Roadway Lighting Design Manual

April 2003

Moving Minnesota

TABLE OF CONTENTS

1. INTRODUCTION

1.1 Background

This Roadway Lighting Design Manual has been developed to provide training on the design of roadway lighting systems. Participants will learn the fundamentals needed to design lighting systems. Example problems will help develop the concepts needed to understand and design a lighting system. A full lighting plan set is provided as a reference.

This Manual has been divided into eight Chapters as follows:

- Chapter 1 is the introduction.
- Chapter 2 presents Lighting Basics with background information on lighting subjects.
- Chapter 3 covers Lighting Equipment including lamps, luminaires, poles, ballasts, service cabinets, light bases, and equipment pads.
- Chapter 4 covers the basics of Photometry.
- Chapter 5 addresses the Mn/DOT Lighting Design methods and covers the Mn/DOT Lighting Plan Preparation steps.
- Chapter 6 outlines Specifications and Agreements as pertaining to roadway lighting plans.
- Chapter 7 contains two sample Mn/DOT Lighting Plans.
- Chapter 8 is the Appendix with Glossary of Terms, References, a report titled Safety Benefits of Roadway Lighting, Standard Plates, a sample Special Provision, miscellaneous information, and an index.

> The purpose of this manual is to present the fundamental concepts and standard practices related to the design of lighting systems for **Mn/DOT**. This manual is structured to parallel the progression of decisions, activities and functions related to the design of lighting systems.

1.2 Course Schedule

Day 1

Time	Topic	Chapter	Page #	Comments
7:30	Registration	-	-	-
8:00	Introduction	1	1-1	
8:15	Lighting Basics	2	2-1	terms, purpose, visibility, warrants, configurations
9:45	Break	-	-	-
10:00	Lighting Equipment	3	3-1	lamps, luminaires, cabinets, bases, pads
12:00	Lunch	-	-	-
1:00	Photometry	4	4-1	Isofootcandle charts, depreciation factors
2:15	Break	-	-	-
2:30	Lighting Design	5	5-1	Lighting design process
4:00	Adjourn*	-	-	-

* Note: Instructors will be available after training to answer individual questions.

Day 2

Time	Topic	Chapter	Page #	Comments
8:00	Introduction & Recap	-	-	-
8:15	Lighting Design	5	5-1	continued
9:45	Break	-	-	-
10:00	Lighting Design	5	5-1	continued
12:00	Lunch	-	-	-
1:00	Specifications and Agreements	6	6-1	Design standards, special provisions (Mn/DOT presentation)
2:15	Break	-	-	-
2:30	Lighting Plan Preparation	5.3	5-21	Mn/DOT plan set prep
3:45	Course Wrap-up and Questions	-	-	-
4:00	Adjourn*	-	-	-

* Note: Instructors will be available after training to answer individual questions.

1.3 Instructor Information

Jeff Gerken, PE, PTOE is the lead technical expert for the Albeck Gerken team. Jeff is a transportation engineer with Albeck Gerken, Inc. Jeff has provided traffic engineering course development and teaching on three other Mn/DOT training courses and is currently on active duty as a Naval Reserve SEABEE.

John Albeck, PE, PTOE will serve as co-instructor for the course. John is a senior transportation engineer with Albeck Gerken, Inc. John has provided traffic engineering course development and teaching on four other Mn/DOT training courses.

Sarah Tracy, PE will serve as co-instructor for the course. Sarah is a transportation engineer with Albeck Gerken, Inc. Sarah has provided traffic engineering course development and teaching on four other Mn/DOT training courses.

Ray Starr, PE will be the course technical expert. Ray is the Acting State Lighting Engineer in MnDOT's Office of Traffic, Security and Operations. His office sets Mn/DOT's roadway lighting policies and standards, reviews city and county lighting plans, prepares lighting special provisions, and provides guidance to construction personnel and electrical contractors.

Dave Scott will be the course technical expert. Dave Scott is the State Lighting Design Specialist in Mn/DOT's Office of Traffic, Security and Operations. Dave has been working in the field of lighting for 36 years. His focus of experience is primarily in the area of designing electrical lighting projects.

1.4 Acknowledgments

The development of this Roadway Lighting Design Manual has been a result of the combined efforts of the Mn/DOT Office of Traffic, Security and Operations, and Albeck Gerken Traffic Consulting. The contributions by: Ray Starr, Sean Delmore, Dave Scott, and Nicole Rosen are gratefully acknowledged.

1.5 Disclaimer

This Manual is disseminated under the sponsorship of the Minnesota Department of Transportation (Mn/DOT), Office of Traffic, Security and Operations. Mn/DOT and Albeck Gerken Traffic Consulting assume no liability for it contents or use thereof.

Mn/DOT does not endorse software, products or manufacturers. Trademarks of manufacturers' names may appear herein only because they are considered essential to the object of this manual.

Mere possession of this manual does not qualify an individual to design roadway lighting systems. Designing roadway lighting systems is an integrated process that requires a solid understanding of lighting fundamentals.

The contents of this manual reflect the views of the authors, who are responsible for the facts and accuracy of the data presented herein. The contents do not necessarily reflect the official policy of the Minnesota Department of Transportation.

The most current version of this manual in Adobe PDF format is on the Office of Traffic, Security and Operations website. You can find this at:

http://www.dot.state.mn.us/trafficeng/

2. LIGHTING BASICS

Good visibility under day or night conditions is one of the fundamental requirements enabling motorists to move on roadways in a safe and coordinated manner. Properly designed and maintained street lighting will produce conformable and accurate visibility at night, which will facilitate and encourage both vehicular and pedestrian traffic.

The purpose of roadway lighting is to attain a level of visibility which enables the motorist and pedestrian to see quickly, distinctly, and with certainty all significant detail, notably the alignment of the road (its direction and its surround) and any obstacles on or about to enter the roadway. Nearly all aspects of traffic safety involve visibly.

This chapter will cover:

- Definition of frequently used lighting terms
- The purpose of roadway lighting
- Visibility of objects
- Lighting warrants
- Types of lighting systems configurations
- Minnesota's Energy Law

Many of the items in this Manual and chapter are references from the publication An Informational Guide for Roadway Lighting, American Association of State Highway and Transportation Officials (AASHTO), Washington, DC, 1984.

2.1 Definition of Terms

Light Terms and Measurement Units (additional definitions can be found in Appendix A - Glossary of Lighting Terms):

Luminaire. A complete unit consisting of a lamp or lamps together with the parts designed to distribute the light, to position and protect the lamps and to connect the lamps to the power supply.

Illuminance (E). The density of luminous flux incident on a surface; the quotient of the flux divided by the area of the surface, when the surface is uniformly illuminated. Mn/DOT uses the illuminance method of calculation for lighting design.

Lumen (lm). A unit of measure of the quantity of light. One lumen is the amount of light which falls on an area of one square foot every point of which is one foot from the source of one candela. A light source of one candela emits a total of 12.57 lumens.

Footcandle The english unit of Illuminance; illuminance on a surface one square foot in area on which there is uniformly distributed a light flux of one lumen. One footcandle equals 10.76 lux.

Initial Lamp Lumens (LL). Initial bare bulb lumen output of a light source.

Coefficient of Utilization (CU). A design factor that represents the percentage of bare lamp lumens that are utilized to light the pavement surface. This factor is based on the luminaire position relative to the lighted area.

Lamp Lumen Depreciation Factor (LLD). A design factor used to depreciate the output of a lamp due to life-cycle output reduction. Mn/DOT uses a LLD = 0.80.

Luminaire Dirt Depreciation Factor (LDD). A design factor used to depreciate the output of a lamp due to dirt affecting the interior and exterior of the luminaire and to some extent the lamp itself. Various degrees of dirt accumulation may be anticipated depending on the area in which the luminaire is located. Mn/DOT uses a LDD = 0.90.

Average Initial Illuminance. The average level of horizontal illuminance on the roadway pavement area at the time the lighting system is installed when lamps are new and luminaires are clean: expressed in average footcandles (or lux if SI) for the pavement area.

Average Maintained Illuminance*.* The average level of horizontal illuminance on the roadway pavement when the output of the lamp and luminaire is diminished by the maintenance factors; expressed in average footcandles (or lux if SI) for the pavement area.

Uniformity Ratio*.* The ratio of the Average Maintained Illuminance level to the Minimum Maintained Illuminance level. The uniformity ratio is used as a design check to ensure lighting performance.

Seeability. Is a non-technical term, which describes how well the eye sees. It includes the ability to define form, but it also includes color discrimination and color rendering. Footcandle levels, while a measurement of light quantity, are not the sole indicator of seeability. There are also measuring methods for determining light quality, such as Color Rendering Index (CRI).

2.2 Purpose of Roadway Lighting

2.2.1 Traffic Engineering Objectives

a. Promotion of safety at night by providing quick, accurate, and comfortable seeing for drivers and pedestrians.

b. Improvement of traffic flow at night by providing light, beyond that provided by vehicle lights, which aids drivers in orienting themselves, delineating roadway geometries and obstructions, and judging opportunities for overtaking.

c. Illumination in long underpasses and tunnels during the day to permit drivers entering such structures from the open to have adequate visibility for safe vehicle operation.

2.2.2 Other Objectives

a. Reduction of street crimes after dark. From the traffic engineer's perspective, this ancillary benefit could attract non-traditional funding sources.

b. Enhancement of commercial (especially retail sales) properties by attracting evening shoppers, audiences, and other users.

Not all these objectives are necessarily achieved by good lighting alone.

2.3 Visibility of Objects and Lighting Quality

2.3.1 Visibility

Visibility is the state of being perceived by the eye. The purpose of roadway lighting is to attain a level of visibility which enables the motorist and pedestrian to see quickly, distinctly, and with certainty all significant detail, notably the alignment of the road (its direction and its surrounds) and any obstacles on or about to enter the roadway. Nearly all aspects of traffic safety involve visibility. Some factors that directly influence visibility are:

(1) Brightness of an object on or near the roadway

(2) General brightness of roadway background – ambient light

(3) Size of object and identifying detail

(4) Contrast between an object and its surroundings

(5) Contrast between pavement and its surroundings as seen by the observer

(6) Time available for seeing the object

(7) Glare (Disability glare - reducing ability to see or spot an object and Discomfort glare - ocular discomfort that doesn't affect the visual acuity or ability to discern an object)

(8) Driver vision

(9) Condition of windshield

Good visibility on roadways at night results from lighting (both fixed and vehicular), which provides adequate pavement illuminance with good uniformity and appropriate illuminance of adjacent areas, together with reasonable freedom from glare.

2.3.2 Quality

Quality of lighting refers to the relative ability of the light available to provide the contrast difference in the visual scene in such a manner that people may recognize the cues required for the seeing task.

Certain factors are involved in producing a quality lighting system, however, a number of the factors are interrelated and care should be taken in balancing these factors to obtain maximum quality. Reduction in disability glare will improve visibility and reduction in discomfort glare should improve driver performance. Reflected glare will conceal some contrast differences and should be reduced. A change in pavement illuminance will change contrast and uniformity of pavement illuminance and other background areas will also effect quality.

Changes made in some of these areas may adversely affect others. Care must be taken to obtain the proper compromise by adjusting luminaire type, mounting height, uniformity and luminaire locations.

2.4 Types of Lighting System Configurations

2.4.1 Continuous Freeway Lighting

Continuous freeway lighting places lights in the merging traffic and gore areas in the same locations as partial interchange lighting, and, in addition, places lights along ramps, loop, on the through roadway through the interchange, and sometimes on the crossroad between the ramp terminals. Continuous lighting can include a number of interchanges and is usually in an Urban Area.

2.4.2 Partial Interchange Lighting

Partial freeway lighting is the lighting of ramp terminals and on and off ramps.

2.4.3 Complete Interchange Lighting

Complete interchange lighting places lights in the merging traffic and gore areas in the same locations as partial interchange lighting, and, in addition, places lights along the ramps, on the through roadway through the interchange, and on the crossroad between the ramp terminals. The state no longer installs complete interchange lighting, only continuous or partial interchange lighting.

2.4.4 Underpass Lighting

Where the AASHTO Guide indicates that underpass lighting is desirable, the lights are typically high pressure sodium underpass fixtures for each direction of travel on the roadway, mounted on the abutment of the bridge or on a pier. If such mounting would place a luminaire more than about 10 feet from the edge of the traveled roadway, the luminaire is typically mounted on the bottom of the diaphragm.

2.4.5 Lighting for Other Streets and Highways

Lighting levels and uniformity ratios for streets and highways other than freeways are contained in Chapter 5. The design for these roadways is often matched to existing lighting in a city rather than to freeway design standards. Federal participation in lighting other streets and highways is limited to the cost of installing lighting to the levels indicated in the AASHTO Guide.

2.4.6 Lighting on Bridges

The roadway on a bridge is normally treated the same as other parts of the roadway. If there is no lighting on the adjacent roadway, there is normally no need for lighting on the bridge. An exception is a very long bridge, which may be lit even though the roadway is not lit at other locations.

Where lights are to be installed on a bridge, the desirable locations for the lighting units are at abutments and at pier locations, or at distance from an abutment or pier not to exceed 25 percent of the length of he span. This placement of the lighting units reduces the effects of vibration. The light poles should utilize davit type mast arms and shorter mast arm lengths so that there are no joints to be weakened by vibration.

If a local governmental agency requests ornamental lighting on a new Mn/DOT bridge or bridge replacement project, Mn/DOT will participate in funding in accordance with current cost participation guidelines.

The installation of navigation and air obstruction lights are an integral part of the bridge design. The Office of Bridges and Structures may ask the lighting designer to coordinate electrical service points for the roadway lighting and navigational/air obstruction lighting.

2.4.7 Lighting of Roadways with Median Barriers

In high volume urban areas it is very difficult to maintain barrier lighting, and if possible, lights should be placed on the outside of the edge of the roadway.

Median barrier mounted lights should not be used in high volume areas without a 10-foot inside shoulder. If used, median barrier mounted luminaires typically use double 6-foot davit-type mast arms.

2.4.8 Lighting at Intersections

Lighting at intersections is usually justified and will alert the driver to an approaching intersection. Luminaires should be placed on or near prominent conflict points.

Lighting should be provided at all signalized and flashing beacon intersections. A signal pole shaft extension with a luminaire mast arm should be utilized whenever possible to avoid adding more poles at the intersection. Street lights on traffic signal poles should be fed from the traffic signal service point. Additional light poles may be necessary when the intersection has channelization or complex turning lanes. The level of illumination of a signalized intersection is dictated by the area classification of the roadway. Suggested levels of illumination and average horizontal footcandles for roadway lighting are given in Chapter 5.

The level of illumination at an intersection should be greater than that between intersections where there is continuous lighting.

Where the level of illumination is low between intersections, such as 0.6 footcandles, the light intensity at the intersection should be doubled as a rule.

2.5 Lighting Warrants

The primary purpose of warrants is to assist administrators and designers in evaluating locations for lighting needs and selecting locations for installing lighting. Warrants give conditions that should be satisfied to justify the installation of lighting. Meeting these warrants does not obligate the state or other agencies to provide lighting or participate in its cost. Conversely, local information in addition to that reflected by the warrants, such as roadway geometry, ambient lighting, sight distance, signing, crash rates, or frequent occurrences of fog, ice, or snow, may influence the decision to install lighting.

Warrants for freeway lighting are contained in the AASHTO Guide, with the modifications and additions indicated below:

2.5.1 Continuous Freeway Lighting

Case CFL-1 - Continuous freeway lighting is considered to be warranted on those sections in and near cities where the current ADT is 40,000 or more.

Case CFL-2 - Continuous freeway lighting is considered to be warranted on those sections where three or more successive interchanges are located with an average spacing of 1½ miles or less, and adjacent areas outside the right-of-way are substantially urban in character.

Case CFL-3 - Continuous freeway lighting is considered to be warranted where for a length of 2 miles or more, the freeway passes through a substantially developed suburban or urban area in which one or more of the following conditions exist:

a. local traffic operates on a complete street grid having some form of street lighting, parts of which are visible from the freeway;

b. the freeway passes through a series of developments such as residential, commercial, industrial and civic areas, colleges, perks, terminals, etc., which includes roads, streets and parking areas, yards, etc., that are lighted;

c. separate cross streets, both with and without connecting ramps, occur with an average spacing of ½ mile or less, some of which are lighted as part of the local street system; and

d. the freeway cross section elements, such as median and borders, are substantially reduced in width below desirable sections used in relatively open country.

Case CFL-4 - Continuous freeway lighting is considered to be warranted on those sections where the ratio of night to day crash rate is at least 2.0 or higher than the state wide average for all unlighted similar sections, and a study indicates that lighting may be expected to result in a significant reduction in the night crash rate.

Continuous freeway lighting should be considered for all median barriers on roadway facilities in urban areas. In rural areas each location must be individually evaluated as to its need for illumination.

2.5.2 Complete Interchange Lighting

Complete interchange lighting generally is warranted only if the mainline freeway has continuous lighting.

2.5.3 Partial Interchange Lighting

Case PIL-1 **-** Partial interchange lighting is considered to be warranted where the total current ADT ramp traffic entering and leaving the freeway within the interchange areas exceeds 5,000 for urban conditions, 5,000 for suburban conditions, or 2,500 for rural conditions.

Case PIL-2 **-** Partial interchange lighting is considered to be warranted where the current ADT on the freeway through traffic lanes exceeds 25,000 for urban conditions, 20,000 for suburban conditions, or 10,000 for rural conditions.

Case PIL-3 **-** Partial interchange lighting is considered to be warranted where the ratio of night to day crash rate within the interchange area is at least 1.25 or higher than the state wide average for all unlighted similar sections, and a study indicates that lighting may be expected to result in a significant reduction in the night crash rate.

2.5.4 Non-Freeway Lighting

The AASHTO Guide also contains guidelines on special considerations for roadway lighting.

The AASHTO Guide gives no specific warrants for continuous lighting of roadways other than freeways (roads with fully controlled access, no at-grade intersections), but does suggest some general criteria that may apply when considering the installation of lighting.

Lighting of at-grade intersections is warranted if the geometric conditions mentioned in the AASHTO Guide exist or if one or more of the following conditions exists:

1. **Volume -** The traffic signal warrant volumes for the minimum vehicular volume warrant, the interruption of continuous traffic warrant, or the minimum pedestrian volume warrant are satisfied for any single hour during conditions other than daylight, excluding the time period between 6:00 a.m. and 6:00 p.m.

2. **Crashes** - There are three or more crashes per year occurring during conditions other than daylight.

3. **Intersecting Roadway** - The intersecting roadway is lighted.

4. **Ambient Light** - Illumination in areas adjacent to the intersection adversely affects the drivers' vision.

5. **Channelization** - The intersection is channelized and the 85^{th} percentile approach speed exceeds 40 miles per hour. A continuous median is not considered as channelization for the purpose of this warrant.

6. **School Crossing** - Scheduled events occurring at least once per week during the school year make it necessary for 100 or more pedestrians to cross at the school crossing during any single hour in conditions other than daylight, or a traffic engineering study indicates a need for lighting.

7. **Signalization** - The intersection is signalized.

8. **Flashing Beacons** - The intersection has a flashing beacon.

Warrants covering lighting for tunnels, underpasses, rest areas, and signs are contained in the AASHTO Guide.

2.6 Minnesota's Energy Law

The following paragraph is the new wording for the existing Minnesota Statute 216C.19. The wording was modified by 1992 legislation.

Energy Conservation

Subd. 1. After consultation with the commissioner and the commissioner of public safety, the commissioner of transportation shall adopt rules under chapter 14 establishing minimum energy efficiency standards for street, highway and parking lot lighting. The standards must be consistent with overall protection of the public health, safety and welfare. No new highway, street or parking lot lighting may be installed in violation of these rules. Existing lighting equipment, excluding roadway sign lighting, with lamps with initial efficiencies less than 70 lumens per watt must be replaced when worn out with light sources using lamps with initial efficiencies of at least 70 lumens per watt.

See chart in section 3.1 of this manual to determine lamp efficiencies.

Attention to residential activity is crucial when considering lighting systems since some installations have resulted in local citizen complaints due to the amount of lighted area. This is particularly true with high mast lighting (see section 3.8.3) but must be considered for any installation. High mast tower lighting may be objectionable near residential neighborhoods because the high luminaire mounting heights, sometimes exceeding 100 feet, can cause glare and excess light to those areas.

