# Lighting Design

by

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## Table of Contents



# I. Introduction

The general purpose of roadway lighting is to provide improved visibility for the various users of the roadways and associated facilities.

"Users" refer to vehicle operators (automobiles, trucks, buses, motorcycles, bicycles), pedestrians and other citizens such as merchants and shoppers.

"Associated Facilities" refer to physical features along the roadway (barriers, bridge piers, ditches, curbs, channelization, etc.).

Roadway lighting on local streets provides pedestrian visibility as well as driver visibility. Lighting increases the comfort level and safety of the motorist. Lighting can be expected to reduce night crashes by approximately 30 percent.

## A. Objectives of Roadway Lighting

- To supplement vehicle headlights, extending the visibility range beyond their limits both laterally and longitudinally.
- To improve the visibility of roadway features and objects on or near the roadway.
- To delineate the roadway ahead. To improve visibility of the surroundings.
- To reduce the apprehension of those using the roadway.

## B. Visibility Requirements

Vision – The eyes are the primary source of information. As light decreases, vision and the detection of information are severally impaired or nonexistent.

*Contrast* is the difference in brightness between the object and background. The ability to discern objects increases or decreases as the contrast level between the two increase or decrease. Drivers normally see objects in silhouette – a dark area against a bright background. This bright background can cause a glare resulting in a reduction in the contrast level thereby partially or totally obscuring the details to be seen.

## II. Analyzing Lighting Needs

The warrants for roadway lighting are located in AASHTO's "An Informational Guide for Roadway Lighting". The manual contains a basic guide for highway lighting and contains design guidelines and warranting criteria.

A lighting justification analysis was created due to the energy crisis of the 1970's and based on recommendations of a research project; a lighting justification program was developed. It is used to calculate the cost benefit analysis of lighting. The Office of Traffic Operations in Tallahassee may be contacted for a copy of the program.

## III. Lighting Equipment

### A. Light Sources

There are two general types of light sources: filament and arc-discharge.

| Light Source | Type | Lumens | Life (hrs) |
|---|---|---|---|
| Filament Lamp | Incandescent | 10-15 | 12,000 |
| Discharge Lamp | Fluorescent | 60-70 | 7,500-24,000 |
| | Mercury Vapor | 50-65 | 24,000 |
| | Metal Halide | 90-110 | 10,000-20,000 |
| | High Pressure Sodium | 125-140 | 24,000 |
| | Low Pressure Sodium | 180 | 18,000 |

*Incandescent Lamp*

The incandescent lamp has a filament that is an electrical resistance wire enclosed in a gas filled bulb. Current passing through the filament heating the filament to incandescence produces light. The gases are inert, usually nitrogen or krypton, which reduce evaporation of the filament and act as a thermal barrier.

*Discharge Lamp*

The discharge lamp produces light by exciting gases or metal vapors in a lamp or tube. Electrical potential is applied to electrodes. Gas is ionized and current flows between the electrodes. The lamps have a negative resistance and must have a ballast to maintain proper current level. The ballast regulates input power for the lamp.

*Fluorescent Lamp* - The fluorescent lamp produces light by a fluorescent coating on the inside of the tube which is activated by an ultraviolet energy generated by an arc.

*Mercury Vapor* - The mercury vapor lamp consists of an arc tube inside the outer bulb containing mercury vapor and electrodes. Light is produced from ionization of mercury vapor. Lamps may be clear or coated with phosphors to improve color rendition.

*Metal Halide* - Metal halide light is produced by a combination of metallic vapors. The lamp has excellent color rendition, but has a short lamp life.

