for a quick checking of the most critical voltage drop on a circuit. MSHA requires pole-by-pole voltage drop computations on each of the lighting circuits, for all roadway and interchange projects. The maximum allowed voltage drop for any given circuit should not exceed 5 percent of the operating voltage.

The procedure to determine the voltage drop is as follows:

1. Layout the preliminary circuits.

2. Define a preliminary wire size.

3. For each circuit, determine the length of a circuit run between the electrical source and the load, i.e. the lighting standard or overhead sign.

4. Compute the voltage drop for each circuit based on the following equations:

The following equations can be used to calculate voltage drop:

**Equation LT. 2 - Resistive Method**

$$VD = \frac{P \times L \times R \times I}{1000}$$

**Equation LT. 3 - Circular-mil Method**

$$VD = \frac{P \times L \times k \times I}{CM}$$

Where,

P = 2 for single phase

L = One way length of circuit (feet)

*k* = Use values of 11.2 for copper for the circular-mil method.

R = Use resistance value from chapter 9, table 8 of the NEC for the resistive method.

I = load current (amps)

CM = area of the wire being used (circular mils)

Although both methods are acceptable and used by the NEC, equation 3 (CM) method is the common and preferred method used by MSHA.

Once the preliminary run of the voltage drop is computed, if the drop is unacceptable, then it is necessary to rerun this process again with either a new circuit layout, a different wire size or possibly both until an acceptable efficient system is reached.

Table LT.3 provides a side-by-side comparison of the relationship that conductor size has with equations 2 and 3. Table LT.4 also shows the comparison of conductor size with equations 2 and 3 but shows converted Conductor Resistance values that are based on a temperature of 40°C rather than 75°C.

The difference in results between the NEC equations and the MSHA equation is based on the relationship between resistance and temperature as follows:

- Resistance increases as conductor temperature increases.

The NEC voltage drop equation is based on a conductor temperature of 75°C while the MSHA assumes a conductor temperature of 40°C based on their experience. Since resistance will increase with a temperature increase, the NEC equation will produce a higher, more conservative voltage drop. MSHA follows the NEC, however, is not bound.

Voltage Drop Example 1 shows the calculation of the voltage for a single phase, 120 volt circuit with 3 luminaires, and Voltage Drop Example 2 shows the calculation of the voltage for a single phase, 240 volt circuit with 3 luminaires.

**Table LT.3 - Comparison of Conductor Size and Voltage Drop Equations**

| Conductor Size (AWG) | Conductor Resistance* (ohm/kFT) | Area (Circular mils) | NEC Method R/1000** | MSHA Method 11.2/CM** | Difference |
|---|---|---|---|---|---|
| 18 | 7.95 | 1620 | 0.00795 | 0.00691 | 0.00104 |
| 16 | 4.99 | 2580 | 0.00499 | 0.00434 | 0.00065 |
| 14 | 3.14 | 4110 | 0.00314 | 0.00272 | 0.00042 |
| 12 | 1.98 | 6530 | 0.00198 | 0.00171 | 0.00027 |
| 10 | 1.24 | 10380 | 0.00124 | 0.00107 | 0.00017 |
| 8 | 0.778 | 16510 | 0.000778 | 0.000678 | 0.0001 |
| 6 | 0.491 | 26240 | 0.000491 | 0.000427 | 0.000064 |
| 4 | 0.308 | 41740 | 0.000308 | 0.000268 | 0.00004 |
| 3 | 0.245 | 52620 | 0.000245 | 0.000212 | 0.000033 |
| 2 | 0.194 | 66360 | 0.000194 | 0.000169 | 0.000025 |
| 1 | 0.154 | 83690 | 0.000154 | 0.000134 | 0.00002 |

*Conductor Resistance is based on Direct-Current Resistance at 75°C (167°F). This example uses Uncoated Copper conductors with 7 strands for all conductor sizes except 1 AWG; 19 strands were used for this example.