3. LIGHTING EQUIPMENT

In this Chapter you will be introduced to lighting equipment as related to roadway lighting design. Lighting components can be grouped together in terms of their functions. They are generally described as the optical system, the electrical system, and the structural system.

The items covered include:

- Lamps
- Luminaires
- Ballasts
- Service Cabinets
- Poles
- Light Bases (Foundations)
- Equipment Pads
- Selection of the lighting equipment

Lighting equipment component understanding and proper selection is crucial to the overall success of the roadway lighting design project.

The optical system is comprised of the light source (lamp), reflector, refractor, and housing which comprise a luminaire. The electrical system is made up of the ballast, wiring, photocells, and other minor components. The structural system supports the luminaire and associated equipment and is comprised of the mounting brackets, pole, and foundation. The design guidelines presented in this manual require selection of components such as luminaires and pole equipment. Other equipment such as electrical service cabinets will be determined based on these choices.

3.1 Lamps

The most important element of the illumination system is the light source. It is the principal determinant of the visual quality, economy, efficiency, and energy conservation aspects of the illumination system. An electric light source is a device, which transforms electrical energy, or power (in watts), into visible electromagnetic radiation, or light (lumens). The rate of converting electrical energy into visible light is call "luminous efficacy" and is measured in lumens per watt.

Three general types of lamps are presently in use for roadway lighting: incandescent, fluorescent, and high-intensity discharge (HID). Only HID lamps are currently used for Mn/DOT lighting projects.

3.1.1 Roadway Lighting Lamp Characteristics

General characteristics for roadway lamps are shown in the table below.

Type of Light	Initial Light Output lumens x 10^3	Approximate Efficacy lumens/Watt	Approximate Lamp Life hours x 10^3**
Clear Mercury	3.7-57	37-57*	18-28
Phosphor-coated Mercury	4.0-63	40-63*	18-28
Metal Halide	34-100	85-100*	10-15
High Pressure Sodium	9.5-140	95-140*	15-28
Low Pressure Sodium	1.8-33	100-183*	10-18
QL Induction Lighting	3.5-12	67-74 (based on 100 h)	100

*These values exclude wattage losses due to ballast. **Number of hours for a group of lamps at which 50 percent will remain in operation; based on 10 hours of operation per start.

QL Induction lighting is a combination of electromagnetic induction and gas discharge lighting. An electric current passing through a coil generates an electromagnetic field, inducing an electric current in the gas filling of a low pressure gas-discharge lamp. A ferrite core intensifies this induction. This induced current causes rise to ultra-violet radiation that in turn is converted into visible light by fluorescent powders inside the lamp bulb. An induction lighting system comprises an electronic circuit (high frequency generator), the power coupler (antenna) and the low-pressure gas discharge lamp without the use of any filaments or electrodes.

The estimated life of a QL lamp system is 60,000 Hours 'over 13 years on a 12 hour cycle' this is significantly longer than that of any other available light source. Due to the absence of an electrode, the technical life is determined by the electronic components of the HF generator.

3.1.2 Background History of Lamps for Roadway Lighting

The incandescent or filament lamp was the most commonly used for many years. It was inexpensive, simple, and easy to install. It produced pleasing color rendition and its small size permitted good light control with a reasonably sized fixture. However, its low efficacy and short rated life have made it undesirable for new installations.

The fluorescent lamp is no longer used for new roadway lighting installations, but is still utilized for tunnel and sign lighting. Its large size makes it difficult to obtain good light control in a reasonably sized luminaires. The fluorescent lamp requires a ballast and its light output is affected by low temperature more than other lamps. Its one advantage is the broad light patterns that it provides on wet streets.

The mercury lamp replaced the incandescent lamp in popularity. The initial cost is higher and it requires a ballast, but its high efficacy and long life make it considerably more attractive than the incandescent lamp. The blue-white color of the clear lamp is generally acceptable, and the arc tube size provides a light source that is small enough to permit good light control. A phosphor-coated outer bulb, featuring both higher output and more pleasing color rendition, is also available. However, since light control is more important in roadway lighting than color rendition clear lamps are normally used.

The *metal halide lamp* is a type of mercury lamp in which the arc tube contains, in addition to mercury, certain iodide compounds that improve both the efficacy and the color rendition without the use of a phosphor-coated bulb. The light source size is that of the arc tube, permitting good light control in the same fixture used for clear mercury lamps and excellent color rendition, however lamp life is low.

The *high pressure sodium (HPS) lamp* has replaced the mercury lamp. It is characterized by a golden-white color light output. HPS lamps are normally operated with special ballasts that provide the necessary high voltage to start the lamp. Some of the newer HPS lamps include:

- Improved color rendition.
- Internal starting devices that operate with mercury or metal halide lamp ballasts.
- Dual arc tube or "standby" lamps that provide light as soon as power is restored after a momentary power interruption and that, in addition, have a rated life of 40,000 hours.
- End of life indicators

The *low pressure sodium (LPS) lamp* is characterized by a monochromatic bright yellow color light output. This lamp requires special ballasts and increases materially in size as the wattage increases; the 185-W lamp is 3.5 feet long. This large size makes it difficult to obtain good light control in a reasonably sized fixture. The poor color rendition and large size of the LPS lamp have made it unpopular for use in other than industrial or security applications.

3.1.3 Mn/DOT Practice Concerning Lamps

Different types of lamps and luminaires have different advantages and disadvantages which make them more suitable or less suitable for a particular use.

The HPS lamp is most commonly used by Mn/DOT. The lamp emits light across the spectrum with a predominance in the orange-yellow region. The HPS lamp is very efficient and is the best for most roadway lighting. HPS is not good for use on signs because the light it produces does not render the proper colors on standard signs. The lamp requires a ballast and special device to produce a very high voltage surge for starting. The HPS lamp usually cycles on and off at the end of normal life.

The metal halide (MH) lamps are occasionally used on Mn/DOT projects because of the elimination of the mercury vapor luminaires. The only Mn/DOT MH lamp installations are in rest areas and weigh stations. Mercury vapor lamps are no longer used by Mn/DOT, see section 2.6 for further details. Some MH lamps are in operation as part of high mast tower lighting and rest area lighting. The color value of the metal halide lamp is good and phosphor is not required. There are two versions of the lamp, one designed for basedown operation and the other for baseup operation. The lamp must operate in the proper position.

The fluorescent lamp is no longer installed on new systems, but is still in operation on some existing sign lighting systems. The fluorescent lamp has shown a poor maintenance history and is adversely affected by cold weather.

The LPS lamp is a very efficient light source in that it provides the most light for the same amount of electricity of any of the light sources described. LPS lighting has proven to have maintenance problems requiring frequent lamp replacement. The LPS lamp provides very poor color rendition. The lamps are very long, altering the light distribution pattern from the luminaires, for these reasons Mn/DOT does not use LPS light sources.

The incandescent lamp is rarely if ever used for roadway lighting because of its low efficiency and short lamp life in comparison with HID light sources.

The efficiency of a lamp in converting electrical energy to light, the ability of the lamp to maintain its light output over the course of the lamp life, the length of the lamp life, the color of the light, and the distribution of the light are all factors which affect the cost and effectiveness of installing, operating, and maintaining the lights, and, hence, affect the choice of light source.

3.2 Luminaires

A luminaire is defined as a complete unit consisting of a lamp, together with the parts designed to distribute the light, to position and protect the lamp, and to connect the lamp to the power supply. Components that make up a luminaire include reflector, refractor and the housing.

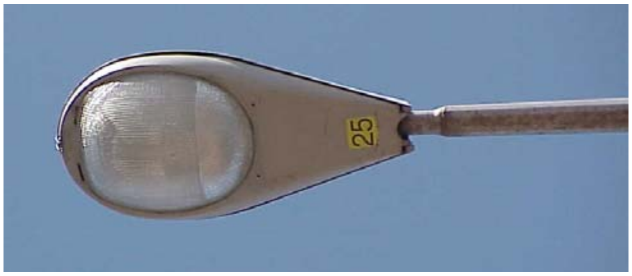
The reflector is used to change the direction of the light output. Its purpose is to redirect the otherwise wasted light output in the direction desired. The refractor controls and redirects the light emitted from the lamp and coming off the reflector by means of its prismatic construction. The refractor also serves to protect the lamp from external damage.

Several factors have influenced the choice of the type of luminaire that Mn/DOT currently uses. The luminaires should be a standard type that is maintainable by and approved by the Office of Maintenance (Electrical Services Section) and the Office of Traffic and, where applicable, the power company.

Luminaires for roadway lighting should normally be the shallow glass "cobra head" style, “vertical” head style, or “high mast” style. However, in certain circumstances "shoebox" style and "circular" style luminaires are being used. Shoebox style luminaires are often appropriate for the interior lights in rest areas. Where a municipality is maintaining the lights, other decorative luminaires may be used.

Luminaires should only have photocells when the electrical service point (feedpoint) does not provide photoelectric control.

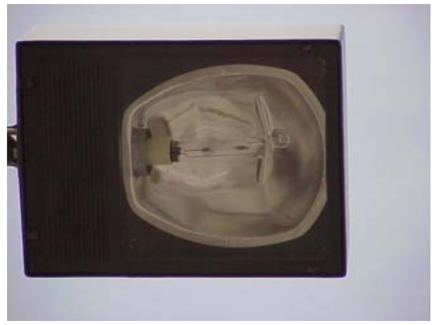
Several images of standard luminaire types follow.



Cobra Head Style Luminaires

Vertical Mount Style Luminaires

High Mast Style Luminaires



Shoebox Style Luminaires

Decorative Style Luminaires (referred to as Minneapolis Style)

Rest Area Luminaires (Shoebox with Drop Lens)

Bridge Underpass Luminaire

3.3 Ballasts

A ballast is required for all HID and fluorescent lamps. A ballast generally serves three functions. First it provides the proper open circuit voltage to start the lamp (some HID lamps require an additional igniter to achieve proper starting voltage). The second function is to keep the lamp operating within its design parameters. Arc discharge lamps have a very low inherent operating resistance or impedance. Furthermore, if no ballast controls an operating HID lamp, the current would increase continually causing the impedance to decrease continually, causing the current to continually increase even more. This cycle will continue until the lamp burns out. This phenomenon is call negative resistance. The ballast provides a control function and limits the power available to the lamp. The third function of the ballast is to adapt the lamp to any one of the line voltages commonly available.

Mn/DOT uses regulator or constant wattage type ballasts. A table summarizing ballast characteristics is presented below for the types of ballasts Mn/DOT uses.

Ballast Type	Line Voltage	Variation in Lamp Wattage vs. Line Voltage		Power Factor (min)	Starting Current	Lamp Current Crest Factor	Ballast Losses
		Line Volts	Lamp Watts				
Regulator or Constant Wattage	120/240 v or 240/480v	± 10 %	± 3-5 %	90%	Lower than operating	1.6-1.8	17-30 %

Ballasts for high pressure sodium lamps are located in the luminaire, the only exception would be pedestrian lighting where ballasts can be installed in the 10 foot pole.

3.4 Service Cabinets

The electrical service point (feedpoint) consists of a lighting service cabinet complete with circuit breakers and photoelectric control where applicable, a concrete foundation or wood pole for mounting, electrical connections to the power company service conductors, provisions for grounding, and a meter and meter socket when necessary. See Standard Plate 8140 for service cabinet wiring.

3.4.1 Service Cabinet, Secondary Type L2

This is a pad mounted service cabinet with power distribution blocks, 2-100 ampere 2-pole circuit breakers and 16-20 ampere single pole branch circuit breakers. This allows for eight 3-wire circuit runs from the cabinet consisting of two current carrying conductors, one neutral conductor and a ground. Each circuit having a load capacity of 32 amps. In a 240 volt system this can accommodate 213-250 watt HPS luminaires and in a 120 volt system 98-250 watt HPS luminaires. A photocell is provided in this service cabinet.

3.4.2 Service Cabinet, Secondary Type L1

This is a pad mounted service cabinet with power distribution blocks, with a 100 ampere 2-pole main circuit breaker and 8-20 ampere single pole branch circuit breakers. This allows for four 3-wire circuit runs from the cabinet consisting of 2 current carrying conductors, one neutral conductor and a ground. Each run having a load capacity of 32 amps. In a 240 volts system this can accommodate 106-250 watt HPS luminaires and in a 120 volt system 49-250 watt HPS luminaires. A photocell is provided in this service cabinet.

Type L1 or L2 Cabinet

3.4.3 Service Cabinet, Secondary Type A

This pole mounted service cabinet is identical to a pad mounted Type L1, with a 100 ampere 2-pole main circuit breaker and 8-20 ampere single pole branch circuit breakers. This allows for four 3-wire circuit runs from the cabinet consisting of 2 current carrying conductors, one neutral conductor and a ground. Each run having a load capacity of 32 amps. In a 240 volts system this can accommodate 106-250 watt HPS luminaires and in a 120 volt system 49-250 watt HPS luminaires. A photocell is provided in this service cabinet.

Type A Cabinet

3.4.4 Service Cabinet, Secondary Type B

This pole mounted service cabinet has a 60 ampere 2-pole main circuit breaker and 4-20 ampere single pole branch circuit breakers. This allows for two 3-wire circuit runs from the cabinet consisting of 2 current carrying conductors, one neutral conductor and a ground. Each run having a load capacity of 32 amps. In a 240 volts system this can accommodate 53-250 watt HPS luminaires and in a 120 volt system 24-250 watt HPS luminaires. A photocell is provided in this service cabinet.

The service cabinets described above can accommodate the number of lights indicated, if it does not exceed a 3 percent voltage drop.

3.5 Poles

3.5.1 General Information

The latest version of the "Standard Specifications for Structural Supports for Highway Signs, Luminaires and Traffic Signals", published by AASHTO, specifies structural requirements for light poles. The Federal Highway Administration may have requirements differing from those found in this AASHTO standard, particularly with regard to breakaway devices, and the lighting system designer should check on such requirements before specifying types of poles for a lighting project.

The designer must determine the pole height, type and length of mast arm(s), material and finish, and method of mounting. Whenever possible, these choices should conform to standard products offered by manufacturers.

Pole height affects the illumination intensity, uniformity of brightness, area covered, and relative glare of the unit. Higher mounted units provide greater coverage, more uniformity, and a reduction of glare, but a lower footcandle level. By using higher poles, fewer poles are required and they can be set back farther from the traveled roadway. Typical pole heights are 30 feet, 40 feet, and 49 feet. Power lines, nearby airports, and nearby residential neighborhoods may limit the height of poles used for lighting.

Where pole height is not restricted, high mast tower lighting may replace conventional lighting units at locations with complex roadways, such as at freeway interchanges. High mast tower lighting is a lighting system that places several high wattage luminaires atop high towers to illuminate a large area. It uses fewer poles, places poles farther from the traveled roadway, and provides a more uniform and pleasing lighting pattern than conventional lighting. High mast tower lighting may be objectionable near residential neighborhoods because the high luminaire mounting heights, sometimes exceeding 100 feet, can cause glare and excess light to those areas.

Conventional lighting units should have davit type mast arms or tenon type mounting assembly unless a desire for decorative lighting dictates another type of arm, or unless the lights must match existing light poles with a different type of arm.

Mn/DOT roadside light poles up to and including 40 feet in height mount on the Design E light bases. Poles higher than 40 feet and up to 49 feet in height mount on the Design H light base. These light bases and the anchorage for light standards mounted on a bridge or median barrier are detailed in the Mn/DOT Standard Plates Manual. Applicable standard plates are located in the appendix. Pole anchorages in a median barrier require a specially widened section of the barrier, called an AL section, to be itemized in the road plans.

The designations for the various pole types are given in section 3.5.4 below.

3.5.2 Breakaway Pole Issues

Most poles can be non-breakaway, however not all poles can be breakaway. Breakaway poles must meet 1985 AASHTO breakaway requirements. Mn/DOT's standard aluminum and stainless steel poles have been tested to meet breakaway requirements. Wood pole luminaire supports do not meet 1985 AASHTO breakaway requirements.

Where traffic speeds exceed 40 mph, any poles located within the "clear zone" (See the Mn/DOT Road Design Manual for the definition of "clear zone") must either be breakaway devices, or must be protected by a suitable traffic barrier (guardrail). A breakaway pole has a special base and has been tested as a complete unit to show that it will "break away" when hit and will not impede a vehicle's movement more than a maximum set amount. In urban areas with speeds less than 30 mph and pedestrians present, a knocked down pole may present a greater hazard to traffic and pedestrians than would a non-breakaway device, and in such locations non-breakaway poles should be used. In urban areas with speeds between 30 mph and 40 mph, the designer may choose either breakaway poles or non-breakaway poles. These criteria for the use of breakaway poles apply regardless of the state's participation in the project.

Types of pole bases include the tapered high base, the anchor base, the shoe base, and the standard transformer base. Types of breakaway poles include the stainless steel progressive sheer base with a stainless steel shaft, the frangible cast aluminum transformer base with an aluminum pole shaft and arm, a slip base pole, and an aluminum shoe base pole.

3.5.3 Placement Issues

Pole placement is an engineering decision which should be based upon geometry, character of the roadway, physical features, environment, available maintenance, economics, aesthetics, and overall lighting objectives.

Physical roadside conditions may require adjustment of the spacing determined from the base levels of illumination, indicated in the AASHTO Guide. Higher levels of illumination are justified when overhead structures, safety, and object clearances restrict the placement of poles. It is advisable to provide the higher illumination levels at diverging and merging areas.

Site considerations affecting pole placement include the presence at the site of noise walls, existing guard rail, rock, narrow roadside clearances, power lines, nearby airports, traffic signals and nearby residential neighborhoods. Poles should be placed behind noise walls if the site permits. Poles should be placed at least 2 feet behind any existing guard rail, or at a distance that will allow the guard rail to properly deflect upon impact. When street lights are installed in conjunction with traffic signals, the lights should be installed on the same poles as the traffic signals, if possible.

Long radius curves may be lighted as a straight roadway. Luminaires mounted on the inside of a short radius curve require closer spacing in order to produce adequate pavement brightness on the curved section, but are a preferred placement over the outside of a short curve. Light poles on the inside of a banked curve should be placed such that they will not be hit by trucks.

Light pole placement should consider maintenance. Bucket trucks must be nearly level to operate and are limited in the height and distance from the roadway that the bucket can reach. Different types of trucks may have different working ranges. Poles should also be placed to minimize knockdowns.

3.5.4 Pole Designations

Generally, the pole type designation contains the mast arm length, the type of pole, and the nominal pole height.

The first character before the dash is the mast arm length, usually 6', 9' or 12'.

The character(s) just preceding the dash indicate the type of pole used. See the list below. If no characters are in this position, the pole has a transformer base or high base, is intended for mounting on a light base, and has no finish for an aluminum or stainless steel pole or is galvanized for a steel pole.

The characters after the dash give the nominal pole height.

The pole type characters are as follows:

A - Anchor bolt pole (no transformer base)

B - Barrier or bridge mounting (6 bolt cluster)

C - Corten steel (no finish applied)

D - Double mast arms

M - Minneapolis style pole

P - Painted pole

S - Combination traffic signal and street light pole

W - Wood pole lighting unit (for temporary lighting)

X - Decorative pole (with inclined beam arm)

VM - Vertical mount

Examples of Pole designations:

1. **9-40**: 9' mast arm with 40' mounting height, transformer base or high base, and aluminum or stainless steel, as indicated in the plans.
2. **6BD-40**: 6' double mast arms with 40' mounting height, provisions for barrier mounting.
3. **VMD-45**: Tenon mount double vertical luminaire with 45' mounting height.

Bentstraw Type Pole (6X-40)

Bridge Pole (6B-40)

Standard Pole with 9 Foot Davit (9-40)

Double Davit Arm (6D-49)

Double Vertical Mount Pole Arrangement (VMD-45)

High Mast Tower Poles (3-100, 4-100, etc.)