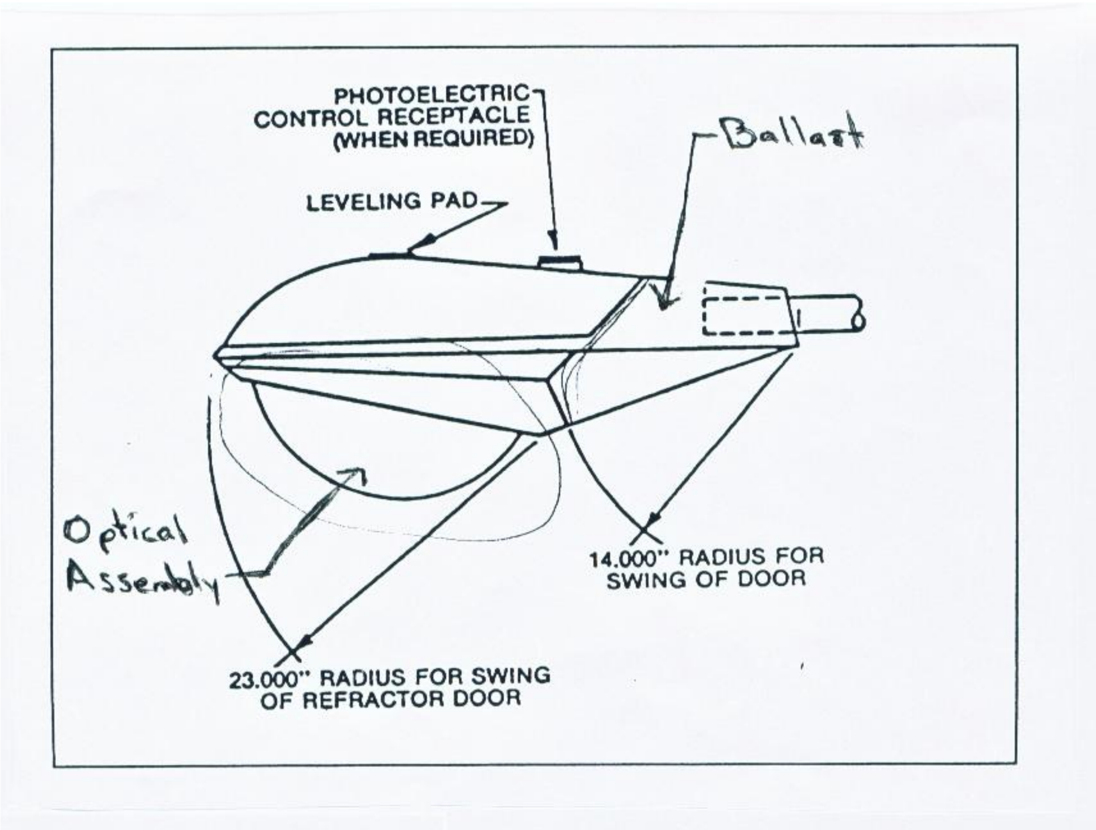
*High Pressure Sodium* - The high pressure sodium lamp produces light from sodium vapor. The arc tube is normally filled with sodium, mercury and xenon. Xenon is used for starting and mercury for color. This lamp has no starting electrode and produces a high voltage pulse of 2,500 to 4,000 volts.

*Low Pressure Sodium* - The low pressure sodium lamp is very efficient. However, it is monochromatic (single color only). It has a large physical size and the light is hard to control. It also has a lower lamp life.

## B. Luminaries

The luminaire components consist of a housing of the ballast and optical assembly. The optical assembly components consist of the lamp, reflector and refractor. The lamp produces the light output for the luminaire. The reflector is mounted above the lamp inside the optical assembly. It reflects or redirects the light. The refractor is mounted below the lamp and in some luminaries encloses the lamp cavity. The refractor is made of a transparent, clear material, glass or a strong plastic material. It has a large number of prisms and is enclosed or open at the bottom. A graphic of a typical luminaire is shown below.



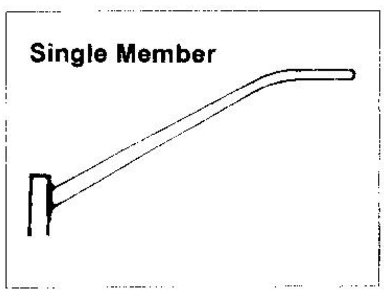

**C. Luminaire Supports**

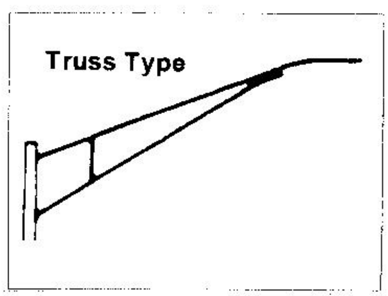
Luminaire supports are generally frangible/breakaway base. The breakaway criteria are covered in the AASHTO Specifications. The term "breakaway support" refers to all types of sign, luminaire and traffic signal supports that are design to yield when hit by a vehicle. The release mechanism may be a slip plane, plastic hinges, fracture elements, or a combination of these. The standard pole is made of aluminum. However, in some locations they may be concrete or fiberglass. Joint use poles may combine the luminaire with signals or utilities on wood, concrete, or steel poles. All conventional height poles shall be breakaway unless bridge or barrier wall mounted. High mast poles are made of steel or concrete.