**Values for R/1000 and 11.2/CM represent the conductor properties related components in the Voltage Drop Equations and are considered in this comparison.

**Table LT.4 - Comparison of Conductor Size with Converted Temperatures and Voltage Drop Equations**

| Conductor Size (AWG) | Converted Conductor Resistance* (ohm/kFT) | Area (Circular mils) | NEC Method R/1000** | MSHA method 11.2/CM** | Difference |
|---|---|---|---|---|---|
| 18 | 7.05 | 1620 | 0.00705 | 0.00691 | 0.000141 |
| 16 | 4.43 | 2580 | 0.00443 | 0.00434 | 0.000085 |
| 14 | 2.79 | 4110 | 0.00279 | 0.00272 | 0.000065 |
| 12 | 1.76 | 6530 | 0.00176 | 0.00171 | 0.000046 |
| 10 | 1.10 | 10380 | 0.00110 | 0.00107 | 0.000029 |
| 8 | 0.690 | 16510 | 0.000690 | 0.000678 | 0.000012 |
| 6 | 0.435 | 26240 | 0.000435 | 0.000427 | 0.0000085 |
| 4 | 0.273 | 41740 | 0.000273 | 0.000268 | 0.0000052 |
| 3 | 0.217 | 52620 | 0.000217 | 0.000212 | 0.0000053 |
| 2 | 0.172 | 66360 | 0.000172 | 0.000169 | 0.0000031 |
| 1 | 0.137 | 83690 | 0.000137 | 0.000134 | 0.0000026 |

*Conductor Resistance is based on Direct-Current Resistance at 40°C (104°F). This example uses Uncoated Copper conductors with 7 strands for all conductor sizes except 1 AWG; 19 strands were used for this example.

**Values for R/1000 and 11.2/CM represent the conductor properties related components in the Voltage Drop Equations and are considered in this comparison.