3.5.5 Mn/DOT Standard Pole Equipment

A limited number of standard pole and fixture types have been approved for Mn/DOT use. The state will construct, maintain and pay for the power costs associated with these systems if agreed upon. The following are Mn/DOT's standard pole and fixture types:

1. Davit Pole/Cobra Head Luminaire

   250 - 400 watt HPS lamp

   40 ft. - 49 ft. round tapered (16 sided) stainless steel or round tapered aluminum pole

   40 ft. – 49 ft. galvanized steel (bridges, retaining walls and median barriers)

   6 ft. - 12 ft. davit style mast arm

2. Bent Straw Pole/Shoebox or Round Luminaire

   250 watt HPS lamp

   30 ft. - 40 ft. painted square tapered steel or aluminum pole

   6 ft. straight tapered mast arm

3. Tenon Top Pole/Vertical Mount Luminaire

   250 - 400 watt HPS lamp

   40-49 ft. round tapered (16 sided) stainless steel or round straight aluminum pole

   Pole top or twin bullhorn bracket mount

4. High Mast Towers

   1000 watt HPS lamp

   100 ft. - 140 ft. corten steel pole with stainless steel luminaire support ring

   3 - 4 luminaires per tower

5. Rest Area

   Walkway light poles with 12” arm/shoebox or round luminaire

   100 watt HPS or 165 watt QL induction

   12’ Painted 4” square steel poles

3.6 Light Bases (Foundations)

In order to adequately support the luminaire and pole structure, the foundation must be designed to support the weight of the structure as well as resist wind loads and vibrations. Mn/DOT uses four standard light bases, P, E, H, and tower. Standard Plates 8127B and 8128B describe bases E and H respectively and are located in the Appendix as well as the detail sheet for the P type base. A tower base detail sheet is included in the 35W sample plan located in Chapter 7.

P Base (concrete or steel): $\leq$ 20 foot poles

E Base (concrete or steel): $\leq$ 40 foot poles

H Base (concrete or steel): $\leq$ 49 foot poles

Steel Base (E, H, or P) **Concrete Base (E, H, or P)** **Tower Type Bases**

3.7 Equipment Pads

A concrete equipment pads includes conduit and anchorage hardware within the concrete foundation, reinforcement bars if using the precast option, all wiring and hardware necessary, and all grounding bonding materials as indicated in the details in the plan.

Standard Plates 8105 and 8106 describe equipment pads A and B respectively. Equipment pads A and B are standard concrete foundations used my Mn/DOT, however other non-standard pads are occasionally used. These Standard Plates are located in the Appendix.

3.8 Selecting the Lighting Systems

Mn/DOT utilizes three types of lighting systems; Cobra Head, Vertical Mount, and High Mast for interchanges, intersections (high mast not used), and continuous lighting installations.

3.8.1 Cobra Head Lighting Systems

The most common equipment used is the 40 foot (12 m) pole with a 250 watt HPS luminaire (cobra head style), davit type mast arms are 9 foot (3 m) on ramps and loops and 12 foot (4 m) on the through roadway. Spacing of the 40 foot (12 m) poles are usually 240-250 feet (73-75 m) depending on the desired footcandle level and the number of lanes. This equipment is used for roadway configurations with 2 or 3 lanes in each direction. When 40 foot poles (with 250 watt HPS) are used for three lanes they should never be spaced more that 240 feet apart. When circumstances allow, Mn/DOT can use shoebox or round luminaires on light poles.

When lighting a roadway configuration with 3 or more lanes a mixture of 40 foot (12 m) poles and 49 foot (15 m) poles can be used. 40 foot (12 m) poles should be used on the ramps and loops and 49 foot (15 m) poles on the through roadway. The 49 foot (15 m) poles can be roadside mounted lighting units or median barrier mounted lighting units. The 49 foot (15 m) lighting unit should have a 400 watt HPS luminaire and spaced 280-300 feet (85-92 m) apart. Median barrier lighting units should have twin 6-foot (2 m) arms and roadway mounted lighting units should have 12 foot (4 m) arms.

The median barrier twin mast arm lighting units has certain advantages such as; provides same number of luminaires with fewer poles; utilizes back light from luminaires; and are less likely to be knocked down. The disadvantages of median lighting are that traffic control is required when working on median lights and the potential danger to employees working on the median lights.

Median barrier mounted lights should not be used in high volume areas without a 10 foot (3 m) inside shoulder.

3.8.2 Vertical Mount Lighting Systems

When adequate clearance and slopes are available, vertical mount lighting units may be utilized. The vertical mount poles are typically 45 foot (13.7 m) poles with single or double tenon mounted with a 250 watt HPS luminaire. 49 foot (15 m) poles may also be utilized with a 400 watt HPS luminaire. Vertical mounted poles can be used on median barrier and bridges.

3.8.3 High Mast Lighting Systems

The third type of equipment Mn/DOT uses is high mast lighting. High mast lighting implies an area type of lighting with 3 or 4 - 1000 watt HPS luminaires mounted on free standing poles or towers, at mounting heights varying from approximately 100 feet (30 m) to 120 feet (36.5 m) or more. At these mounting heights high output luminaires develop a highly uniform light distribution.

High mast lighting is used principally where continuous lighting is desirable such as 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.

High mast lighting is also desirable where there is minimal residential and where maintenance of conventional lighting units may be a hazard to the traveling public and the maintenance personnel. Attention to residential activity is crucial since some installations of high mast lighting have resulted in local citizen complaints due to the amount of lighted area.

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 a 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.

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.

3.8.4 Shoebox or Round Lighting Options

There are cases where a more decorative lighting system is desired. Tainted brown poles with brown shoebox or circular luminaires and an inclined beam mast arm are the only decorative lighting that Mn/DOT will maintain. The painted poles can be used on median barriers and bridges.

The shoebox or round luminaire style of lighting should only be used on two-lane roadways. The poles should be 35-40 feet with 6 foot inclined beam mast arm and 250 watt HPS luminaires. The spacing of these poles must be calculated for each installation.

4. PHOTOMETRY

In this Chapter you will be introduced to photometry as related to roadway lighting design. The items covered include:

- Photometrics
- Lamp and Luminaire Depreciation Factors

This chapter covers the basics of light source test data, depreciation factors that affect the performance of light sources and the terminology used in discussing lighting source physics.

4.1 Photometrics

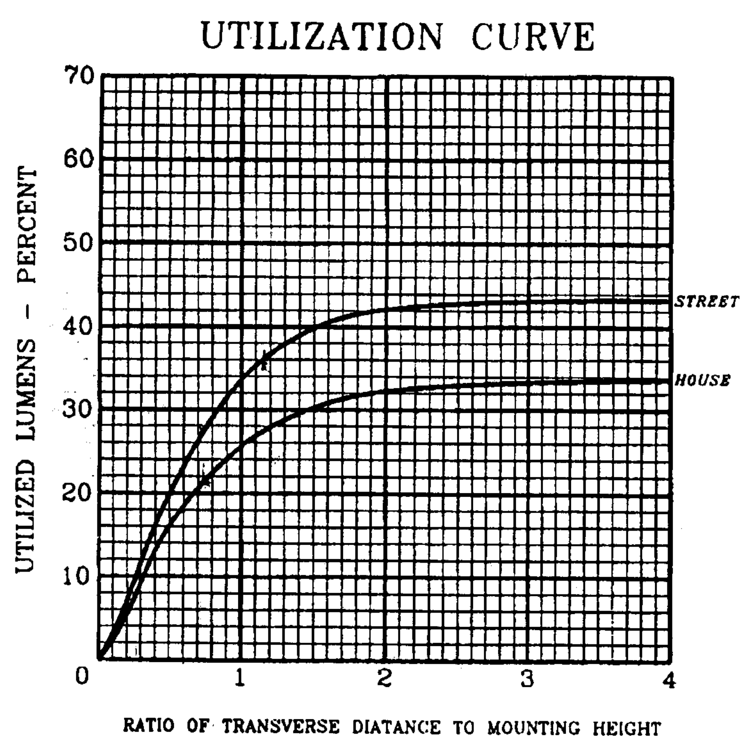
The term Photometry is used to define any test data which describe the characteristics of a luminaire's light output. The most common types of photometric data include isofootcandle performance charts, coefficient of utilization curves, vertical and lateral light distribution data, lumen maintenance curves, and dirt depreciation curves. The purpose of photometry is to accurately describe the performance of a luminaire to enable the designer to select the lighting equipment and to design a layout plan which best meets the needs of the job.

Following is a review of the more frequently used types of photometric data.

4.1.1 Coefficient of utilization

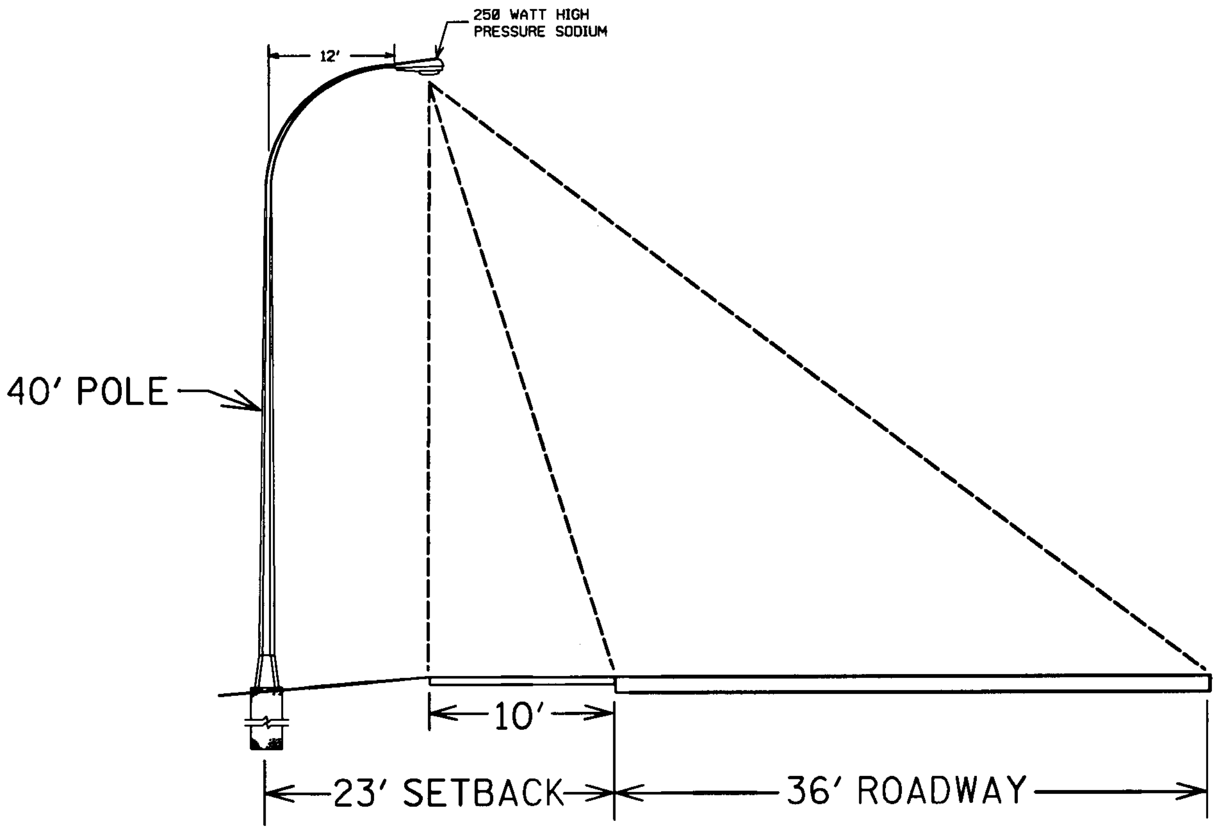
A coefficient of utilization (CU) refers to the ratio of lumens which ultimately reach the work plane to the total lumens generated by the lamp. A coefficient of utilization curve is provided for luminaires intended for outdoor use. The CU can be read directly from the curve and inserted into the standard spacing formula (described later).

A Utilization Curve for a typical cobra head HPS luminaire is shown below.



Two curves are shown in the graphic, one for the street side (normally the desired area to be lit) and one for the house side (or the direction away from the primary lit direction). The street curve represents the utilization of the bare lamp, in percent, as the ratio of lateral distance to mounting height increases.

To compute the CU for the following example, following the steps given.



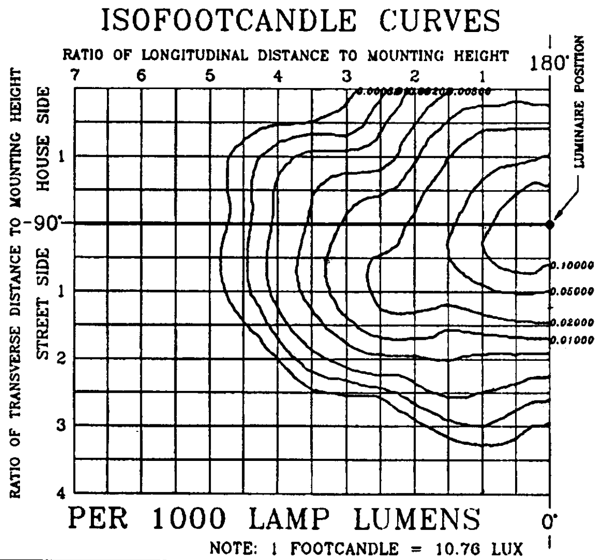
The CU is computed as follows:

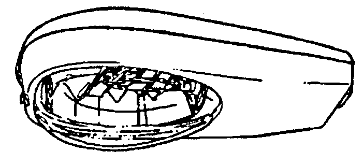
1. To obtain the pavement area CU, enter the CU curve for the Street Side at the correct transverse distance to mounting height ratio. In this case, the ratio would be 46/40 or 1.15. Follow the chart up until you reach the Street curve and read the Utilized Lumens (in percent). This results in 36 percent.
2. To obtain the shoulder area CU, enter the CU curve for the Street Side at the correct transverse distance to mounting height ratio. In this case, the ratio would be 10/40 or 0.25. Follow the chart up until you reach the Street curve and read the Utilized Lumens (in percent). This results in 10 percent.
3. The CU from the "triangle" that forms from the luminaire to the near pavement edge is subtracted from the "triangle" that forms from the luminaire to the far side pavement edge. This results in a CU of approximately 26 percent.

4.1.2 Isofootcandle chart

An isofootcandle chart is used to describe the light pattern a luminaire produces. These charts show exact plots or lines of equal footcandle levels on the work plane with the fixture is at a designated mounting height.

An isofootcandle curve for a typical cobra head HPS luminaire is shown below.





GENERAL INFORMATION

TEST DISTANCE	7 METERS
MAX CANDELA	496
MAX CONE	70
MAX VERTICAL PLANE	67.5
MAX CANDELA AT 90°	2
MAX CANDELA AT 80°	16
NADIR FOOTCANDLES	.16
NADIR CANDELA	148

MULTIPLY ALL LUMEN, CANDELA, AND FOOTCANDLE VALUES BY THIS RATIO

$$RATIO = \frac{\text{ACTUAL LAMP LUMENS}}{1000}$$

PHOTOMETRIC TEST IN ACCORDANCE WITH IES GUIDE

LIGHT FLUX VALUES

	LUMENS	PERCENT OF LAMP
DOWNWARD STREET SIDE	437	44
UPWARD STREET SIDE	0	0
DOWNWARD HOUSE SIDE	341	34
UPWARD HOUSE SIDE	0	0
TOTAL	778	78

TEST NUMBER 96121307

MOUNTING HEIGHT CORRECTION FACTORS FOR OTHER THAN 30 FEET.

USE TABLE BELOW OR FACTOR = $\frac{900}{(\text{ACTUAL MH})^2}$

MOUNTING HEIGHT-FEET	20	25	30	35	40	45	50
FACTOR	2.25	1.44	1	.73	.56	.44	.36

Once the CU is determined for the luminaire and mounting height desired, the isofootcandle chart can be used to determine the Minimum Maintained Illumination Value (or other discrete points in the system).

1. Before using the isofootcandle chart, the point at which the minimum maintained illumination value is desired must be determined. For purposes of example, assume 120 feet to the right or left of the current position. This is a longitudinal distance (along the roadway) that will depend on actual pole spacing.
2. Enter the isofootcandle chart at the Luminaire Position point and move left to the correct Ratio of Longitudinal Distance to Mounting Height. In this case the ratio would be 120/40 or 3.0. If required, move up or down to correct for the exact luminaire position in relation to point of interest (no correction for our example). Read the illumination factor directly from the isobar, use interpolation if required. In this case, the value would be 0.0125. This value represents the uncorrected footcandles at the location tested. This information is used to determine the proper spacing and design standards, which are discussed in detail in Chapter 5.

4.1.3 Vertical Light Distributions

Vertical light distributions are divided into three groups, short, medium, and long. Classification is based on the distance from the luminaire to where the beam of maximum candlepower strikes the roadway surface.

Short distribution - The maximum candlepower beam strikes the roadway surface between 1.0 and 2.25 mounting heights from the luminaires

Medium distribution - The maximum candlepower beam strikes the roadway at some point between 2.25 and 3.75 mounting heights from the luminaires

Long distribution - The maximum candlepower beam strikes the roadway at a point between 3.75 and 6.0 mounting heights from the luminaires

On the basis of the vertical light distribution, theoretical maximum spacing is such that the maximum candlepower beams from adjacent luminaires are joined on the roadway surface. With this assumption, the maximum luminaire spacings are:

- Short distribution - 4.5 mounting heights
- Medium distribution - 7.5 mounting heights
- Long distribution - 12.0 mounting heights

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

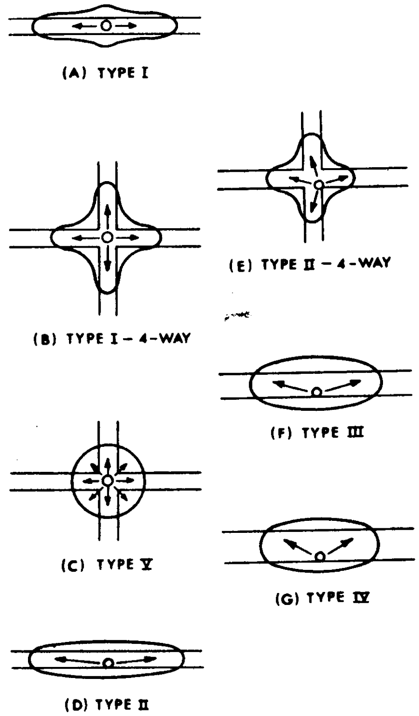
Vertical light distributions are characteristics of the luminaire and should be considered early in the design process.

4.1.4 Lateral Light Distributions

The Illuminating Engineering Society established a series of lateral distribution patterns designated as Types I, II, III, IV, and V. In general, we may describe Types I and V as luminaires mounted over the center of the area to be lighted. Type I applies to rectangular patterns on narrow streets, while Type V applies to areas where light is to be distributed evenly in all directions. Type V and a modified Type I are generally the class of luminaire applied in high mast lighting systems.

Types II, III, and IV are classes of luminaires to be mounted near the edge of the area to be lighted. Type II applies to narrow streets, Type III to streets of medium width, while Type IV applies to wide street applications. These are illustrated below.

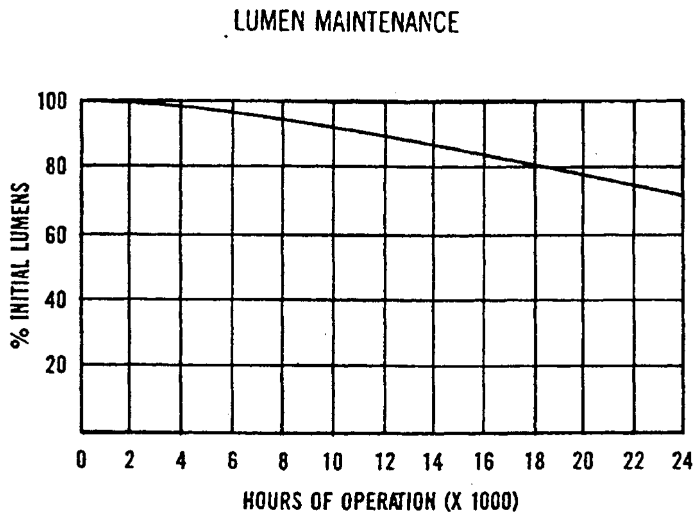
As with vertical light distributions, lateral light distributions are characteristics of the luminaire and should be considered early in the design process.