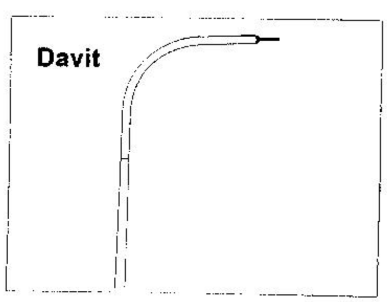
FDOT has developed an aluminum light pole standard for Conventional Lighting foundations. The standard provides details for 40, 45 and 50 foot luminaire mounting heights on poles mounted either at grade or on fills up to 25 feet in height, all of which accommodate fixture arm lengths of 8, 10, 12 and 15 feet. Standard Aluminum Light Poles have been designed for 110, 130, and 150 mph design wind speeds. High mast lighting (80 feet or greater) requires a foundation design in the plans.

**D. Bracket Arm Types**

Bracket arm types may consist of single member, truss, or davit. The length and rise may vary. The length is determined in the design of the lighting system and is measured to the center of the luminaire. The rise is the difference in elevation between the attachment at the pole and connection to the luminaire. The contractor usually calculates the rise because it depends on the length of the pole and mounting height required.



## IV. Conventional Lighting

Conventional lighting consists of any number of mounting heights depending upon the desired lighting level. The standard FDOT mounting heights are 40, 45, and 50 feet. There is one luminaire per pole for conventional mountings. There can be two luminaries per pole if it is median mounted. The following table outlines the FDOT requirements for illumination levels and uniformity ratios for conventional lighting.

**Table 7.3.1 Conventional Lighting – Roadways (FDOT PPM, Chapter 7)**

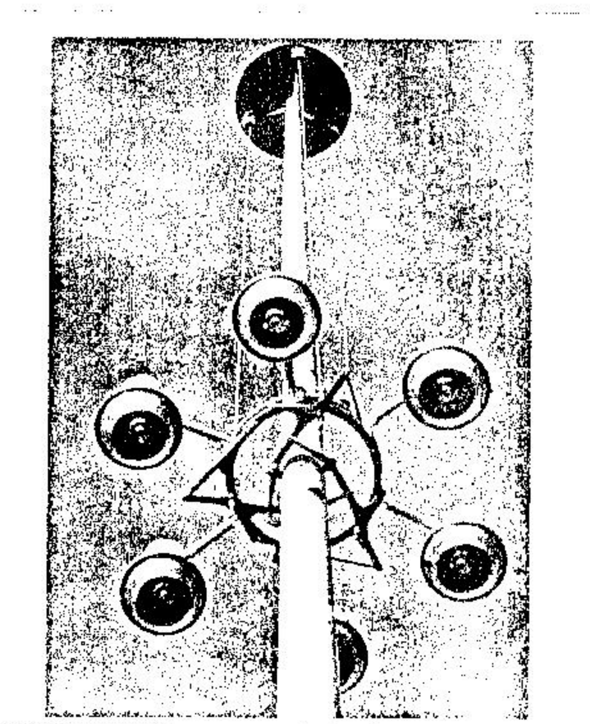
| Roadway Classifications | Illumination Level Average Initial Horizontal Foot Candle (H.F.C.) | Uniformity Ratios | |
|---|---|---|---|
| | | Avg./Min. | Max./Min. |
| Interstate, Expressway, Freeway & Major Arterials | 1.5 | 4:1 or less | 10:1 or less |
| All Other Roadways | 1.0 | 4:1 or less | 10:1 or less |
| * Pedestrian Ways and Bicycle Lanes | 2.5 | 4:1 or less | 10:1 or less |

## V. High Mast Lighting

High mast lighting consists of a mounting height of 80 feet or greater. The standard mounting height is 120 feet. There are several luminaries per pole. The number of luminaries depends on the light level required. The maximum number of luminaries per pole is 12 high mast or 16 flood. The luminaries are attached to a ring by cables and to a winch inside the pole base. The ring and luminaries lower to the ground for maintenance. Either a heavy duty drill motor attaches to the pole to operate the winch or a previously installed electric motor lowers the ring. The following table outlines the FDOT requirements for illumination levels and uniformity ratios for high mast lighting.