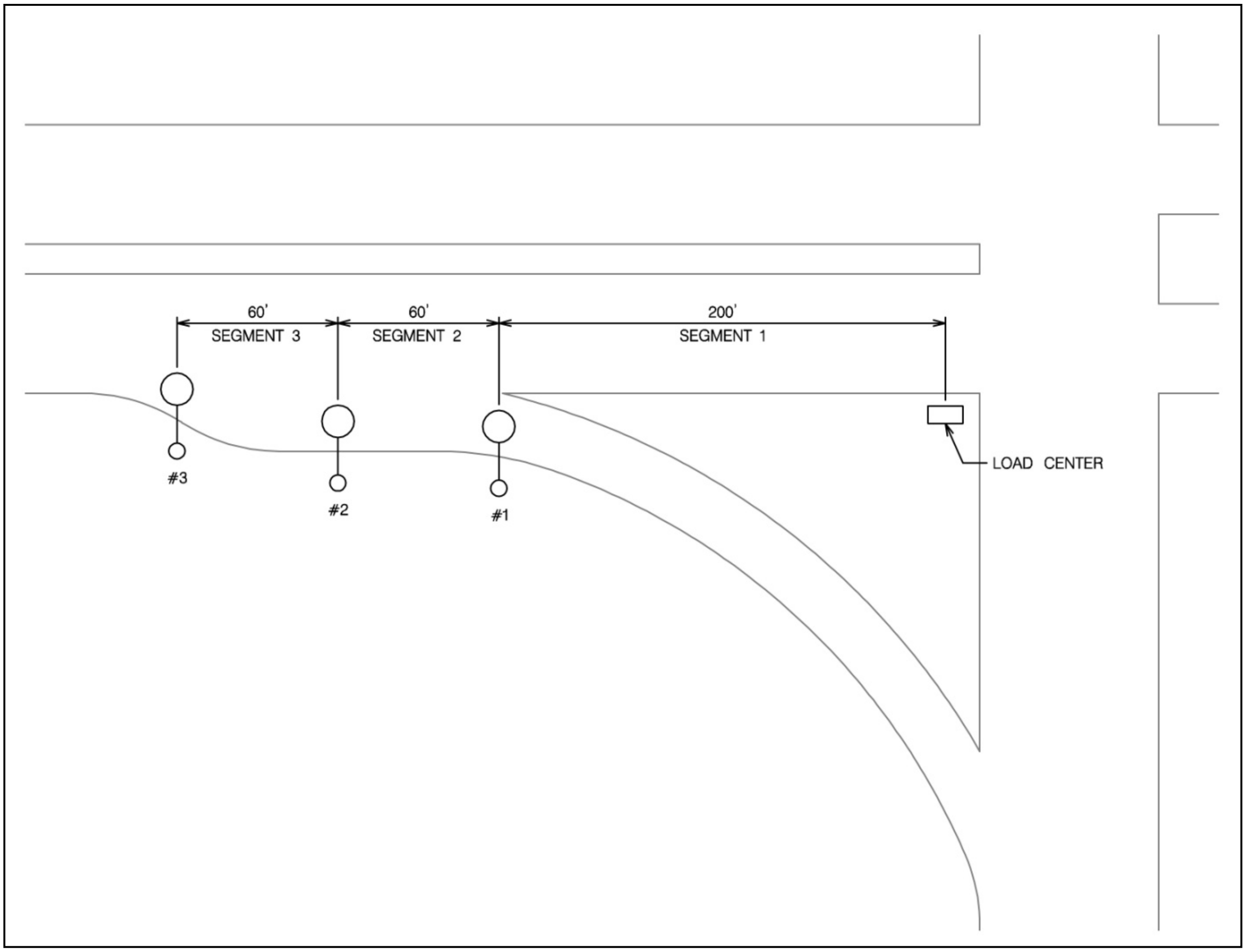


**Figure LT.5 - Sample Plan for Voltage Drop Calculation**

Voltage Drop Example 1:

Calculate the voltage drop for the lighting layout shown in Figure LT.5. Assume that the circuit is 120 volt, single phase and each luminaire draws 2 amps. Use #6 AWG for circuit conductors.

VD = $\frac{2 \times L \times k \times I}{CM}$

%VD = VD / V

*Segment 1*

VD1 = $\frac{2 \times 200 \times 11.2 \times 6}{26{,}240}$

VD1 = 1.02 V

*Segment 2*

VD2 = $\frac{2 \times 60 \times 11.2 \times 4}{26{,}240}$

VD2 = 0.21 V

*Segment 3*

VD3 = $\frac{2 \times 60 \times 11.2 \times 2}{26{,}240}$

VD3 = 0.11 V

VD = VD1+VD2+VD3

VD = 1.02+0.21+0.11 = 1.34 V

%VD = 1.34 / 120 * 100

%VD = 1.12%

Voltage Drop Example 2:

Calculate the voltage drop for the lighting layout shown in Figure LT.5. Assume that the circuit is 240 volt, single phase. Assuming that the luminaires are the same as used in Example 1, each will draw 1 amp at 240 volts. Use #6 AWG for circuit conductors.

VD = $\frac{2 \times L \times k \times I}{CM}$

%VD = VD / V

*Segment 1*

VD1 = $\frac{2 \times 200 \times 11.2 \times 3}{26{,}240}$

VD1 = 0.51V

*Segment 2*

VD2 = $\frac{2 \times 60 \times 11.2 \times 2}{26{,}240}$

VD2 = 0.11 V

*Segment 3*

VD3 = $\frac{2 \times 60 \times 11.2 \times 1}{26{,}240}$

VD3 = 0.05 V

VD = VD1+VD2+VD3

VD = 0.51+0.11+0.05 = 0.67 V

%VD = 0.67 / 120 * 100

%VD = 0.56%

## Control Panel

The Lighting Control Cabinet and associated equipment is determined based on the combined load on all circuits.