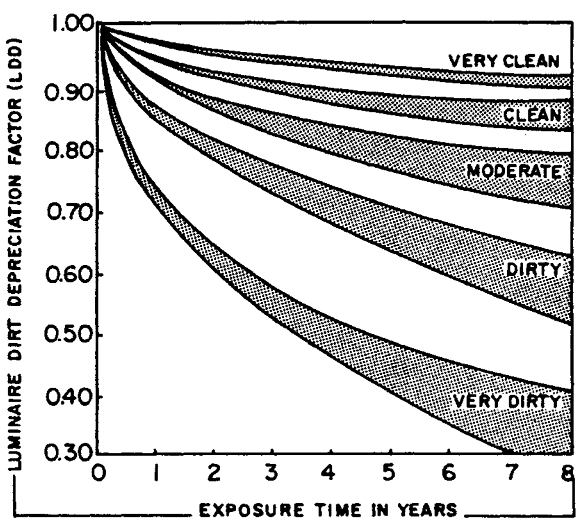


4.2 Lamp and Luminaire Depreciation Factors

In determining the light output for a luminaire the lighting system designer must consider the luminaire light loss factor. The luminaire light loss factor is a combination of several factors including the Lamp Lumen Depreciation (LLD) factor and the Lamp Dirt Depreciation (LDD) factor. The loss factor is applied to the light output of a new luminaire (initial light output) to determine the light output of the luminaire after a fixed period of time (maintained light output). The AASHTO Guide discusses the different aspects of the light loss factor. With these considerations, the actual factor to apply to arrive at a maintained light output value for the luminaire is an educated guess. However, Mn/DOT uses a LLD of 0.80 (for HPS) and a LDD factor of 0.90 (a combined 0.72 factor). The standard light loss factor would represent a loss of 28 percent of the initial lumen output accounting for output loss due to burn time and dirt covering the luminaire. Adjustments to these factors are warranted under special circumstances.

The LLD and LDD factor nomographs are illustrated below.





Select the appropriate curve in accordance with the type of ambient as described by the following examples:

Very Clean – no nearby smoke or dust generating activities and low ambient contaminant level. Light traffic. Generally limited to residential or rural areas. The ambient particulate level is no more that 150 micrograms per cubic meter.

Clean – No nearby smoke or dust generating activities. Moderate to heavy traffic. The ambient particulate level is no more than 300 micrograms per cubic meter.

Moderate – Moderate smoke or dust generating activities nearby. The ambient particulate level is no more than 600 micrograms per cubic meter.

Dirty – Smoke or dust plumes generated by nearby activities may occasionally envelope the luminaires.

Very Dirty – As above but the luminaires are commonly enveloped by smoke or dust plumes

5. LIGHTING DESIGN

In this Chapter you will be introduced to the Mn/DOT roadway lighting design process. The items covered include:

- Lighting Design
- Recommended Footcandle Levels
- Electrical Distribution
- Lighting Design Computer Programs
- Temporary Lighting

This chapter discusses the steps to consider when designing roadway lighting, and preparation of a Mn/DOT roadway lighting design project plan set.

5.1 Lighting Design

Once the decision is made to install new lighting, the design stage can begin. This section describes typical Mn/DOT designs. The design must be appropriate for the site and must provide the level and uniformity of light suggested in the AASHTO guide. The lighting described in this section follows the illuminance method of lighting design, which does not take into account the reflectivity of the pavement. Lighting may also be designed using the luminance method described in the AASHTO Guide, which does take into account the reflectivity of the pavement. Both methods produce satisfactory results.

5.2 Mn/DOT Roadway Lighting Design Process

These steps are arranged in the order in which they are usually encountered in the design process. The context in which they are presented is that of a completely new design to be accomplished by an individual with an adequate engineering background, but less than average lighting experience.

DESIGN STEP	DESIGN CONSIDERATION
1. Assess the Facility to be Lit; Determine the minimum footcandle levels	• Perform preliminary design checklist to determine specific lighting needs. Use the checklist on the following pages. • Determine the facility or functional classification of the roadway you are designing for. Use the recommended footcandle level table to determine minimum footcandle levels and uniformity ratios.

5.2.1 Lighting Design Checklist

T.H__________________at_________________________ Date_______________________________

Final Design Squad______________________________ S.P.________________________________

City ______________________________ County____

Field Reviewer_____________________ Speed Limits:______________________________________

Utilities________________________ Power Company ____

Funding ____

LIGHTING DESIGNER QUESTIONS

1. Alignment of traffic lanes or number of lanes: _______________________________________
2. Are there retaining walls or guardrail in the area:_____________________________________
3. Any ground mount or overhead signing: ____
4. Any overhead power lines: ____
5. Width of shoulders (include median shoulders): ______________________________________
6. Any sidewalks/paths: ____
7. What is the topography (slopes, grades, etc.): _______________________________________
8. Urban or rural:____
9. Business or residential: ____
10. Any intersecting roadways: ____
11. Describe the basic geometry: ____
12. Speed: ____
13. Any ambient lighting: ____
14. Traffic signals or beacons: ____
15. Median Barrier: ____
16. Any non-standard or ornamental lighting required: ___________________________________
17. Do we need to remove or relocate any lighting: _____________________________________
18. Do we need to relocate any utilities: ____
19. Which type of lighting system is being installed ____________________________________
20. High Mast Lighting

    Are there nearby residential areas? ____

    Foundation recommendations are required for the bases, date request sent: _________________
21. Vertical Mount Lighting

    Is there sufficient R/W? ____

22. Standard Cobra Head/Shoebox Lighting

    Cutoff or shallow glass: ____

23. Are there bridges involved: ____

    Bridge nos: ____

    Air obstruction lights required: ____

    Navigation lights required: ____

24. What Configuration and type of Lighting System is being proposed

    Complete Interchange_________________

    Partial Interchange____________________

    Continuously Lit__________________

25. Will maintenance agreement with local agency need to be in writing?_____________________________

5.2.2 Lighting Design Issues:

The following issues are associated with the Lighting Design Checklist and are intended to provide background on what the impacts of various lighting design issues are based on the site analysis.

1. A curve could mean the difference between partial and continuous lighting. The number of lanes will affect pole height and wattage or the need to light both sides.
2. Lighting anchorages may be needed in retaining walls. The height of the wall also affects pole height. Poles may be placed closer to roadway if guardrail is in place.
3. Power may be required to light sign. Lights should not be placed too close to sign as this may reflect on sign and affect visibility.
4. Should remain a safe distance from power lines (20 feet is recommended).
5. Affects pole height and wattage.
6. Indicates pedestrians and higher footcandle levels may be desirable.
7. Steep grade may require higher poles.
8. Urban areas generally have continuous lighting while rural areas do not. Also light pollution and light trespass are issues in urban areas.
9. Light trespass is a larger issue in residential areas.
10. Is additional lighting needed on cross street and if so, will an agreement be needed with another entity.
11. None
12. Lighting may not be required if speed limit is below 40 mph.
13. Ambient lighting can reduce the need for lighting.
14. A combined signal and lighting pad (SOP) may be required. Lights on signals will affect spacing.
15. Lights may need to be placed on barrier if there is no room on the outside. Generally, lights should not be placed in median because they are hard to maintain.
16. Mn/DOT does not stock parts for this type of lighting, therefore it is maintained by a municipality or county.
17. The age of the system or maintenance problems would affect removal.
18. None
19. System should match those on either side of project.
20. Will shields keep light out of residential areas?
21. Pole setbacks are 33’ to 36’ from edge of travel roadway.
22. Cutoffs are used near airports.
23. Navigational lights should have a separate SOP, normally 120/240v metered. Utility companies do not have a rate for air obstruction lights, so they must be metered.
24. None
25. None

5.2.3 Recommended Footcandle Levels

Minimum Average Maintained Illuminance (Eh) and Maximum Uniformity Ratios by Facility Classification and Pavement Classification

Roadway and Walkway Classification		R1		R2 & R3		R4		Uniformity avg/min
		Foot-candles	Lux	Foot-candles	Lux	Foot-candles	Lux	
Freeway		0.6 - 0.8	6 - 9	0.6 - 0.8	6 - 9	0.6 - 0.8	6 - 9	3:1 to 4:1
Expressway	Commercial	0.9	10	1.3	14	1.2	13	3:1
	Intermediate	0.7	8	1.1	12	0.9	10	
	Residential	0.6	6	0.8	9	0.7	8	
Major	Commercial	1.1	12	1.6	17	1.4	15	3:1
	Intermediate	0.8	9	1.2	13	1.0	11	
	Residential	0.6	6	0.8	9	0.7	8	
Collector	Commercial	0.7	8	1.1	12	0.9	10	4:1
	Intermediate	0.6	6	0.8	9	0.7	8	
	Residential	0.4	4	0.6	6	0.5	5	
Local	Commercial	0.6	6	0.8	9	0.7	8	6:1
	Intermediate	0.5	5	0.7	7	0.6	6	
	Residential	0.4	3	0.4	4	0.4	4	
Alleys	Commercial	0.4	4	0.6	6	0.5	5	6:1
	Intermediate	0.3	3	0.4	4	0.4	4	
	Residential	0.2	2	0.3	3	0.3	3	
Sidewalks	Commercial	0.9	10	1.3	14	1.2	13	3:1
	Intermediate	0.6	6	0.8	9	0.7	8	4:1
	Residential	0.3	3	0.4	4	0.4	4	6:1
Pedestrian Ways and Bicycle Lanes		1.4	15	2.0	22	1.8	19	3:1
Rest Areas	Entr and Exit Gores Interior Roadways	--	--	0.6 - 0.8	6 - 9	--	--	3:1 to 4:1
	Parking Areas	--	--	1.0	11	--	--	3:1 to 4:1

R1 = cement/concrete, R2 = asphalt/gravel, R3 = asphalt/rough texture (typical highway),
R4 = asphalt/smooth texture

Roadway and Walkway Classification

(a) Freeway. A divided major highway with full control of access and with no crossings at grade.

(b) Expressway. A divided major arterial highway for through traffic with full or partial control of access and generally with interchanges at major crossroads. Expressways for non-commercial traffic within parks and park like areas are generally known as parkways.

(c) Major. The part of the roadway system that serves as the principal network for through traffic flow. The routes connect areas of principal traffic generation and important rural highways entering the city.

(d) Collector. The distributor and collector roadways serving traffic between major and local roadways. These are roadways used mainly for traffic movements within residential, commercial, and industrial areas.

(e) Local. Roadways used primarily for direct access to residential. commercial, industrial, or other abutting property. They do not include roadways carrying through traffic. Long local roadways will generally be divided into short sections by collector roadway systems.

(f) Alleys. A narrow public way within a block, generally used for vehicular access to the rear of abutting properties.

(g) Sidewalks. Paved or otherwise improved areas for pedestrian use, located within public street right of way, which also contain roadways for vehicular traffic.

(h) Pedestrian Ways. Public sidewalks for pedestrian traffic generally not within rights of way for vehicular traffic roadways. Included are skywalks (pedestrian overpasses), subwalks (pedestrian tunnels), walkways giving access to park or block interiors and crossings near centers of long blocks.

(i) Bicycle Lanes. Any facility that explicitly provides for bicycle travel.

Area Classifications

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

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

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

DESIGN STEP	DESIGN CONSIDERATION
2. Selection of Equipment: Light Source (Luminaire Equipment) and Mounting Height (Pole Equipment)	• The type of light source selected determines the lumen output, efficacy, energy requirements, lamp life, color, optical controllability, temperature sensitivity, and environmental effects. The type of light source selected in this step will, of course, affect the rest of the design process. The various light sources used in Mn/DOT roadway applications are discussed in Chapter 3. • Determine desired pole equipment. See Chapter 3 and 4 for Mn/DOT pole equipment. If considering high mast lighting, consider sensitivity to residential area. • Light source size and mounting height are directly related; therefore selected as a combination rather than individually. Information concerning utilization of the actual light output of a given light source used in a specific luminaire at a particular mounting height can be determined from photometric data available from the various lighting equipment manufacturers. An example of one such set of data is shown in Chapter 4. • The correct matching of mounting height with light source size should result in meeting minimum illumination and uniformity criteria set forth in the AASHTO guide while being responsive to economic and safety criteria. • Thus far in the design process, a lamp luminaire combination has been selected and a tentative mounting height has been chosen. The next step is to select the lateral and longitudinal mounting dimensions. The lateral dimension, or the distance from the roadway edge to the luminaire, is mainly governed by the need to place the luminaire over or near the roadway edge, yet meet guidelines for clear zone. Safety considerations and right-of-way restrictions require the use of various length mast arms in order to correctly locate the luminaire support while leaving the luminaire at its desired position. Longitudinal spacing is determined in the next step.
3. Determine Pole Spacing	• The first three steps in the design process were primarily judgment decisions related to the selection of light source, luminaire type, and mounting height. In the next step, the luminaire longitudinal spacing is calculated by using the following equation: Luminaire Spacing = $\frac{LL \times CU \times LLD \times LDD}{Eh \times W}$ Where, LL = Initial lamp lumens CU = Coefficient of utilization LLD = Lamp lumen depreciation factor (0.8) LDD = Luminaire dirt depreciation factor (0.9)

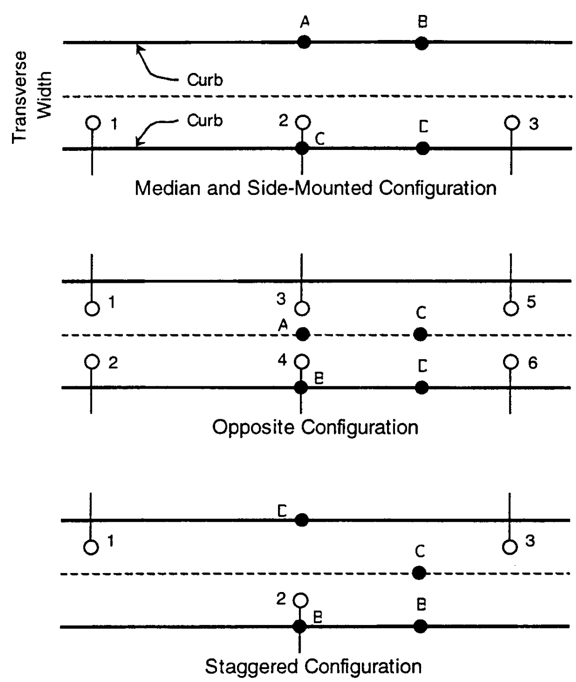
DESIGN STEP	DESIGN CONSIDERATION
	Eh = Average maintained level of illumination W = Width of lighted roadway • As this formula is usable in both the U.S. and the SI system of measures, either units can be used. The resultant luminaire spacing will of course be obtained in units corresponding to the system units used. • The lamp lumen output (LL) is determined in Step 2 using the photometric data for the light source the designer selected. • Coefficient of utilization (CU) is determined using the utilization curves specific to the source and roadway characteristics. See chapter 4 for an example. • Lamp lumen depreciation factor (LLD) for Mn/DOT designs is 0.80. • Luminaire dirt depreciation factor (LDD) for Mn/DOT designs is 0.90. • The average maintained level of illumination (Eh) is determined in Step 1 from the table in section 5.2.3. • The roadway width (W) is determined from the curb to curb or pavement edge to pavement edge lateral distance of the system you are designing. • The following example calculates the maximum pole spacing given the following conditions: LL = 27,500, CU = 0.26, LLD = 0.80, LDD = 0.90, Eh = 0.60, and W = 36. Therefore the maximum spacing would be approximately 240 feet. • Refer to the illustrations of standard pole locations in section 5.2.2 for standard pole spacing for common situations.
4. Check Design Accuracy	• The luminaire spacing equation as defined in the previous design step is based on the average level of illumination or lumens per square foot or square meter on the area of roadway under consideration. This establishes the quantity of illumination. Up to this point, nothing has been calculated regarding the quality of illumination. The uniformity ratio relating the average illumination level to the point of minimum illumination is used as one way of specifying the quality of lighting. Because the average level of illumination is already defined by the design process (Eh), the next step involves finding the minimum point of illumination. This can be determined by inspection of the isofootcandle diagram contained in photometric data for the particular luminaire. Referring to the isofootcandle diagram in chapter 4.1.2, the lines in this curve define the level of illumination that will occur at various mounting heights from the luminaire. Several correction factors must be applied to the values of these lines before they are in a usable form. These are summarized below: • Correction for light source size. The values in the isofootcandle diagram are based on 1000 bare lamp lumens. Thus, for a 27,500

DESIGN STEP	DESIGN CONSIDERATION
	lumen lamp, each of the curve values would need to be multiplied by a factor of 27.5.

- Correction for mounting height. The curve values are typically shown for one mounting height. Because the level of illumination is inversely proportional to the distance from the source, correction factors are given for adapting the curve values for various mounting heights.
- Correction for maintenance factors. In the luminaire spacing equation, factors for lamp lumen depreciation (LLD) and luminaire dirt depreciation (LDD) are used to convert the initial illumination values into maintained illumination values or that which is expected to exist after the system has been operating for some period of time. Because this maintenance correction factor is used in calculating the average illumination, it must also be used in finding the value for minimum illumination.
- Thus, the above correction factors make possible the use of the following uniformity equation:

$$\text{Uniformity Ratio} = \frac{\text{Average Maintained Illumination Value}}{\text{Minimum Maintained Illumination Value}}$$

- Once it is understood how these values are defined, the remaining step is to locate the point of minimum illumination expected to occur on the roadway. Depending on the roadway width, mounting height, type of luminaire, and mounting configuration, the minimum point will usually occur at one of several typical locations. These locations are shown in the following figure.



DESIGN STEP	DESIGN CONSIDERATION
	• After checking the illumination at each of the anticipated low points, the minimum illumination is used to determine the uniformity ratio. If this value is within the acceptable range for the particular area and type of roadway, the illumination design is acceptable. Example: Compute the uniformity ratio at the minimum point (applying adjustment factors as needed) which is located between two luminaires. Assume Average Maintained Illumination Level is 0.6 footcandles and the Maximum Uniformity Ratio is 3:1, 250W HPS, standard Mn/DOT maintenance factors, assume the minimum point of illumination from the isofootcandle chart results in an uncorrected illumination of 0.0125, correct for mounting height (use photometric data), add adjacent luminaire influence if applicable. • Lumens = 27,500 (see Appendix F) • LLD = 0.8 (Mn/DOT standard value) • LDD = 0.9 (Mn/DOT standard value) • Correction Factor (CF) for Mounting Height (MH) = 0.56 (40' pole instead of 30', see photometric data in Appendix F) • Point of interest is influenced by adjacent luminaire • Average Maintained Illumination level = 0.6 (Table in section 5.2.3) (27,500/1000)(0.8)(0.9)(0.56)(0.0125 + 0.0125)= 0.277 footcandles • Uniformity Ratio: 0.6 / 0.277 = 2.13 (less than 3:1, adequate design) • If the calculated uniformity ratio exceeds the given value, the design process should be repeated using other combinations of luminaire distributions, socket setting in the same luminaire, different mounting heights, luminaire types, and configurations. One step is to decrease the luminaire spacing; however, this tends to increase the average level of illumination above the desired minimum value. In this situation, an increase in mounting height may be a better choice in attempting to improve uniformity, as the increased height will cause the light to be more evenly spread out. Luminaire type and distribution, and spacing configuration may also be altered. For example, if the far side of the roadway in a one-side system is too dark, the use of either a staggered configuration or a luminaire type with a wider light distribution would be possible solutions. The use of electronic computers in lighting design greatly speeds up this process
5. Determine Source of Power	• The lighting designer must meet and discuss the source of power with the power company. Document all decisions made. • Use the following checklist to determine the source of power.

5.2.4 Source of Power Checklist

Feed Point #____________

☐New ☐Inplace

FIELD WALK / POWER COMPANY MEETING

CHECKLIST

T.H________________at_______________________ Date_______________

Designer_____________________________________ S.P._______________

Pwr.Co. Field Rep. Name, Telephone, Address __________________________

____

Power Company ____

Proposed Letting Date ____

* All correspondence with power company need to be in writing.

1. TYPE OF CONSTRUCTION AND POSSIBLE IMPLICATIONS

Discuss construction staging, timeline of project and proposed letting date.