**Table 7.3.2 Highmast Lighting – Roadways (FDOT PPM, Volume 1, Chapter 7)**

| Roadway Classifications | Illumination Level Average Initial (H.F.C.) | Uniformity Ratios | |
|---|---|---|---|
| | | Avg./Min. | Max./Min. |
| Interstate, Expressway, Freeway, & Major Arterials | 0.8 to 1.0 | 3:1 or less | 10:1 or less |
| All Other Roadways | 0.8 to 1.0 | 3:1 or less | 10:1 or less |



## VI. Sign Lighting

Overhead sign structures require overhead sign lighting so the messages are visible during the day and night. The following table outlines the FDOT requirements for illumination levels and uniformity rations for sign lighting.

**Table 7.3.3 Sign Lighting (FDOT PPM, Volume 1, Chapter 7)**

| Ambient Luminance | Illumination Level Average Initial (H.F.C.) | Uniformity Ratios Max./Min. |
|---|---|---|
| Low | 15-20 | 6:1 |
| Medium & High | 25-35 | 6:1 |

## VII. Underdeck Lighting

Many of the major interchanges today have numerous wide overpasses. In these locations, lighting is required for the roadways underneath the overpasses for both day and night visibility. Underdeck lighting is accomplished my mounting either pier cap or pendant hung fixtures under the bridge structure. Pier cap luminaries should be installed when bridge piers are located less that 15 feet from edge of travel lane. Pendant hung luminaries shall be mounted to the bottom of the bridge deck and should be suspended where 50% of the lamp is below the bridge beam. Under no circumstances shall any luminaire or conduit be allowed to attach onto the bridge girders. The light levels for underdeck lighting shall be equal to the adjacent roadway lighting. The following table outlines the FDOT requirements for the light source and mounting location for underdeck lighting.

**Table 7.3.4 Underdeck Lighting – Roadways (FDOT PPM Volume 1, Chapter 7)**

| Luminaire Type | Light Source (High Pressure Sodium) | Mounting Location |
|---|---|---|
| Pier Cap | 150 watt to 250 watt HPS | Pier or Pier Cap |
| Pendant Hung | 150 watt to 250 watt HPS | Bridge Deck |

## VIII. Mounting Height Restrictions

FDOT has established a minimum mounting height for high pressure sodium (HPS) luminaires of various wattages. The following table shows the minimum mounting heights per luminaire wattage.

**Table 7.3.6 Mounting Height Restrictions (FDOT PPM Volume 1, Chapter 7)**

| Luminaire Wattage | Light Source | Mounting Height (Min.) (Feet) |
|---|---|---|
| 150 | High Pressure Sodium (HPS) | 25 |
| 200 | High Pressure Sodium (HPS) | 30 |
| 250 | High Pressure Sodium (HPS) | 30 |
| 400 | High Pressure Sodium (HPS) | 40 |
| 750 | High Pressure Sodium (HPS) | 50 |
| 1000 | High Pressure Sodium (HPS) | 80 |

## IX. Lighting Project Coordination

Coordination with other offices and other agencies is a very important aspect of project design. It is important that the lighting designer coordinates with roadway design, utilities, drainage, and structures.

- The roadway designer provides the base sheets and cross sections for the lighting design.
- The utilities engineer provides the coordination between the lighting designer and the utilities involved in the project. The engineer can also identify potential conflicts with overhead and underground utilities.
- The drainage designer should check the locations of high mast poles to determine if high water level is a problem. High mast poles are often located in the center of interchange loops that may be the same areas used as drainage retention areas.
- The structural engineer should be contacted early in the design phase to allow adequate time for coordination. While conventional height pole foundations are covered in the FDOT Design Standards and FDOT Standard Specifications, high mast poles require a foundation design. Soil borings are required for this design.