### Connected Load

The connected load refers to the total current and power in each circuit. It is defined by power (kilowatts KW) and current (amps).

The power is determined by summing the line wattage of each luminaire on the circuit.

### Poles

Poles are the number of electrical connection points of the circuit breaker. A two-pole 240V connection system is normally used on all MSHA lighting projects for 120V/240V. A single pole 277V connection is used for 277V/480V systems.

### Frame Size

The frame size refers to the amperage size of the main circuit breaker. A frame size of 100 or 200 amps is normally used on highway lighting projects.

### Trip Size

The trip size refers to the amperage size of each branch circuit breaker. It is primarily used to safely disconnect the circuit in the event of an overload on the circuit breaker. For lighting, the normal operating load shall not exceed 80% of the trip size. A trip size of 20 ampere is normally used on MSHA lighting projects.

## Connector Kits

Connector kits serve two purposes in a typical lighting design. First, connector kits are used for making a serviceable waterproof splice connection of lighting cables for each conductor or duct cable in electrical junction devices such as electrical manholes. Secondly, connector kits are used to connect branch circuit conductors to the luminaire (ballast circuit) conductors in the handhole or transformer base of lighting and sign structures.

There are four types of connector kits; Types I, II, III and IV. Some of the connector kits are used for fused or unfused applications. Fused connectors provide safety measures against knockdown of lighting poles, which causes the cables in the splice box to be disconnected without exposing any of the internal cable wiring.

### Fused vs. Unfused

When a branch circuit conductor must be connected to the luminaire a *fused* connector shall be used. If a branch circuit conductor is being spliced in a junction device, (such as in a manhole or a handhole) an unfused connector should be selected. Neutrals are never fused.

### In-line vs. "Y" Connection

In-line connector kits are used in manholes for continuous runs of duct cables. In-line connectors may be unfused when used in underground handholes and fused when used in pole bases. "Y" connector kits are used in handholes where a single duct cable must be spliced and branched in multiple directions. Figure LT.6 and Figure LT.7 show photographs of splices.

The applications for each connector kit are shown in Table LT.5:

**Table LT.5 - Connector Kits**

| Application → | Unfused In-line | Fused In-Line | Fused Y | Unfused Y |
|---|---|---|---|---|
| Connector Type → | I | II | III | IV |

**Figure LT.6 - Example Inline Connector Kit (Unassembled)**

**Figure LT.7 - Example Y Connector Kit (Unassembled)**

### Number of Connector Kits

Typically, each conductor cable requires a connector kit. Determining the total number of connector kits needed for connection in a lighting system design is based on two factors:

1. The type of service being used (single or three phase system), and

2. The pattern of splices in a junction point either at the pole base or in a manhole/handhole.

The MSHA Book of Standards shows a typical schematic for using all four types of connector kits, under a 120/240 volt lighting system for 240-volt luminaire connections. Likewise, the Book of Standards shows a schematic for typical pole connections under a 277/480 volt system, with 277-volt luminaire connections.

### Lighting Legend

The lighting legend includes symbols and detail callouts that provide the following information for each proposed pole and luminaire: type of luminaire and mounting detail, type and size of cable or wires required, the number and type of connector kits, the station number and offset, the pole number, the mounting height and mast arm length, and the circuit number. A detail callout is also provided for each handhole which provides: the handhole ID number, the handhole ID tag, the number of inline splices – type 1, and the number of 'Y' splices – type 4. For some projects, such as underpass lighting, a modified detail callout for handholes may be used that shows the number of each of the four (4) types of connector kits. Figure LT.8 and Figure LT.9 on the following pages show these detail callouts as well as other typical symbols found on a lighting plan.