New lighting system

Modification of existing system

Replacement of existing system

Temporary lighting system

2. TYPES OF SERVICE

Use in place service:

Overhead or Underground

Pole Mounted or Pad, Channel Mounted or Pad Mounted

120/240 Volt or 240/480 Volt

Install new service:

Temporary service needed for staging

Permanent service

Overhead or Underground

Pole Mounted or Pad: Channel Mounted or Pad Mounted (preferred)

120/240 Volt or 240/480 Volt (preferred), (discuss transformer needs)

3. DEFINE WHO IS RESPONSIBLE FOR CONSTRUCTION/MAINTAINENCE OF VARIOUS PARTS OF INSTALLATION

Knockdowns__________________Underground Cable/Conduit_________________

4. LOCATION OF SERVICE – TOPOGRAPHY OF AREA

Describe quadrant and define approx. location of transformer/pole/pad (face door away from road).

Metered or Unmetered

Agency paying power costs decides – refer to power co. policy.

Document all decisions in writing with the appropriate agency.

5. SIGNALS

Is signal system involved w/project?

If so, coordinate activities:

In Duluth

TMC Cameras

ANTICIPATED LIGHTING SYSTEM LOAD:____________Amps

Identify size of conductors (#2, #6, #0, etc) needed for power to SOP: ______________________

6. METER ADRESS / OR TRANSFORMER # : ____

Confirm with letter to power company.

Billing Address: ____

7. AGENCY RESPONSIBLE FOR PAYING MONTHLY POWER COSTS:

Document all decisions in writing with the appropriate agency.

8. AGENCY RESPONSIBLE FOR PAYING MONTHLY POWER COSTS FOR TEMPORARY LIGHTING:

Document all decisions in writing with the appropriate agency.

9. ANY ADDITIONAL COSTS OR CONNECTION CHARGES TO BE CHARGED BY POWER COMPANY (CONTRACTOR TO GET ESTIMATE):

Document all decisions in writing with the appropriate agency.

5.2.5 Source of Power Issues

1. If major roadway construction is involved, utility lines may need to be relocated. This can affect the location of a SOP for temporary lighting. When modifying a lighting system power to all units should be maintained at all times. Also, when replacing a system the old system must remain operational at all times.

2. Check condition of cabinet and pad if using in place service. Also check for correct voltage.

New Service: To save installation costs, combine same location service for temporary and permanent. Have permanent cabinet installed during early stages if possible. Generally permanent service will be pad mounted and temporary will be pole mounted.

A 120/240 volt system is used for isolated overhead signs, city feedpoints and state feed points with few lights or when 240/480 volt system is not available. 240/480 volt system is preferable for Mn/DOT systems.

3. During construction the contractor is responsible for all maintenance of temporary and in place lighting until Mn/DOT has accepted the new system. After final acceptance Mn/DOT is responsible for all maintenance on State systems (relamping may be done by utilities in some cases). On systems owned by another agency Mn/DOT may maintain knockdowns, underground cable, or service equipment, however this is not desirable.

4. The decision to meter or not is based on whether or not the Utility providing power will relamp Mn/DOT luminaires. Mn/DOT will be performing the minor maintenance, then power should be metered.

5. If signals are involved a combined pad with all signal and lighting cabinets may be desirable. 240/480 volts will be needed for lighting with a step down transformer for 120/240 volt signal power.

6. Mn/DOT should establish an address for the SOP and confirm this with the utility.

7. None

8. Contractor should pay power when SOP is metered. Contractors have no agreements with utilities to pay on a per light basis.

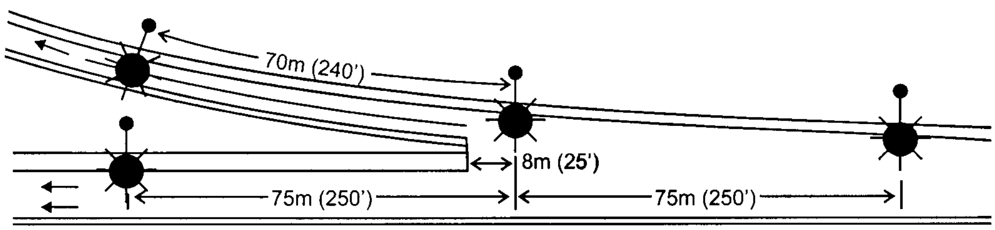
9. These costs should be shown in estimated quantities and verified by contractor.

DESIGN STEP	DESIGN CONSIDERATION
6. Lay Out Lighting System	• Utilize the pole spacing determined in Step 3 taking into account decision points such as intersections, gore areas, overhead signs (reflection issues), etc. See typical pole placement illustrations in section 5.2.6 for common decision points. Also consider above and below ground utilities, overhead obstructions. • The following guidance is provided concerning exact location of lighting poles: The exact locations of light poles may be adjusted to avoid obstructions encountered in the field. Such items as solid rock, power lines, slopes, existing guard rail, etc., may make it necessary or desirable to locate the pole differently than is indicated in the plans. The project engineer may stake the poles up to 10 feet along the direction of the roadway from the locations indicated in the plans. If a farther change is required, the project engineer should consult with the lighting system designer to determine if such a change requires changing the placement of other light poles in the system. The plans typically place the poles 19 - 23 feet behind the edge of the traveled roadway for davit-type mast arms and 33 - 36 feet from the edge of the traveled roadway for tenon-type mount assemblies. If this distance cannot be achieved, contact the State Lighting Engineer. If a guardrail or noise wall exists at the location and is not indicated in the plans, light poles should be placed behind it if possible. Clearance between the back of the guardrail and the front of the light pole should be at least 2 feet. Poles should not be closer than 20 feet in any direction from power lines. If 20 feet cannot be maintained, contact the power company. Poles should not be closer than 25-50 feet in any direction from overhead signs.
7. Lay Out Wiring System and Conduit System	• Mn/DOT typically uses 3/C #4 Direct Buried Armored Cable. • Use 3" Rigid Non-Metallic Conduit (NMC) Schedule 80 under traveled roadways. • Use 1½ RSC for bridges, retaining walls, and Jersey barriers with 1/C #4 wire. • 1½ " Non-Metallic Conduit (NMC) allowed in median barriers. • Determine the conduit requirements based on the current wiring configuration. • Follow 40 percent fill rule for conduit requirements where required. • Determine service cabinet based on lighting system requirements.
8. Calculate Voltage Drops	• To determine the correct electrical components, a voltage drop calculation should be conducted. The procedure to perform voltage drop calculations is illustrated in the section 5.4.
9. Iterate steps 7 and 8	• Perform special wire sizing (if required) and conduit requirements based on voltage drop limitations, continue until a viable wiring system and conduit layout is achieved.

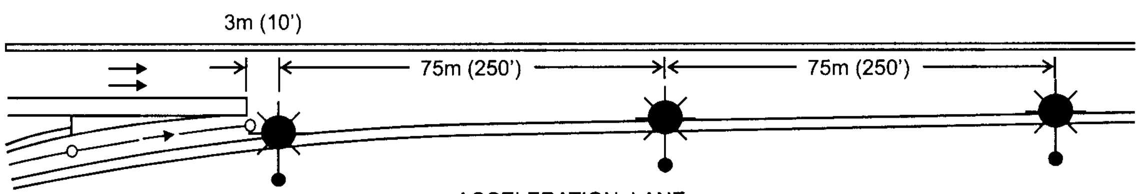
DESIGN STEP	DESIGN CONSIDERATION
10. Complete Wiring Diagram, Service Cabinet, and Number Poles	• Locate service cabinet with considerations for: maintenance (can a vehicle get to the location, can all the lights be seen from the cabinet); outside the clear zone; and approximately equidistance to all wiring to minimize voltage drops.
11. Determine Salvage and Removal Items	• Obtain lighting exhibits or as built in place plans from lighting system owner. • Conduct field review of new system. • The district lighting engineer will provide guidance on salvage items.
12. Determine Temporary Lighting Needs	• Generally, if the system under construction was previously continuously lit, provide temporary lighting. • Temporary lighting is designed to the same standards as permanent lighting.
13. Determine Quantities	• Reference Mn/DOT 2000 Specifications Book for a listing of standard pay items at the end of section 2545. • For non-standard pay items use the following Mn/DOT website: http://www.dot.state.mn.us/stateaid/bams-index.html
14. Finish Plan Set Layout	• See following sections on plan preparation. • A copy of the 35W plan set, which is a large lighting plan set, is located in Chapter 7 for your reference.

5.2.6 Guidelines for the Placement of Luminaires at Typical Decision Points

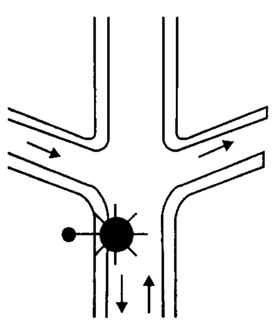
The following graphics come from the Mn/DOT Traffic Engineering Manual. The graphics illustrate guidelines for the placement of lighting poles at common geometric situations. Standard placement of conduit is also illustrated in the later figures.



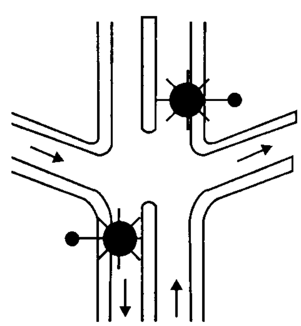
DECELERATION LANE



ACCELERATION LANE



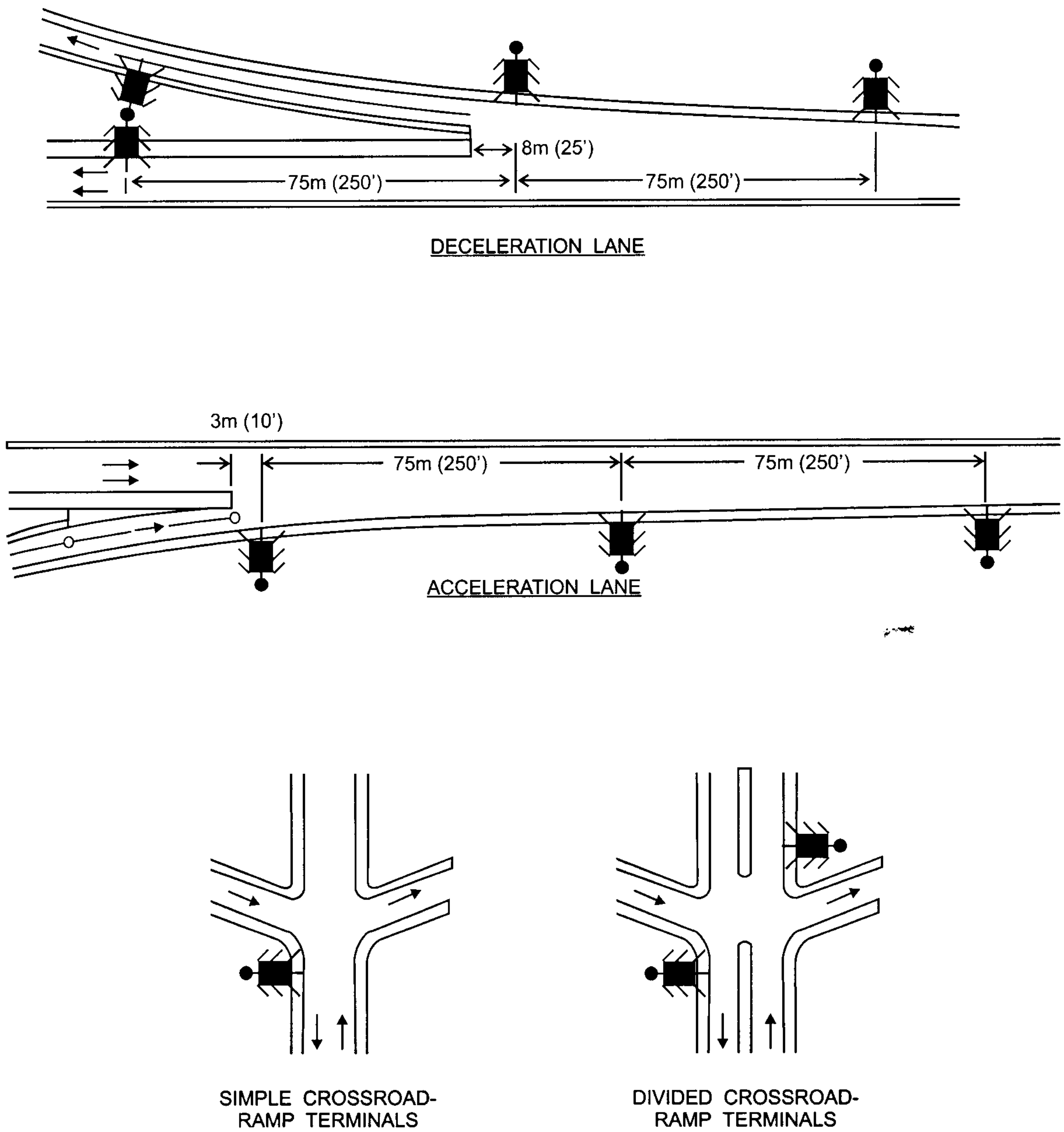
SIMPLE CROSSROAD-
RAMP TERMINALS



DIVIDED CROSSROAD-
RAMP TERMINALS

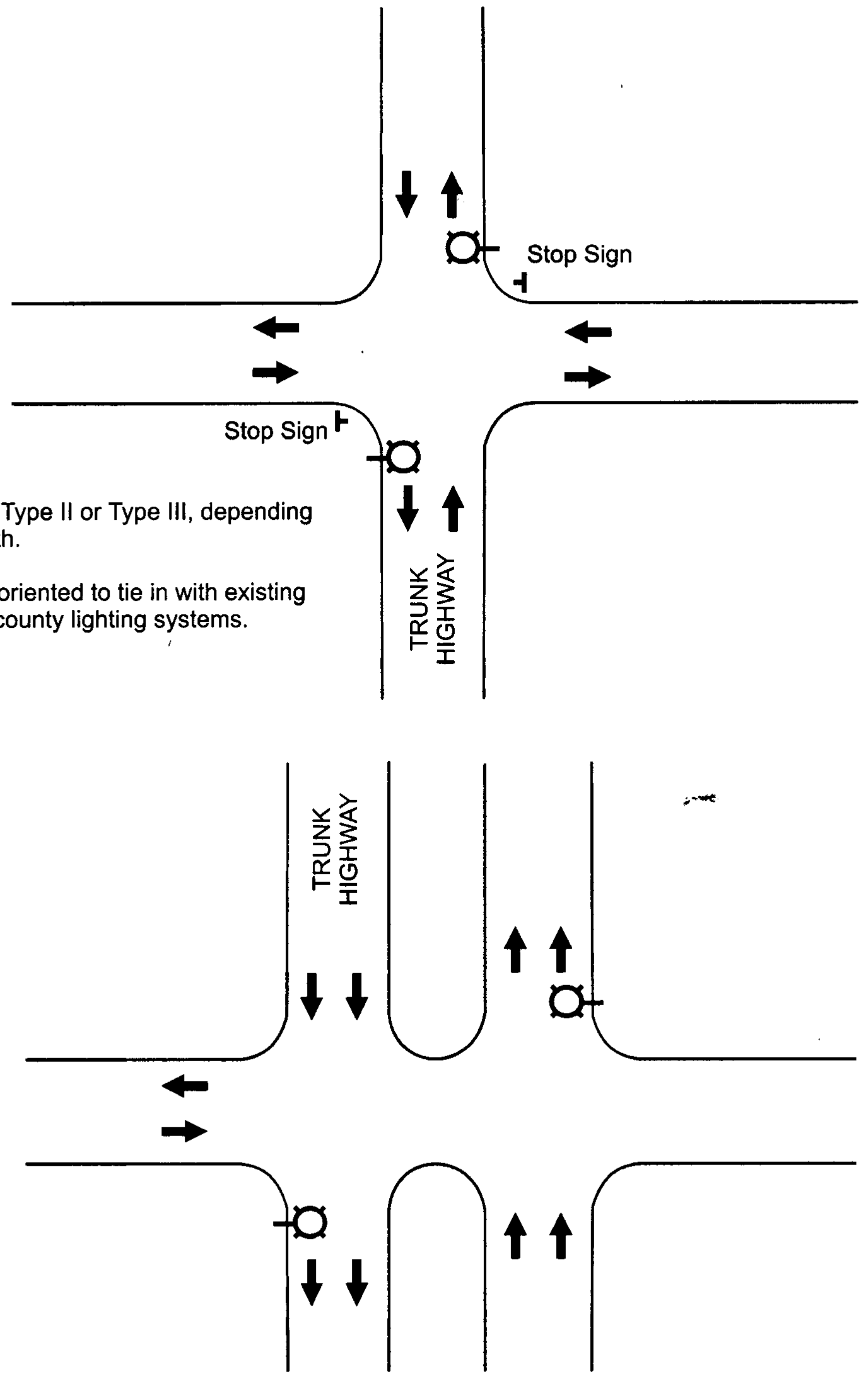
Typical Luminaire Locations for Partial Interchange Lighting with Davit Arm Poles

Assumes: 40’ mounting height, 250w HPS, Cobra Head System



Typical Luminaire Locations for Partial Interchange Lighting using Vertical Mount Poles

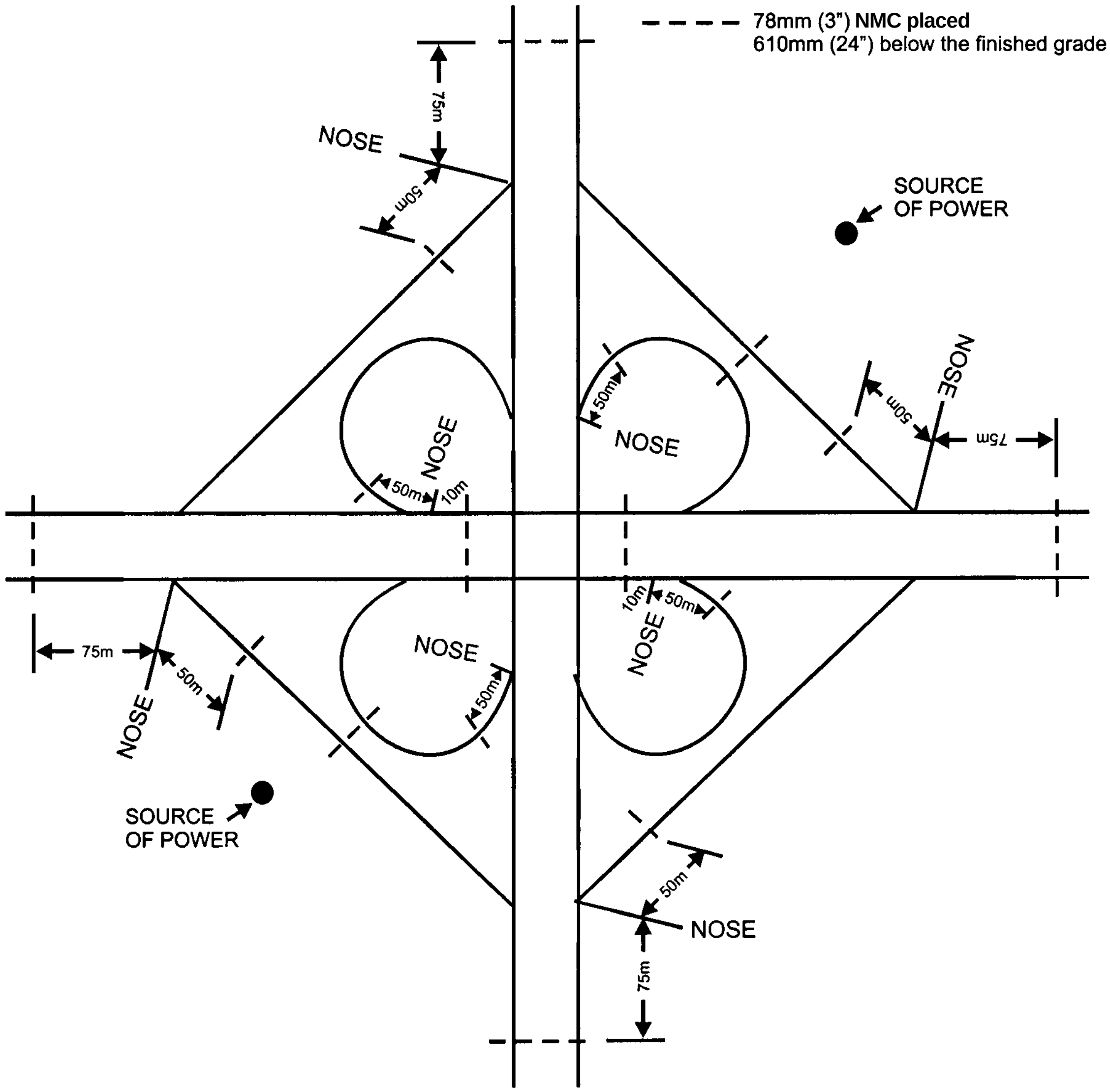
Assumes: 45' mounting height, 250w HPS, Vertical Mount System