## X. Maintenance of Existing Lighting During Construction

The maintenance of existing lighting shall be the responsibility of the contractor only if the lighting is affected by the construction. The contractor should not be expected to replace lamps and pole knockdowns or to repair wiring if these problems are not caused by the construction work. The plans should specify the scope of the contractor's responsibility for the maintenance of existing lighting.

## XI. Voltage Drop Criteria

When determining conductor sizes for lighting circuits, the maximum allowable voltage drop from the service point on any one circuit is 7%.

## XII. Grounding

The grounding requirements for lighting systems shall be as follows:

- Install 20' of ground rod at each conventional height light pole and at each pull box.
- Install 40' of ground rod at each electrical service point.
- At each high mast pole, install an array of 6 ground roads 20' in length, as shown in the Design Standards, Index 17502.

## XIII. Designing the Lighting System

### Design Concepts

There are two concepts or techniques for the design of highway lighting allowed by the AASHTO guide for lighting.

The *Illumination Concept* is the measure of light striking a surface. Illumination is the design method adopted by the FDOT and most agencies in the United States.

The *Luminance Concept* (brightness) is the measure of light reflected from a surface. Luminance requires a more complex design process and knowledge of the reflective characteristics of the pavement surface used. These reflective characteristics change as the pavement ages and with variations in weather conditions.

There are numerous off-the-shelf computer programs to assist the engineer with lighting design. These programs use the information from the proposed luminaire along with the layout input from the engineer to determine if the fixture layout meets criteria.

**Design Criteria**

The designer responsible for a highway lighting project should be aware that the design must comply with various standards. The design criteria for highway lighting are in the FDOT Roadway Plans Preparation Manual, Volume 1, Chapter 7, FDOT Standard Specifications, FDOT Design Standards, AASHTO Roadway Lighting Design Guide and AASHTO Standard Specifications for Structural Supports for Highway Signs, Luminaires and Traffic Signals, and FDOT Structures Manual.

**Lighting Terminology**

It is important in the design of a lighting system that all of the appropriate terminology is understood to ensure the proper design.

*Arm length* is the distance from the support to the middle of the luminaire.

*Coefficient of utilization* is the percent of luminaire output. It is the amount of light that falls on a selected area of roadway.

*House side* is the side of the luminaire casting light away from the roadway.

*Mounting height* is the vertical distance from the roadway the light source.

*Overhang* is the distance between the edge of pavement to the center of the luminaire.

*Pole setback* is the horizontal distance from the edge of the travel lane to the pole.

*Nadir* is that point of the celestial sphere directly opposite to the zenith and directly below the observer. It is the lowest point.

*Roadway width* is the width of the roadway used in the lighting calculations for the luminaire to light.