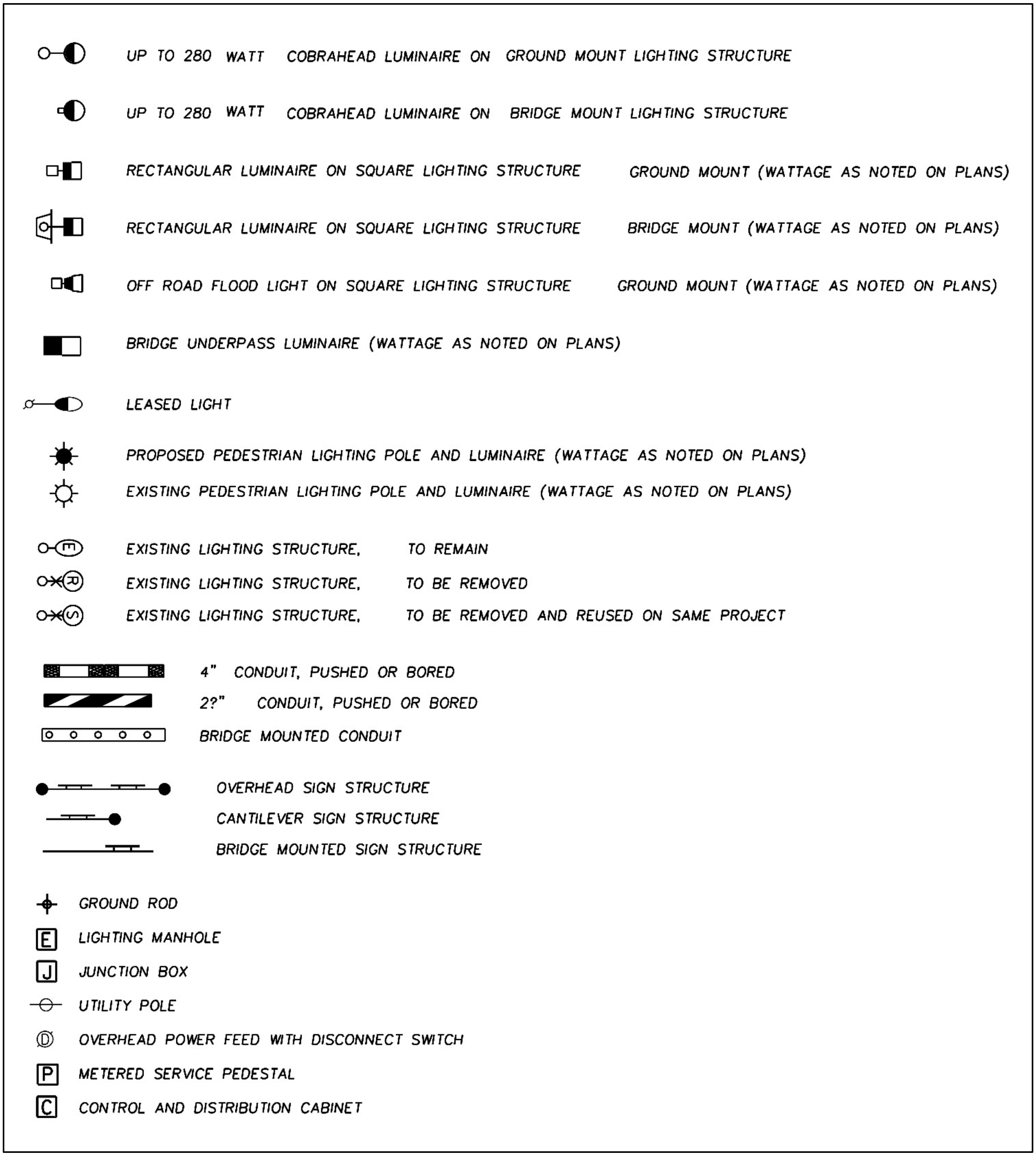


**Figure LT.8 - Lighting Legend**