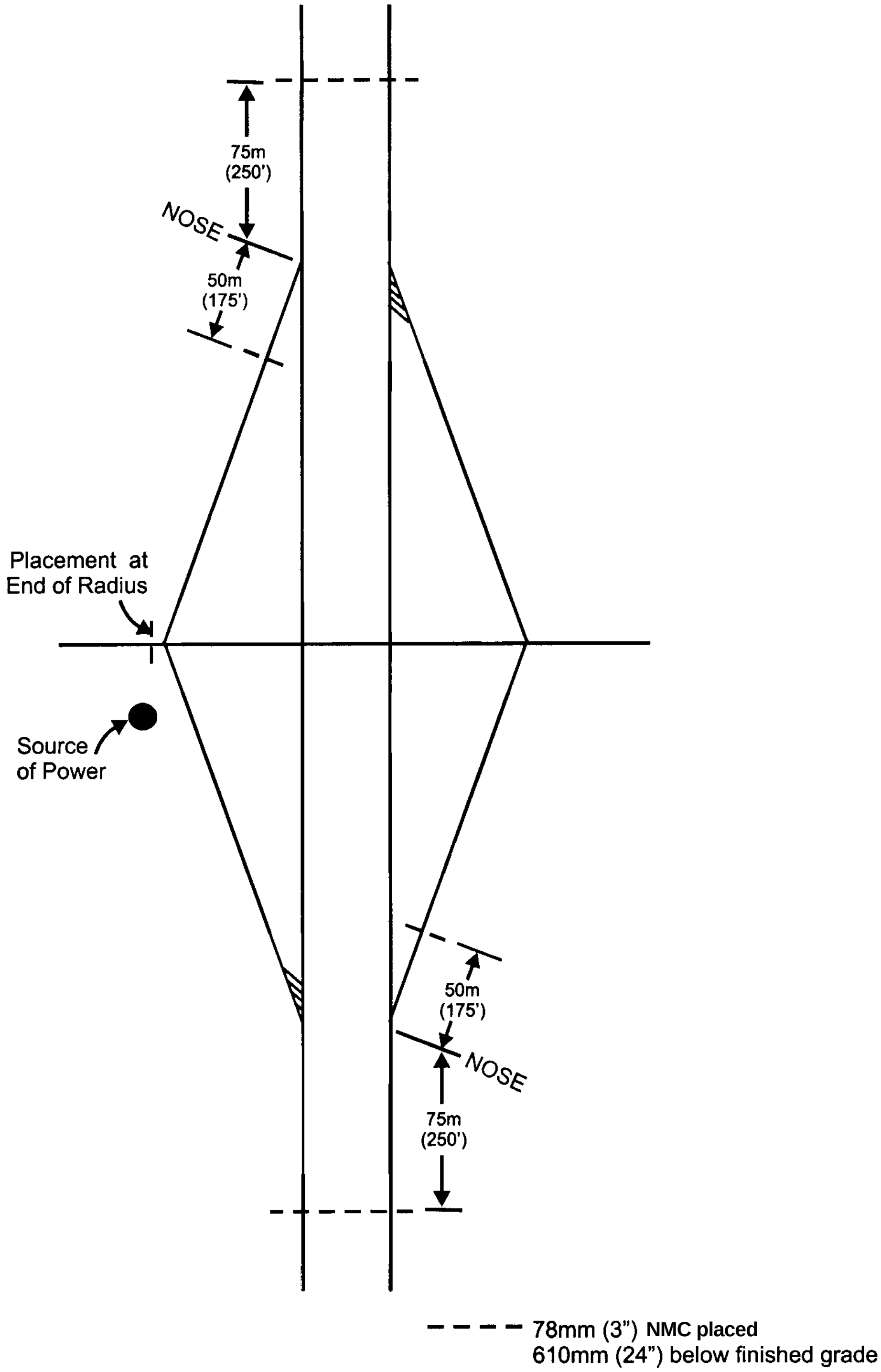
NOTE:
Luminaires shall be Type II or Type III, depending on the roadway width.

Luminaires may be oriented to tie in with existing or proposed city or county lighting systems.

Standard Illumination Plan for Intersections



Typical Conduit Placement for Cloverleaf Interchanges (note metric units)



Typical Conduit Placement for Diamond Interchanges (note metric units)

5.3 Plan Preparation

The Lighting Unit in the Office of Traffic, Security & Operations, the district traffic office, or consultants design the lighting system and draft the plans for lighting systems that will be installed under a state contract.

The lighting plans should include a title sheet showing the project location and description, the state and federal project number(s), the area and job number(s), appropriate signature lines, roadway design values, legends and symbols, a list of scales, and a plan index. Appropriate symbols are contained in the Mn/DOT road design "Technical Manual".

When a municipality is participating in the cost of installing or maintaining the lighting system, the title sheet should include a signature line for the appropriate authority from the municipality. The district traffic engineer should submit a final copy of the plan to the municipality for review and approval before the project is let.

Also included in the lighting plans should be a statement of estimated quantities. Normally, the lighting system pay items are itemized showing items for conduit, cable, light standards, etc. Any notes pertaining to any of the items in the estimated quantities should be included on the estimated quantities sheet. If a lighting system is paid for as a lump sum (this is discouraged), the plans should include a tabulation of the individual items that are part of the lump sum.

It is sometimes desirable to include provisions for conduit, hand holes, and junction boxes as part of the roadway project and to have the rest of the lighting plan as a separate project.

Detail sheets should show pole details for each type of pole used in the project, details for mounting the service panels and photoelectric controls, any special anchorage details, conduit attachment to bridges for underpass lighting, and any other necessary details.

Each layout sheet should include a layout of the roadway and locations of light standards, cable, service panels, conduit, junction boxes, and hand holes. All of these items should be properly labeled and identified. A tabulation should list stations, locations, and types of lighting units.

All luminaires and sign lights indicated in the plans should be labeled with a unique number. Numbers for roadway, tunnel, and underpass luminaires should consist of the feedpoint number above a number indicating the luminaire on that feedpoint. The luminaires should be numbered consecutively. Sign light numbers should consist of the feedpoint number above a letter indicating the sign light on that feedpoint and should be numbered from left to right separately for signs facing each direction of travel on the roadway.

The plans should include wiring diagrams to detail the wiring of the lighting circuits and to show wire sizes.

Information sheets should be included when appropriate.

Contact must be made with the appropriate power company to establish source of power(s). The power company may require extra equipment and have an electrical service charge. All communications with the power company shall be confirmed in writing.

5.3.1 Required Sheets

Standard lighting design plans shall contain at least the following sheets:

Sheet	Stand Alone Lighting Design Plan	Lighting Plan is a Component of a Larger Plan Set
Title Sheet	✓	
Statement of Estimated Quantities	✓	
Tabulation of Estimated Quantities		✓
Details	✓	✓
Lighting Plan Layout	✓	✓
Utilities	✓	*
Traffic Control Plans (High Mast Lighting only)	✓	✓

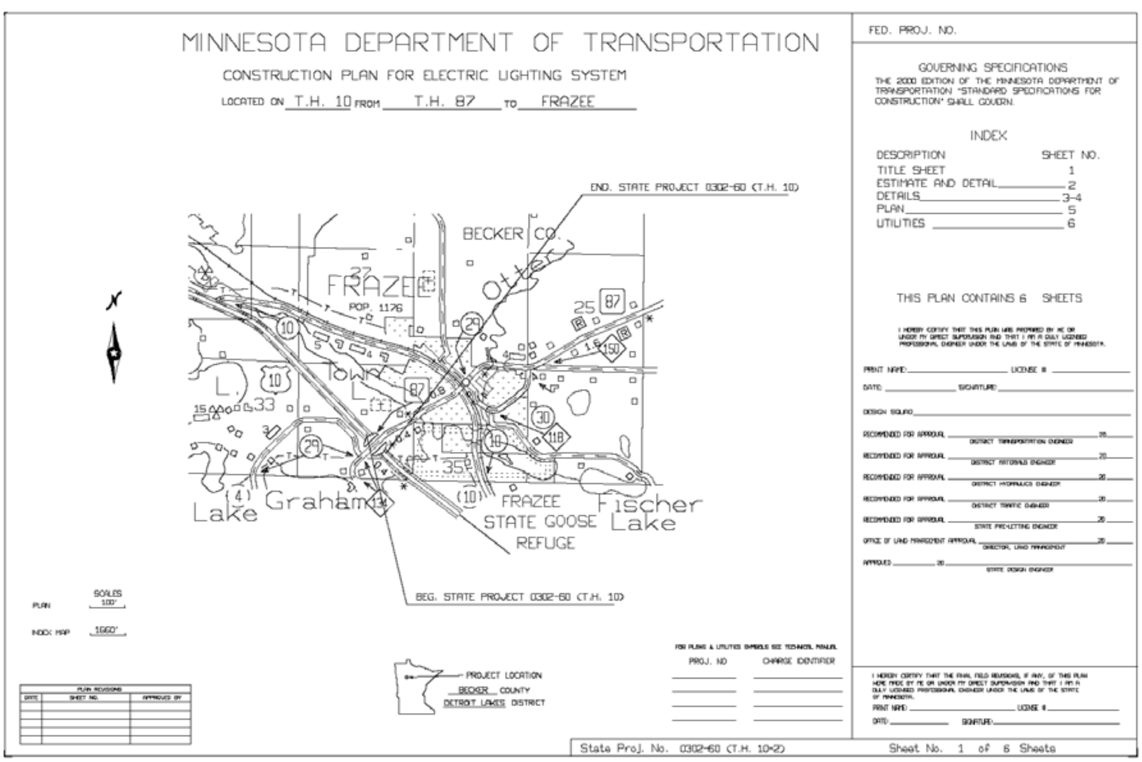
***** Utilities would be included in the overall plan set

Sheet Size and Scale

Final lighting plans should be prepared on 11" x 17" plan sheets. The original title sheet shall be of vellum composition. The scale for the lighting plan does not have to follow the road construction project. Each sheet of the plan must be properly identified in the lower right corner (State Project or State Aid Project Number and Sheet XX of XX).

5.3.2 Title Sheet

The title sheet is required for all stand alone lighting plans. It includes information such as the title block,



project location, governing specifications, etc.

For Mn/DOT lighting unit designed stand alone lighting projects the title sheet is signed by the designer (a licensed professional engineer), but all subsequent sheets utilize an electronic signature block. See the Frazee plan set at the end of this chapter to illustrate this.

If the lighting plan set is part of a larger plan set, a signature block similar to the following is required on all lighting plan sheets.

I hereby certify that sheets___ to ___ have been prepared by me or under my direct supervision and I am a duly licensed professional engineer under the laws of the State of Minnesota.
____
JOE DESIGNER
Date____________________LIC. NO. 12345

The title sheet should include the project location and description, the state and federal project number(s), the area and job number(s), appropriate signature lines, roadway design values, legends and symbols, a list of scales, and a plan index.

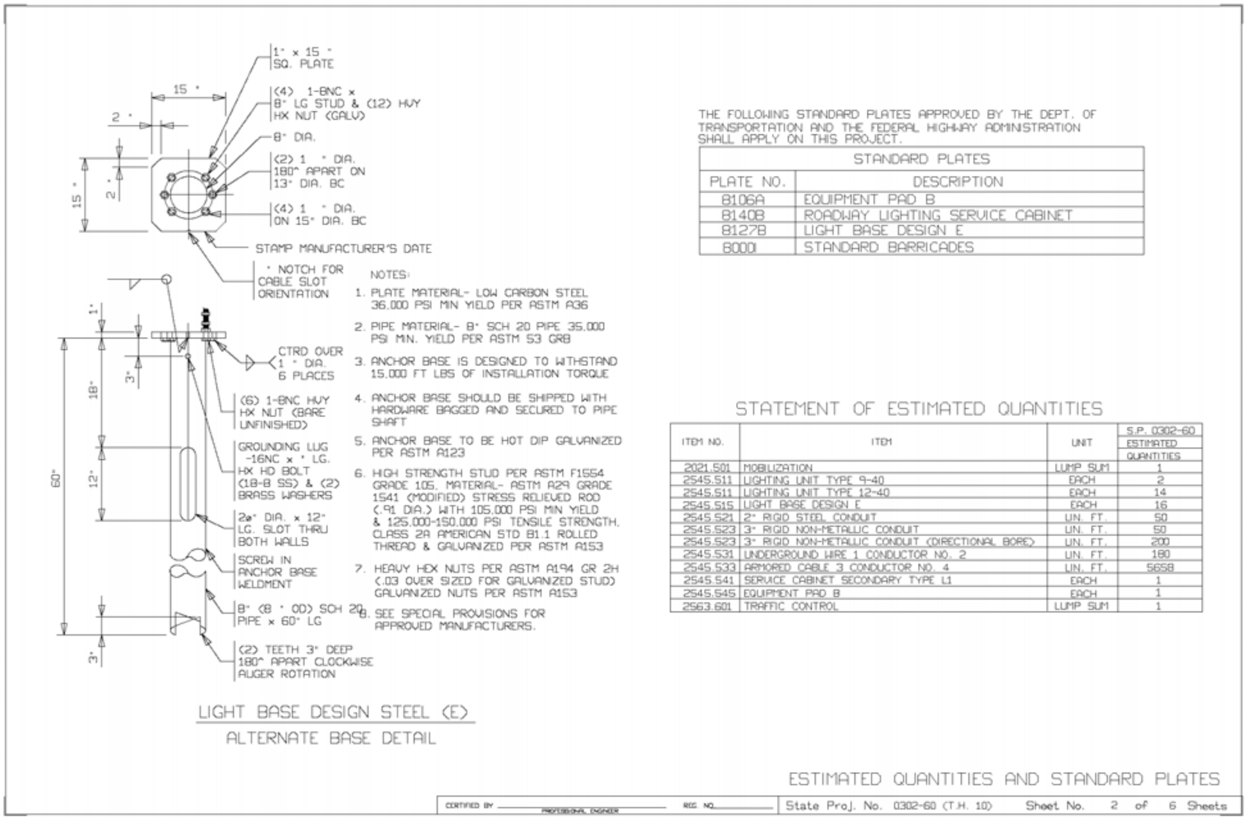
When a municipality is participating in the cost for installing or maintaining the lighting system, the title sheet should include a signature line for the appropriate authority from the municipality. The District Traffic Engineer should submit a final copy of the plan to the municipality for review and approval before the project is let.

5.3.3 Quantity Sheet

Also included in the lighting plans should be a statement of estimated quantities, or tabulation of quantities if part of a larger project. Normally, the lighting system pay items are itemized showing items for conduit, cable, light standards, etc. Any notes pertaining to any of the items in the estimated quantities should be included on the estimated quantities sheet. If a lighting system is paid for as a lump sum (this is discouraged), the plans should include a tabulation of the individual items that are part of the lump sum.

The URL for Mn/DOT standard plates is:

http://www.dot.state.mn.us/tecsup/splate/index.html#index



NOTES:

1. PLATE MATERIAL- LOW CARBON STEEL 36,000 PSI MIN YIELD PER ASTM A36
2. PIPE MATERIAL- 8" SCH 20 PIPE 35,000 PSI MIN. YIELD PER ASTM 53 GRB
3. ANCHOR BASE IS DESIGNED TO WITHSTAND 15,000 FT LBS OF INSTALLATION TORQUE
4. ANCHOR BASE SHOULD BE SHIPPED WITH HARDWARE BAGGED AND SECURED TO PIPE SHAFT
5. ANCHOR BASE TO BE HOT DIP GALVANIZED PER ASTM A123
6. HIGH STRENGTH STUD PER ASTM F1554 GRADE 105. MATERIAL- ASTM A29 GRADE 1541 (MODIFIED) STRESS RELIEVED ROD (.91 DIA.) WITH 105,000 PSI MIN YIELD & 125,000-150,000 PSI TENSILE STRENGTH, CLASS 2A AMERICAN STD B1.1 ROLLED THREAD & GALVANIZED PER ASTM A153
7. HEAVY HEX NUTS PER ASTM A194 GR 2H (.03 OVER SIZED FOR GALVANIZED STUD) GALVANIZED NUTS PER ASTM A153
8. SEE SPECIAL PROVISIONS FOR APPROVED MANUFACTURERS.

LIGHT BASE DESIGN STEEL (E)

ALTERNATE BASE DETAIL

THE FOLLOWING STANDARD PLATES APPROVED BY THE DEPT. OF TRANSPORTATION AND THE FEDERAL HIGHWAY ADMINISTRATION SHALL APPLY ON THIS PROJECT.