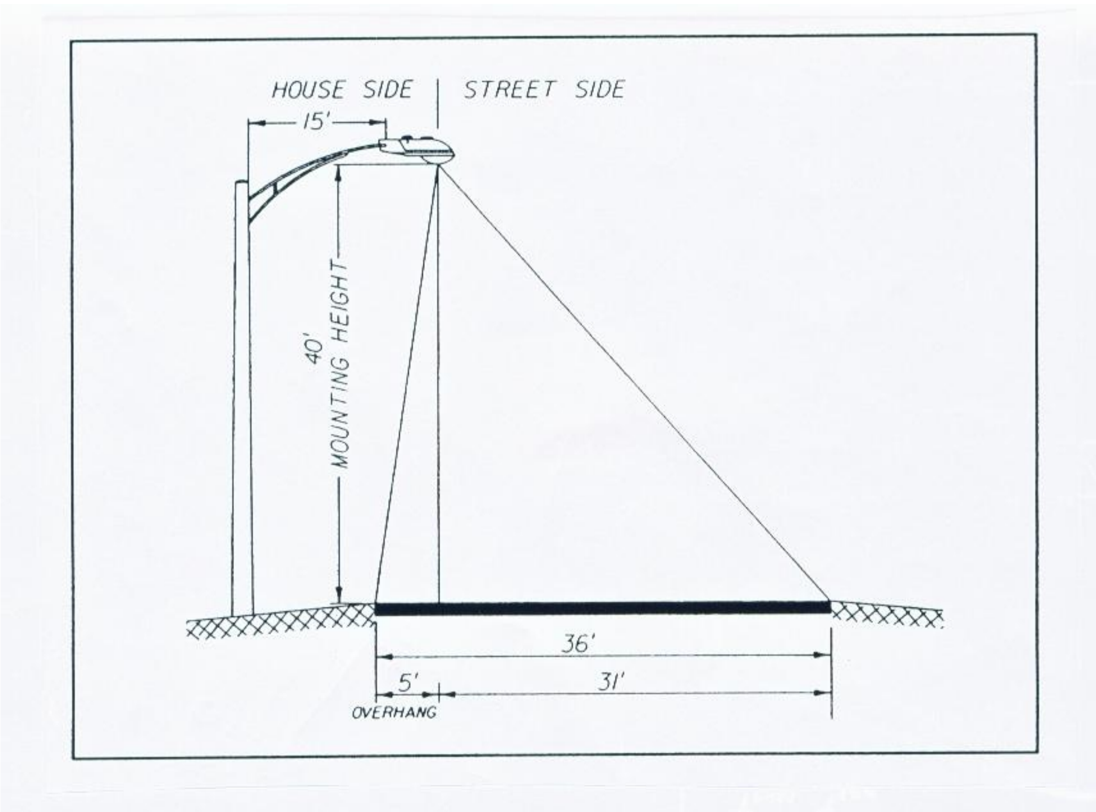
*Street side* is the side of the luminaire casting light towards the roadway.

*Zenith* is the point in the sky directly overhead; that point of the celestial sphere directly opposite to the nadir. It is the highest point.

*Roadway Width* is the width of the roadway for your lighting calculations.

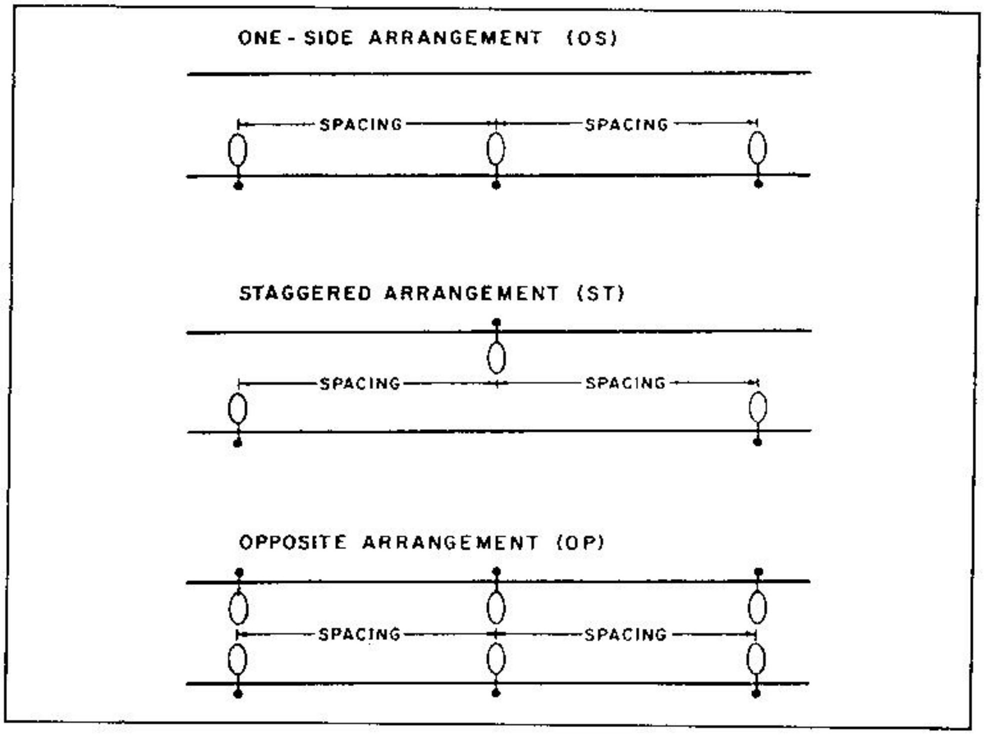
The following graphic provides information on the above definitions.