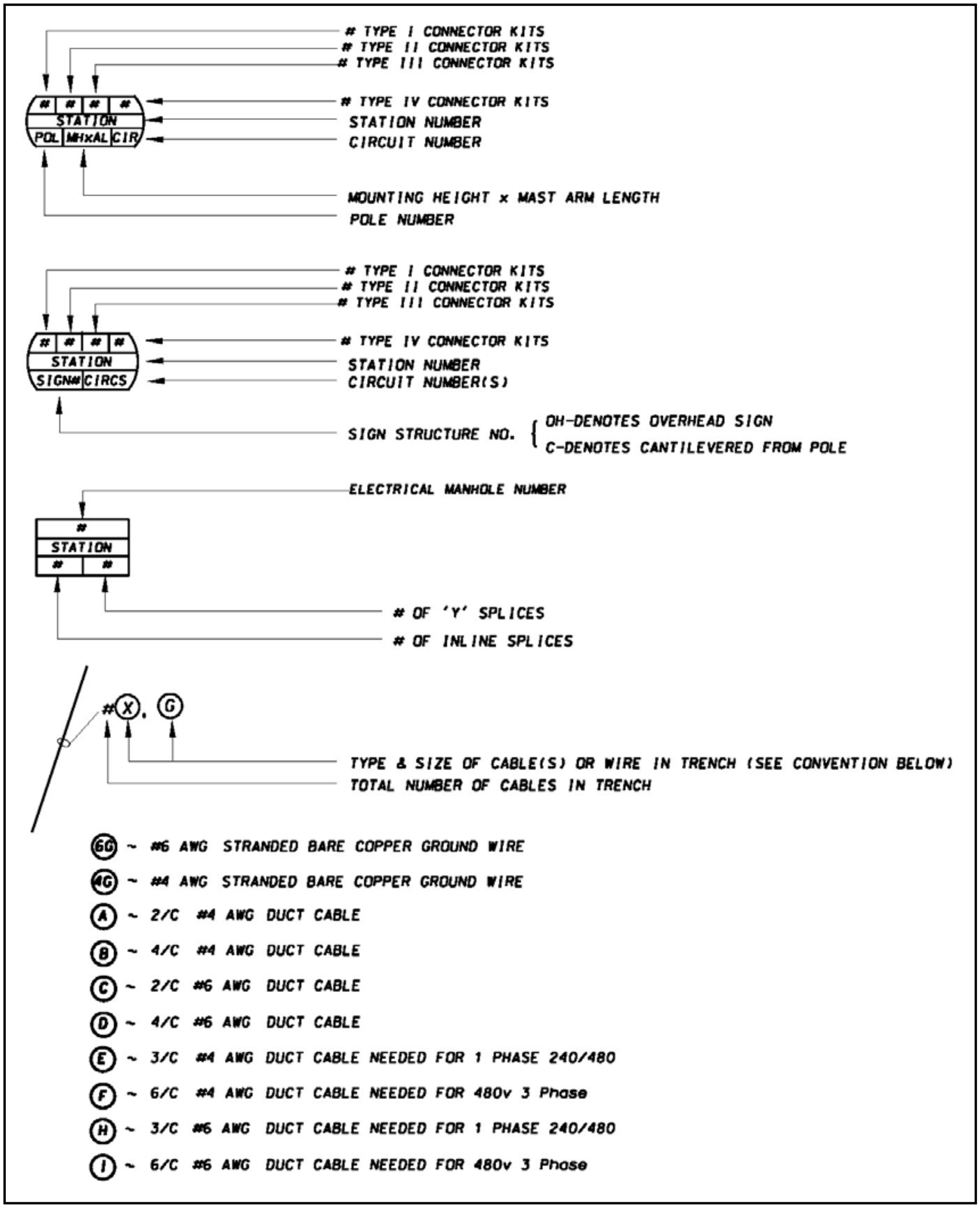


**Figure LT.9 - Lighting Legend**