STANDARD PLATES	
PLATE NO.	DESCRIPTION
8106A	EQUIPMENT PAD B
8140B	ROADWAY LIGHTING SERVICE CABINET
8127B	LIGHT BASE DESIGN E
8000I	STANDARD BARRICADES

STATEMENT OF ESTIMATED QUANTITIES

ITEM NO.	ITEM	UNIT	S.P. 0302-60 ESTIMATED QUANTITIES
2021.501	MOBILIZATION	LUMP SUM	1
2545.511	LIGHTING UNIT TYPE 9-40	EACH	2
2545.511	LIGHTING UNIT TYPE 12-40	EACH	14
2545.515	LIGHT BASE DESIGN E	EACH	16
2545.521	2" RIGID STEEL CONDUIT	LIN. FT.	50
2545.523	3" RIGID NON-METALLIC CONDUIT	LIN. FT.	50
2545.523	3" RIGID NON-METALLIC CONDUIT (DIRECTIONAL BORE)	LIN. FT.	200
2545.531	UNDERGROUND WIRE 1 CONDUCTOR NO. 2	LIN. FT.	180
2545.533	ARMORED CABLE 3 CONDUCTOR NO. 4	LIN. FT.	5658
2545.541	SERVICE CABINET SECONDARY TYPE L1	EACH	1
2545.545	EQUIPMENT PAD B	EACH	1
2563.601	TRAFFIC CONTROL	LUMP SUM	1

ESTIMATED QUANTITIES AND STANDARD PLATES

CERTIFIED BY ____ PROFESSIONAL ENGINEER ____ REG. NO. ____ State Proj. No. 0302-60 (T.H. 10) Sheet No. 2 of 6 Sheets

The following is a list of standard lighting pay items:

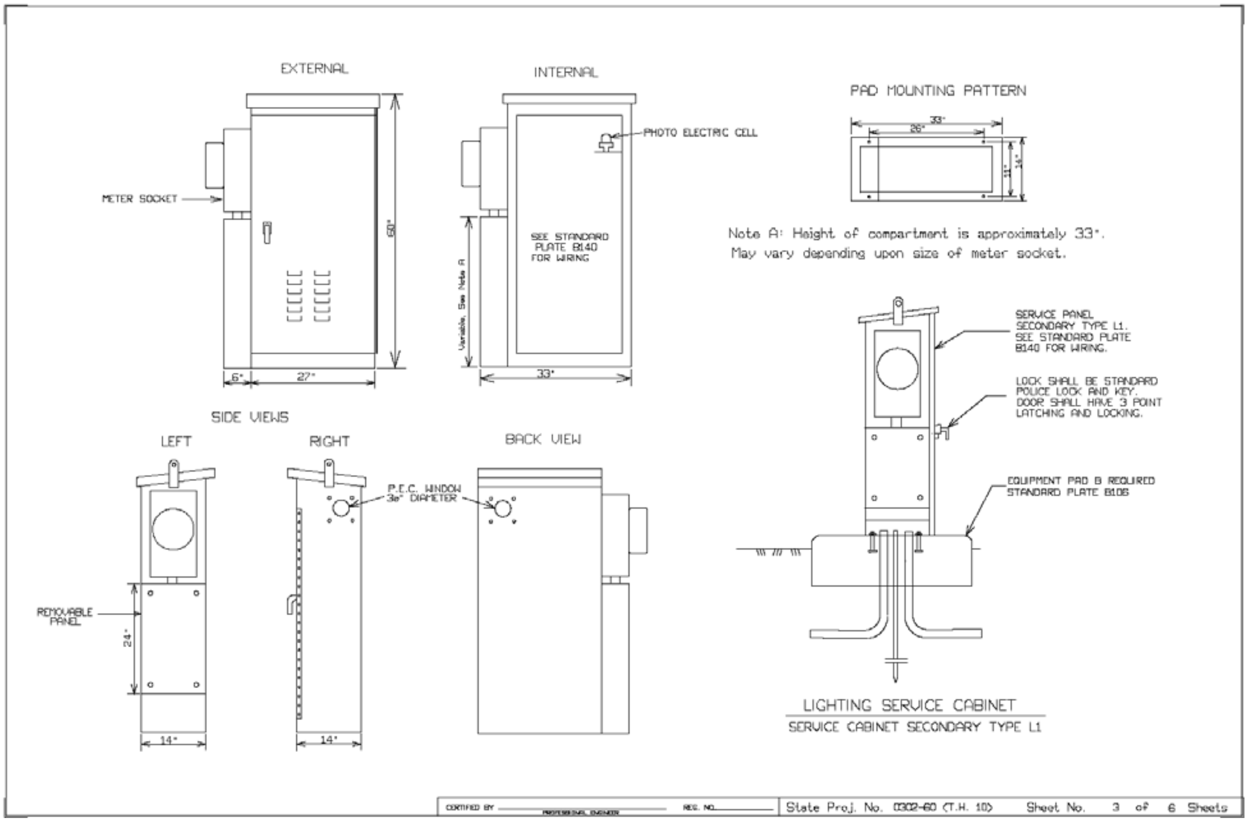
Item No.	Item	Unit
2104.509	Remove____	Each
2104.523	Salvage____	Each
2545.501	Electric Light System	Lump sum
2545.503	Electric Power System	Lump sum
2545.509	Conduit System	Lump sum
2545.511	Lighting Unit, Type_______________	Each
2545.513	Luminaire	Each
2545.514	Underpass Lighting Fixture, Type ____________	Each
2545.515	Light Base, Design _______________	Each
2545.521	____" Rigid Steel conduit	Linear Foot
2545.522	_____" Intermediate Metal Conduit	Linear Foot
2545.523	_____" Nonmetallic conduit	Linear Foot
2545.531	Underground Wire, ___Conductor No.	Linear Foot
2545.533	Armored Cable, ___Conductor No.	Linear Foot
2545.541	Service Cabinet, ___Type	Each
2545.545	Equipment Pad	Each
2545.551	Junction Box	Each
2545.602	Hand Hole	Each
2545.602	Service Equipment	Each
2545.602	Electrical Service	Each
2545.602	Install____	Each

Hints for estimating cable/conduit quantities:

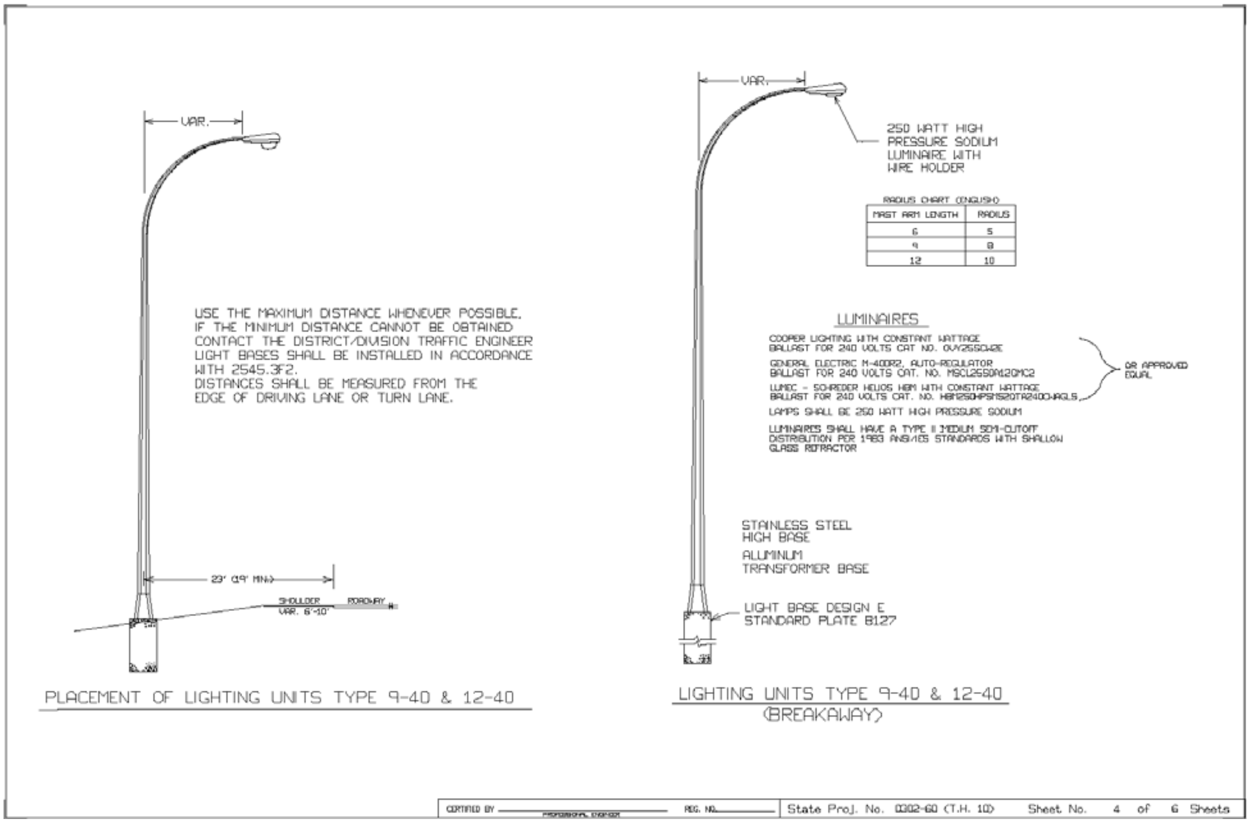
1. Conduit/Conductors: 30' (9 m) up pole to pole mounted transformer.
2. Armored Cable: 5' (1.5 m) in base, 5' (1.5 m) out of base
   [10 feet (3 m) at each base in a run]
   [5 feet (1.5 m) at the base at end of a run]
3. Underground Conductors: 15 feet (4.5 m) in base 15 feet (4.5 m) out of base
4. Measure underground wire or armored cable and add 5 percent, then apply steps 2 and/or 3.
5. Measure overhead cable and add 15 percent.

5.3.4 Detail Sheets

Detail sheets should show details for each type of pole and luminaires used in the project, details for mounting the service panels and photoelectric controls, any special anchorage details, conduit attachment to bridges for



underpass lighting, and any other necessary details.



Pole Type Designation

Generally, the pole type designation contains the mast arm length, the type of pole and the nominal pole height.

The first character before the dash is the mast arm length, usually 6', 9', or 12'.

The character(s) just preceding the dash indicate the type of pole used; see the list below. If no characters are in this position, the pole has a transformer base or high base, is intended for mounting on a light base, and has no finish for an aluminum or stainless steel pole or is galvanized for a steel pole.

The characters after the dash give the nominal pole height.

The pole type characters are as follows:

- A - Anchor bolt pole (no transformer base)
- B - Barrier or bridge mounting (6 bolt cluster)
- C - Corten steel (no finish applied)
- D - Double mast arms
- M - Minneapolis style pole
- P - Painted pole
- S - Combination traffic signal and street light pole
- W - Wood pole lighting unit (for temporary lighting)
- X - Decorative pole (with inclined beam arm)
- VM - Vertical mount

Examples of Pole designations:

1. **9-40**: 9' mast arm with 40' mounting height, transformer base or high base, and aluminum or stainless steel, as indicated in the plans.
2. **6BD-40**: 6’ double mast arms with 40' mounting height, provisions for barrier mounting.
3. **VMD-45**: Tenon mount double vertical luminaire with 45' mounting height.

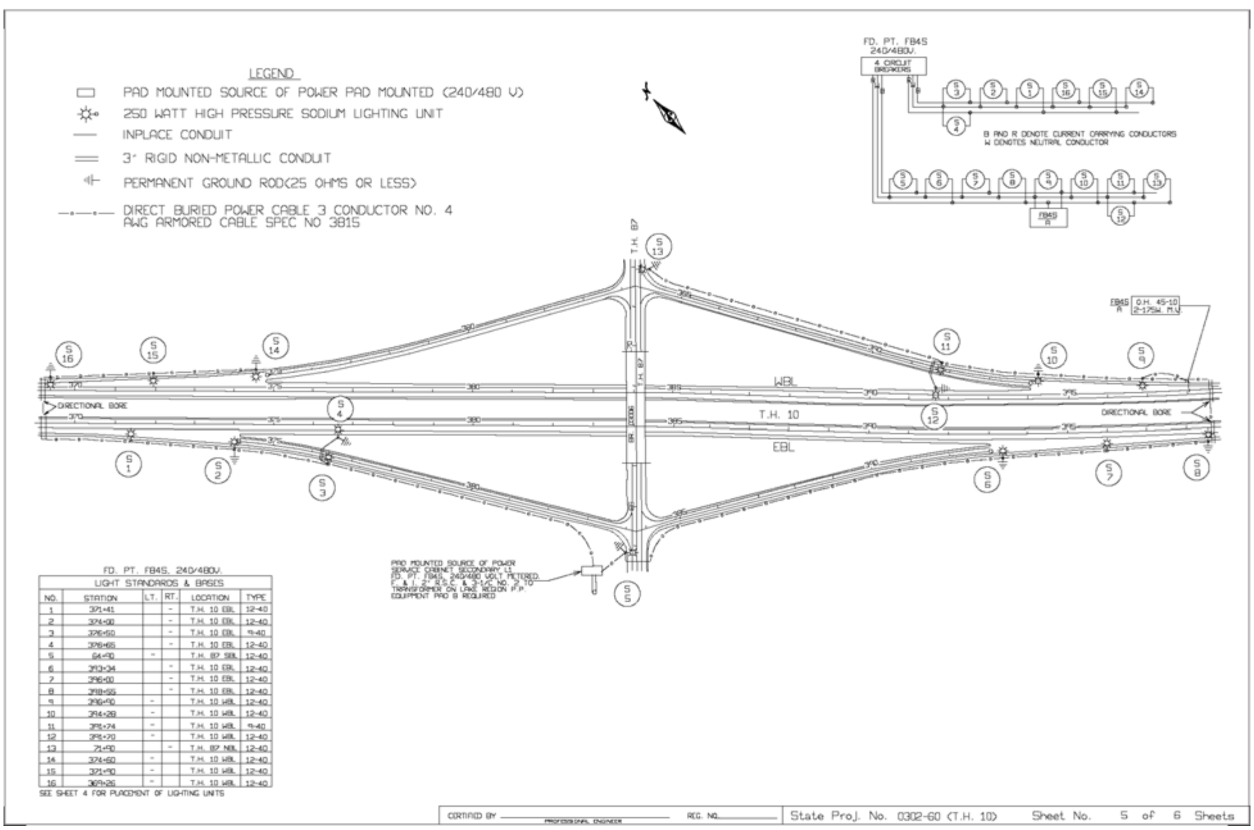
5.3.5 Pole Layout Sheet

Each pole layout sheet should include a layout of the roadway and locations of light standards, cable, service cabinets, conduit, junction boxes, and hand holes. All of these items should be properly labeled and identified. A tabulation should list stations, locations, and types of lighting units.

On the first layout sheet, a legend and symbols should be shown. Appropriate symbols are contained in the Mn/DOT road design "Technical Manual."

All luminaires and sign lights indicated in the plans should be labeled with a unique number. Numbers for roadway, tunnel, and underpass luminaires should consist of the feedpoint number above a number indicating the luminaire on that feedpoint. The luminaires should be numbered consecutively. Sign light numbers should consist of the feedpoint number above a letter indicating the sign light on that feedpoint and should be numbered from left to right separately for signs facing each direction of travel on the roadway.

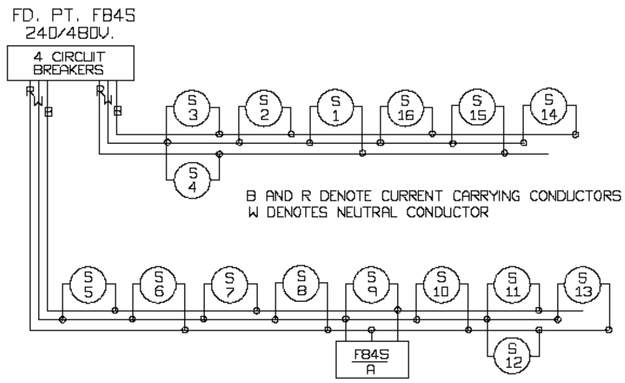
A Light Standards and Bases summary table should be included on the pole layout sheet. See the Frazee



plan below.

Wiring

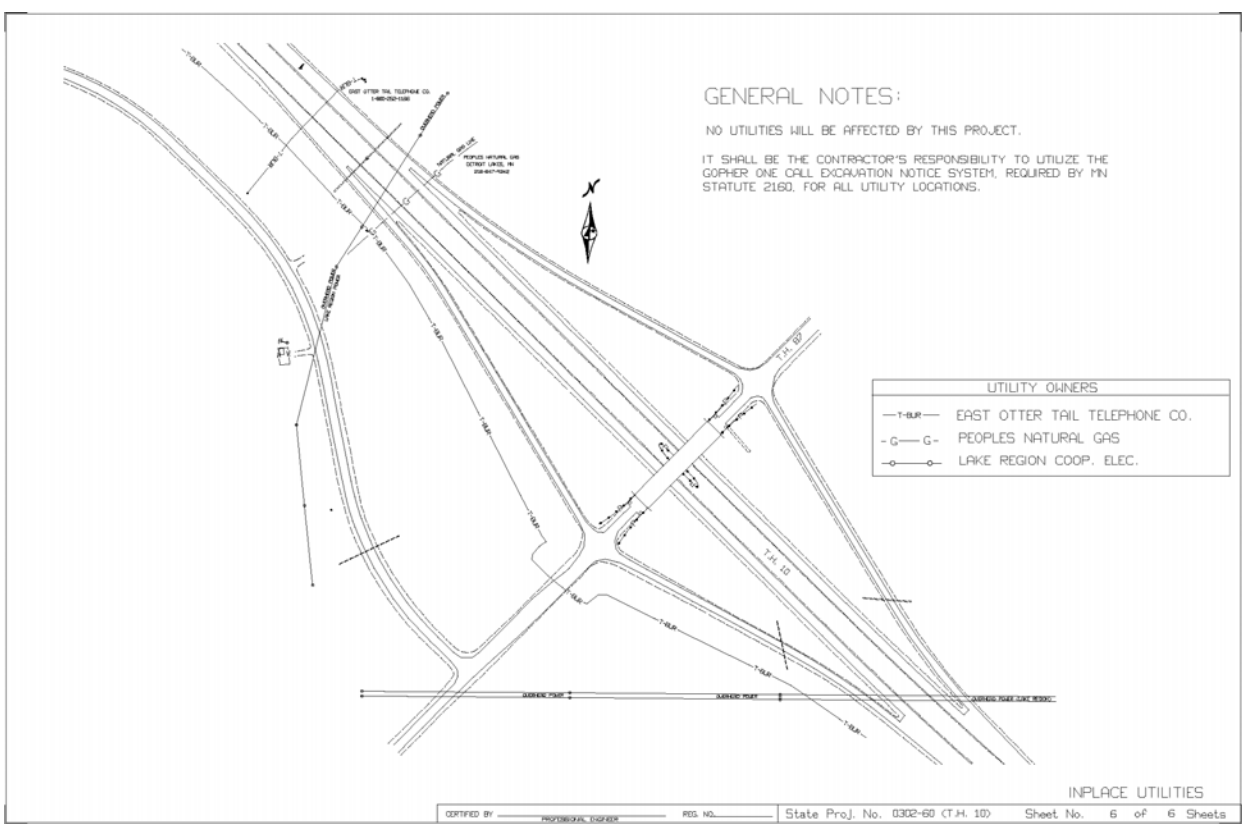
The plans should include wiring diagrams to detail the wiring of the lighting circuits and to show wire sizes. Information sheets should be included when appropriate. Contact must be made with the appropriate power company to establish source of power(s). The power company may require extra equipment and have an electrical service charge. All communications with the power company shall be confirmed in writing.



5.3.6 Utilities Sheet

This sheet details the utilities within the lighting plan area. Typical notes included on the utilities sheet are:

- It shall be the contractor's responsibility to utilize the Gopher One Call Excavation Notice System (phone # 651-454-0002), required by Minnesota Statute 2160 for all utility locations.



- No utilities will be affected by this project (if appropriate).

Shown below is a sample letter for a utility location survey:

Minnesota Department of Transportation

Office of Traffic Engineering
Mail Stop 725
1500 West County Road B2, Suite 250
Roseville, MN 55113

Office Tel: (612) 582-1095
Fax: (612) 582-1033

August 19, 1998

To: Brian Henry
Principle Land Surveyor
Metro – Golden Valley

Or Brad Canady
Land Surveyor
Metro – Oakdale

From: Sue Lodahl
State Lighting Engineer

Subject: Location Survey Request for S.P. XXXX-XXX T.H. XX
Location
Roadway Lighting Plan
Proposed Letting Date

Please conduct a utility location survey for the above mentioned roadway lighting plan on T.H. xxx from ________________________ to ________________________.

The following is a sample memorandum for a request for soil borings and foundations (if high mast lighting in used):

Minnesota Department of Transportation

OFFICE MEMORANDUM

DATE: August 19, 1998

TO: Gary Person
Acting Foundations Engineer

FROM: Sue Lodahl
State Lighting Engineer

PHONE: (612) 582-1095

SUBJECT: S.P. 2785-313, T.H. 494
East Bush Lake Rd. To E. Of T.H. 100.
Request for soil borings and foundation recommendations

We are installing high mast lights in the above mentioned area and attached are plan sheets showing the proposed locations. We are requesting foundation recommendations (type and size of pilings required) for these high mast lights. Electronic files are also available on CA64S1\pub\2785313.tow.

These plans are scheduled for a December, 1997 or January, 1998 letting.

If you have any questions, please give myself or Steve Misgen (582-1072) a call.

Thanks!

cc: Steve Misgen
File

The following is a sample letter to the FAA when a lighting system is located near an airport or heliport:

Minnesota Department of Transportation

Office of Traffic Engineering
Mail Stop 725
1500 West County Road B2, Suite 250
Roseville, MN 55113

Office Tel: (612) 582-1095
Fax: (612) 582-1033

August 19, 1998

Manager, Air Traffic Division, AGL-530
FAA Regional Office
Great Lakes Region
2300 East Devon Avenue
Des Plaines, IL 60018

SUBJECT: S.P. 2732-41(TH 5 in front of Minneapolis/St. Paul Airport)

In accordance with FAA requirements we are submitting an executed form set of FAA Form 7460-1, Notice of Proposed Construction or Alteration for both east/west runways at the Minneapolis/St. Paul Airport.

The roadway lighting is being replace along T.H. 5 in front of the Minneapolis/St. Paul airport. The in place lighting is being replaced with similar structures. Please review the two attached Form 7460-1's, one included for each runway. Presently, obstruction lights are installed on the lighting under runway 30L, but not under 12R. Please review the enclosed forms.

Sincerely,

Susan Lodahl, P.E.
State Lighting Engineer

cc: Project File
Beverly Farraher

5.4 Electrical Distribution

5.4.1 Voltage Drops

A voltage drop calculation shows the amount of voltage that will be present at the farthest luminaire on a lighting branch circuit. The voltage drop is of concern in order to assure that the voltage at all luminaires will be sufficient for the luminaires to operate properly, and also to avoid inefficient operation of the lighting system due to a large amount of power being dissipated in the electrical distribution system (wires).