**Spacing Arrangements**

The most common spacing arrangements are one side, opposite, staggered and median mounted. The lighting designer determines the spacing arrangement. Some spacing arrangements may not provide proper light levels. As an example, for a divided roadway with a median barrier, consider a median mounting. A graphic of the varying spacing arrangements is shown below.




**IES Light Distributions**

IES light distributions are based on vertical light distribution, lateral light distribution, and control of light distribution above maximum candlepower.

*Vertical Light Distribution*

*Short distribution* – The maximum candlepower beam strikes the roadway surface between 1.0 and 2.25 mounting heights from the luminaire.

*Medium distribution* – The maximum candlepower beam strikes the roadway surface at some point between 2.25 and 3.75 mounting heights from the luminaire.

*Long distribution* – The maximum candlepower beam strikes the roadway surface at some point between 3.75 and 6.0 mounting heights from the luminaire.

**Types of Cutoffs**

Control above maximum candlepower affects the glare from a luminaire. The following are the types of luminaries that are available for use.

*Cutoff* - When the candlepower per 1000 bare lamp lumens does not exceed 25 at an angle of 90 degrees above nadir; and 100 at an angle of 80 degrees above nadir. This type of luminaire would be used in an interstate corridor passing through a neighborhood because it would control the spill over light.

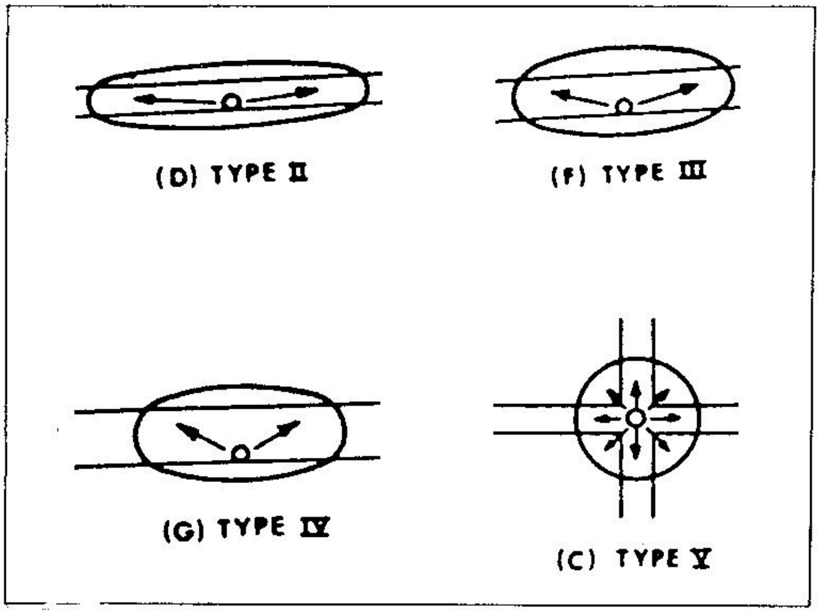
*Semi-cutoff* – When the candlepower per 1000 bare lamp lumens does not exceed 50 at an angle of 90 degrees above nadir; and 200 at an angle of 80 degrees above nadir. This type of luminaire would be used in an interstate corridor passing through a rural area because spill over light would not be or great concern.

*Non-cutoff* – When there is no candlepower limitation in the zone above maximum candlepower. This luminaire would be used in a high mast condition where spill over light is not a concern.

**Types of Distribution**

There are five different lateral distribution patterns to choose from when designing a lighting layout. They consist of Types I, II, III, IV, and V. A graphic of the different patterns is shown below.




- Type II is considered a cutoff fixture. It is the most restrictive pattern of lighting. It concentrates the majority of the light on the roadway. There is minimal spill over light to the house side of the luminaire. This pattern of lighting is ideal for roadways within residential areas.
- Type III is considered a semi-cutoff fixture. It is a less restrictive pattern of lighting than Type II. However, Type III provides light for a wider section of roadway.
- Type IV is considered a semi-cutoff fixture. It is a less restrictive pattern of lighting than Type III. However, Type IV provides light for a wider section of roadway.
- Type V is considered a non-cutoff fixture. It has a high mast lighting pattern. The light is equally distributed in a circle surrounding the luminaries. This pattern of lighting is not suitable for residential areas.

Depending on the lighting design, the luminaire can be set:

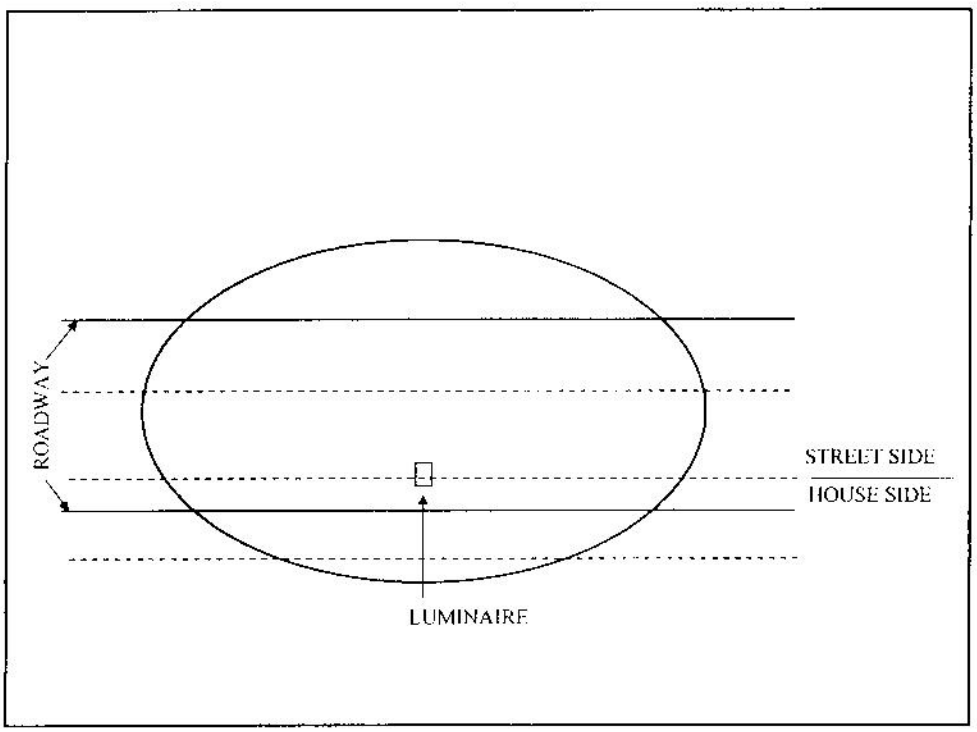
- On the Roadway Edge
- Offset
- Overhang

Generally overhang fixtures will provide the most amount of street side lighting while minimizing house side lighting. However, these fixtures are often more difficult to maintain because the luminaire is located over the lane of traffic.

Fixtures on the roadway edge and offset will provide less street side lighting and more house side lighting than the overhang fixture. However, maintenance is easier because the luminaire is not located over the travel lane.

The following graphic shows an overhang luminaire.




## Photometric Data

The luminaire manufacturers have photometric data sheets for each type of lamp. These data sheets contain valuable information for the lighting designer. It contains the luminaire name and reflector and refractor numbers. Also included are lamp wattages and type of cutoff. This information is used to create a simulation of a utilization curve and isofootcandle curves. These tables show the difference in the amount of light distributed to the street side and house side of the luminaire. This information assists the designer in determining if the proper cutoff fixture is being used for the specific application. The following link is for an example photometric data sheet for the GE Evolve LED Series Roadway Medium Cobrahead fixture.

https://secure.ge-lightingsystems.com/gels01/r2/productcentral/data/roadway/catalog/r000_ge_evolve_led_ermc_2010.pdf

The following equations can be used with the information provided on the photometric data sheet.

**Basic Lighting Equations**

Abbreviations:

FC (Footcandles) or LUX = Light level on the roadway
LL = Lamp Lumens
CU = Coeffiecient of Utilization
MF = Maintenance Factor
W = Roadway Width
SP = Spacing

(English): Footcandle = Lumens/Square Foot

(Metric): Lux = Lumens/ Square Meter

SP = (LL x CU x MF) / (FC x W)

(English): SP = (LL x CU) / (FC x W)

(Metric): SP = (LL x CU) / (Lux x W)