The wires carrying current to the luminaires in the lighting system have a small amount of resistance. The resistance of the wire depends on the size (gage) of the wire, the material of the wire, and the length of the wire. When current flows through the wires on its way to the luminaires, a voltage proportional to the resistance and to the current is developed along the length of the wire. This voltage subtracts from the voltage at the source of power and results in a lower voltage at the luminaires. If the resistance of the wire is too high for the amount of current flowing through it, the voltage dropped along the wire will be too high to allow sufficient voltage at the luminaires. The National Electrical Code suggests a value of 3 percent of the system voltage to be a reasonable limit to the amount of voltage drop to allow in the lighting branch circuit. The voltage along the wire multiplied by the current flowing through the wire yields the power dissipated in the wire. The higher the resistance of the wire, the higher the voltage dropped along the wire, and the more power is used up by the wiring system. The voltage drop calculation determines the size (gage) of wire of a specified material that is necessary to carry the required current the required distance without creating too large of a loss in the wire.

The basic equation that is used to determine the voltage drop in a lighting branch circuit is Ohm's Law

$E = I \times R$

where E is the voltage drop along a segment of wire, I is the current through the same length of wire, and R is the resistance of the length of wire.

This equation is only completely accurate for direct current systems. With the current in the branch circuits limited to 20 amperes by the circuit breakers, and the frequency of the power at 60hz, the equation is fairly accurate for the lighting branch circuits also.

E is the unknown value that is sought. I for any segment of wire is calculated by adding the currents for each luminaire the particular segment of wire feeds (i.e. all the luminaires downstream on that wire). R for a particular segment of wire is calculated by multiplying the length of the wire (in thousands of feet) in that segment by the resistance per 1000 foot of wire for that particular size and material of wire. The total voltage drop to the farthest luminaire is calculated by adding the voltage drops for each segment of wire from the service cabinet to that luminaire. The current for a single luminaire of various types and the resistance values for several types of wire is summarized in the Voltage Drop Calculation Values graphic that follows.

Current in Amps for High Pressure Sodium Luminaires

Luminaire Voltage	Lamp Wattage			
	150	200	250	400
120	1.7	2.1	2.9	4.1
240	0.9	1.1	1.4	2.1

Current in Amps for Mercury Vapor Luminaires

Luminaire Voltage	Lamp Wattage		
	175	250	400
120	1.7	2.1	4.1
240	0.9	1.1	2.1

Resistance of Conductors in Ohms per 1000 Feet

Conductor Material	Conductor Size (AWG)							
	12	10	8	6	4	2	0	00
Copper	1.62	1.018	0.6404	0.410	0.259	0.162	0.102	0.0811

The voltage drop must be calculated for the phase wire (hot wire, ungrounded wire) and for the neutral wire (grounded wire), and these voltages must be added together to arrive at the total voltage drop. In a two-wire circuit, the current that travels out in the phase wire must return in the neutral, and so the current in the neutral wire is the same as the current in the phase wire. The total voltage drop in the two-wire circuit, then, can be calculated by figuring the voltage drop in just the phase wire and multiplying that number by 2.

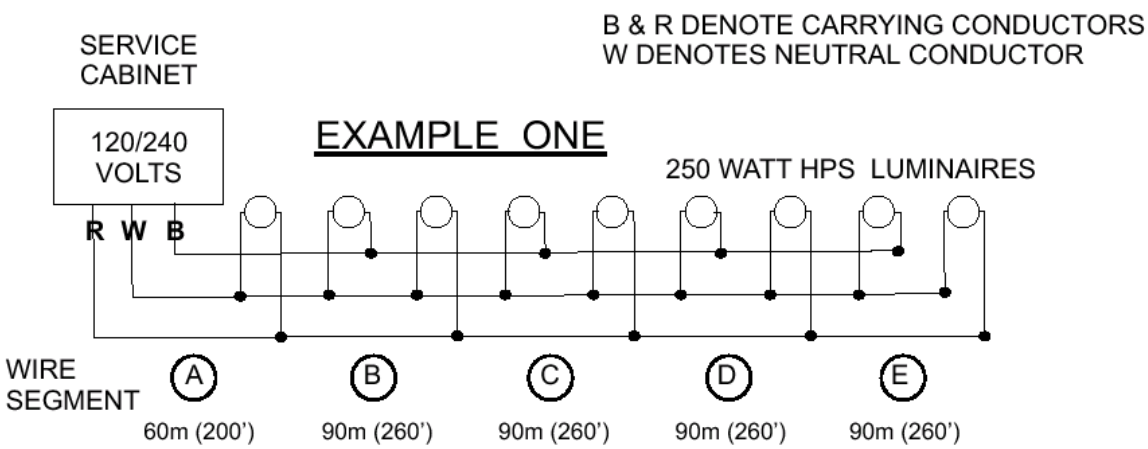
Most of the lighting branch circuits in lighting systems designed by the state are three-wire single phase circuits. A three-wire circuit consists of two phase wires and a neutral wire instead of one phase wire and one neutral wire as in the two-wire circuit. In a three-wire circuit, the neutral is at approximately zero volts with respect to the ground. The two phase wires share the same neutral and are at opposite voltages with respect to the neutral wire. For example, if at some given time the voltage in one phase wire was 240 volts with respect to the neutral wire, then the voltage in the other phase wire at that same time would be 240 volts with respect to the neutral wire. The significance of this voltage arrangement is that the current returning in the neutral wire from one of the phase wires will cancel out the current returning in the neutral wire from the other phase wire. Thus, if the loads on the two phase wires are exactly balanced, there will be no current in the neutral wire, and, therefore, no voltage drop in the neutral wire. In this case, the total voltage drop to the farthest luminaire is simply the total voltage drop in the phase wire, and the neutral wire can be disregarded.

Two examples of a voltage drop calculation are shown below. One example is for single luminaires wired to alternate phase wires as is typically done. The second example is for double luminaire poles such as might be found on a median barrier. Two different voltages are used in the examples to illustrate the application of the voltage drop at different voltages.

Example One: Single Luminaires

The system in this example consists of 250 watt high pressure sodium luminaires on poles 130 feet apart. The wires are number 4 gage single conductor wires in a conduit system. This is a 120/240 volt lighting system. There are 9 lights total on the lighting branch circuit, with the lights wired to alternate phase wires. A circuit such as this might be found in a downtown city street light system.

A wiring diagram for the lighting branch circuit is shown in the Voltage Drop Calculation Examples graphic that follows. The wire segment labels and the distances between the lights are also shown on the diagram.



From the Voltage Drop Calculation Values graphic, the current for a 250 watt high pressure sodium luminaire at 120 volts is 2.9 amperes. The resistance for number 4 gage copper wire is 0.259 ohms per 1000 feet. The following table calculates the voltage drop in the phase wire for each wire segment and gives the total voltage drop. The distance is a given from the layout of the system. The resistance is calculated by multiplying the distance in thousands of feet by the resistance per thousand feet. The current is calculated by multiplying the number of luminaires downstream of each wire segment by 2.9 amperes per luminaire. The voltage drop in each segment of wire is calculated by multiplying the current in each wire segment by the resistance of each wire segment. The total voltage drop is calculated by adding the voltage drops of all the wire segments. The current in the neutral wire is disregarded for this calculation. Depending on the system layout, the voltage drop in the neutral may add to the total voltage drop or subtract from the total voltage drop as calculated. The contribution of the voltage drop in the neutral wire is negligible compared to the voltage drop in the phase wire if the system is reasonably balanced.

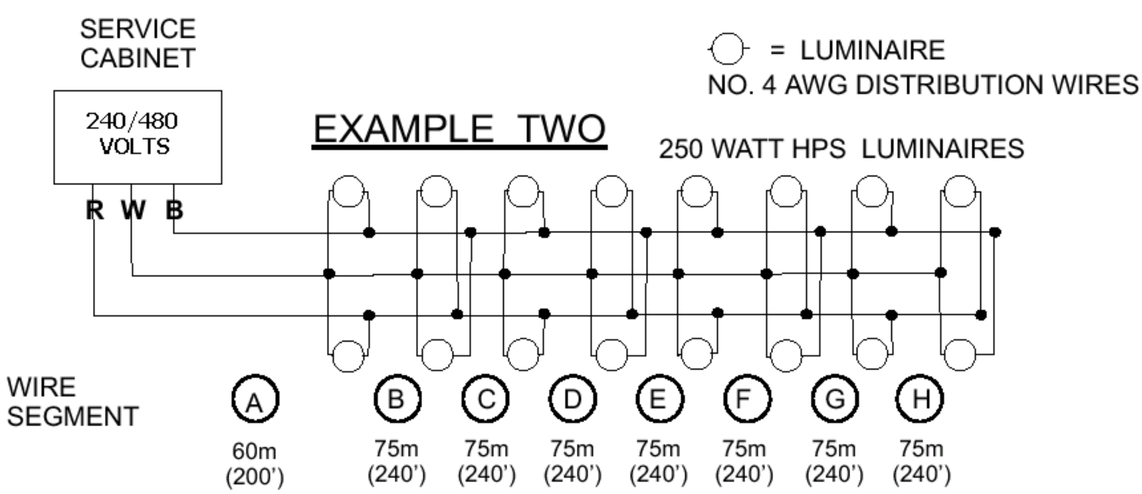
Wire Segment	Distance, feet	Resistance, ohms	Current, amps	Voltage Drop, volts
A	200	0.0518	14.5	0.7511
B	260	0.06734	11.6	0.7811
C	260	0.06734	8.7	0.5858
D	260	0.06734	5.8	0.3905
E	260	0.06734	2.9	0.1952
Total				2.704

Since 3 percent of 120 volts is 3.6 volts, this value is acceptable, and the number 4 wires can be used. The calculation would be identical if three conductor number 4 armored cable were used instead of the single conductor number 4 gage wires. Had number 6 gage wires been used, the resistance would be 0.410 ohms per 1000 feet and the voltage drop would have been 4.2805 volts. This is more than 3 percent of 120 volts, and so number 6 gage wires are too small.

Example Two: Double Luminaires

The system in this example consists of 250 watt high pressure sodium luminaires on poles 240 feet apart with two luminaires on each pole. The wires are number 4 gage single conductor wires in a conduit system. This is a 240/480 volt lighting system. There are 16 lights total on the lighting branch circuit, with one light wired to each phase wire at each pole. A circuit such as this might be found in the median of a freeway.

A wiring diagram for the lighting branch circuit is shown below. The wire segment labels and the distances between the lights are also shown on the diagram.



From the Voltage Drop Calculation Values graphic, the current for a 250 watt high pressure sodium luminaire at 240 volts is 1.4 amperes. The resistance for number 4 gage copper wire is 0.259 ohms per 1000 feet. The following table calculates the voltage drop in the phase wire for each wire segment and gives the total voltage drop. The voltage drop in each segment of wire is calculated in the same manner as in example one. The current in the neutral wire is disregarded for this calculation. If only double luminaire poles are on the branch circuit, the load is exactly balanced at all points on the circuit, there is no current anywhere in the neutral, and the voltage drop is correct as calculated.

Wire Segment	Distance, feet	Resistance, ohms	Current, amps	Voltage Drop, volts
A	200	0.05180	11.2	0.5802
B	240	0.06216	9.8	0.6092
C	240	0.06216	8.4	0.5221
D	240	0.06216	7.0	0.4351
E	240	0.06216	5.6	0.3481
F	240	0.06216	4.2	0.2611
G	240	0.06216	2.8	0.1740
H	240	0.06216	1.4	0.0870
Total				3.0168

Since 3 percent of 240 volts is 7.2 volts, this value is acceptable, and the number 4 wires can be used.

5.5 Lighting Design Computer Programs

There are many lighting software programs to use as a lighting design aid. The cost of the lighting software programs vary from free to moderately expensive. The more capabilities the program has, the higher the cost.

Free lighting software programs are manufacturer developed. These programs usually web based and can be obtained from the manufacturers website or by contacting the manufacturer directly.

Inexpensive lighting software programs are either independently or manufacturer developed. A few examples are:

Independently developed:

- Lumen-Micro (point-by-point plus rendering)
- Autolux (internal to ACAD)

Manufacturer developed:

- Genesys II (Genlyte)
- Lite-Pro (Columbia/LCA)
- Luxicon (Cooper)
- Visual (Lithonia)

Moderately expensive lighting software programs are independently developed. A few examples are:

- AGI32 (point-by-point plus rendering) - used by Mn/DOT

Lightscape (rendering, CAD required)

Accurender (rendering, CAD required)

5.6 Temporary Lighting

The providing of temporary lighting may be desirable in construction areas or near at-grade intersections on highways where the warrants listed previously are met. The Transportation District Engineer may request the installation of temporary lights from a power company, or the temporary lights may be installed by the contractor or state.

Lighting installed by the power company is maintained by the power company, and, while it may be a power company's standard design, it must meet all the state's safety requirements. Temporary lighting installed by the state or the contractor may be maintained by the power company, the state, or the contractor and is the state's or the contractor's design. Temporary lights in a construction zone are subject to being frequently moved, and so maintenance by the contractor is often the simplest to implement in that the state and the power company do not have to keep track of which lights are where at any given time. When the contractor maintains the system, the special provisions should indicate that the contractor also is responsible for paying for the power. If temporary lighting is to be left in place at the end of a project, to be removed as part of a later project, it may be better for the state to maintain the system and pay for the power. Temporary lighting which is not part of an agreement with the power company should be metered.

Power distribution to temporary lighting units is typically by means of self-supporting ACSR messenger quadplex aluminum cable. Quadplex cable should be used to provide the two phase wires, the neutral wire, and the ACSR messenger equipment ground wire. Aluminum wire should not be used if the lighting will be in place for a long period of time.

Light units in the clear zone (30 feet from the edge of the driving lane) must be breakaway. Inplace source of power and future source of power should be used when possible. Vertical mount systems with steel bases provide the best coverage when lighting from one side. Provide continuous temporary lighting on either side of the project termini. Speed limits, alignment, width of lanes, and volumes should be considered when determining the need for temporary lighting.

6. SPECIFICATIONS AND AGREEMENTS

In this Chapter you will be introduced to specifications and agreements as related to roadway lighting design. The items covered include:

- Mn/DOT Lighting Design Standards
- Mn/DOT 2000 Specifications Book
- Special Provisions
- Agreements
- Cost Sharing Policy

This section covers standards, specifications, special provisions, agreements and cost sharing policy as each pertains to lighting design projects.

6.1 2000 Specifications Book

The Mn/DOT Standard Specifications for Construction, 2000 Edition, is now available. This Specification must be used on projects let after July 1, 2001.

The edition of the "Standard Specification for Construction" which applies to a particular project will be noted on the Title Sheet of the Plan. The note on the Plan will read:

The 2000 Edition of the Minnesota Department of Transportation "Standard Specification for Construction" shall govern.

The 2000 standard specification book is for sale by the Manual Sales Office, State of Minnesota, Department of Transportation, 395 John Ireland Blvd., St. Paul, MN 55155-1899. The price is $20.00 plus State Sales Tax plus handling/postage. The price includes future supplements to this edition. Check, draft or money order for the exact amount, made payable to the commissioner of Transportation, must accompany the order. Information may be obtained by calling (651) 296-2216.

6.2 Special Provisions

The special provisions for a lighting project should give any necessary information that is not given in the plans or in the Mn/DOT Standard Specifications for Construction, as well as information that is to be specially brought to the bidders' attention. This information may include an explanation of the electrical distribution system, materials specifications for materials that are not in the standard specifications book, construction requirements that are not included in the standard specifications book, a statement of items that are to be furnished by the state, and an explanation of what is included in each pay item.

All districts will be responsible for preparing lighting special provisions. Sample lighting special provisions can be found on the Office of Traffic, Security and Operations website.

6.3 Agreements (Cost and/or Maintenance)

An agreement is a legal document detailing the cost responsibility of the various parties involved in installing, maintaining, and providing power to a lighting system. At the request of the district, the Lighting Unit prepares agreements for lighting that is not a part of a road construction project.

Agreements for lighting that is a part of a road construction project are normally prepared by the Municipal Agreements Unit of the Office of Technical Support.

6.4 Cost Sharing Policy

The most recent cost share policy can be obtained at the following URL:

http://www.dot.state.mn.us/stateaid/ftp/forms/ds11_1.pdf

7. SAMPLE LIGHTING PLANS

This chapter includes the 35W complete roadway lighting plan set and a Rest Area lighting plan set for reference.

NOTE: The plan sets are reduced to fit in this manual, they are provided as reference only.

Appendix A - Glossary of Lighting Terms

Cone of Vision - A fan-shaped field of view extending in front of a vehicle operator.

Ambient Light **-** Illumination at, near, or around a traffic facility but outside of the right-of-way.

Ballast **-** An auxiliary device used with high intensity discharge (HID) lamps to provide proper starting and operating characteristics. It limits the current through the lamp and may also regulate the voltage.

Candela **-** The unit of luminous intensity (the force generating the luminous flux). Formerly the term "candle" was used.

Complete Interchange Lighting **-** The lighting of the roadway through the interchange, the traffic lanes of all ramps, the acceleration and deceleration lanes, all ramp terminals, and the crossroad between the outermost ramp terminals.

Davit Mast Arm **-** One-piece shaft which curves from vertical to horizontal.

Efficacy, Luminous Efficacy **–** The quotient of the total luminous flux delivered from a lamp to the total power input to the lamp, expressed in lumens per watt.

Glare **-** The brightness of a light source which causes eye annoyance, discomfort, or loss in visual performance and visibility.

Gore **-** On a freeway or expressway, the area where the mainline of the roadway and the ramp diverge or converge.

High Base **-** Transformer base which tapers from a base plate to a smaller shaft.

Horizontal Lux **-** Lux measured in a horizontal plane.

Lamp **-** A source of light. The device within a luminaire which converts the electrical energy to light.

Light-Loss Factor **-** A depreciation factor which is applied to the calculated initial average lux to determine the value of depreciated average illumination at a predetermined time in the operating cycle, usually just prior to relamping, and which reflects the decrease in effective light output of a lamp and luminaire during its life.

Luminance **-** The luminous intensity of any surface in a given direction per unit of projected area of the surface as viewed from that direction, expressed in candela per square meter.

Lux **-** The International System (SI) unit of illuminance. One lux is defined as the illuminance incident on a surface of one square meter, all points of which are one meter from a uniform source of one candela.

Partial Interchange Lighting **-** Lighting which consists of a few luminaires located in the vicinity of some or all ramp terminals. The usual practice is to light those general areas where the exit and entrance ramps connect with the through traffic lanes and those areas where the ramps intersect the crossroad.

Pavement Reflection Factor (or Reflectance) - The ratio of the light reflected by a pavement surface to the light incident upon it.

Post Top Lighting Unit **-** A light pole with a short vertical shaft for mounting the luminaires

Progressive-Shear Base **-** A high base that is riveted or spot-welded to a base plate designed to shear progressively on impact.

Shoe Base **-** A low profile casting that connects the shaft to the pole base plate.

Slip Base **-** A pole base plate designed to slide off a lower plate on impact.

Specular Glare **-** Glare resulting from light being reflected from polished or glossy surfaces.

Transformer Base **-** A box-like structure between the foundation and pole base plate which can be used to accommodate the ballast and the underground wiring connections.

Truss Mast Arm **-** A horizontal bracket used to support the luminaires

Vertical Lux **-** Lux measured in a vertical plane.

Appendix B - List of References

A Policy on Geometric Design of Highways and Streets, American Association of State Highway and Transportation Officials, Washington, DC, 2001.

An Informational Guide for Roadway Lighting, American Association of State Highway and Transportation Officials, Washington, DC, 1984.

Homburger, W.S., J.H. Kell, R.C. Loutzenheiser, W.R. Reilly, Fundamentals of Traffic Engineering, 14th Edition, Institute of Transportation Studies, University of California at Berkeley, Berkeley, CA, 1996.

Manual of Uniform Traffic Control Devices, Federal Highway Administration, Washington, DC, 2000.

Minnesota Manual of Uniform Traffic Control Devices, Minnesota Department of Transportation, Amended 1997.

Minnesota Traffic Engineering Manual, Minnesota Department of Transportation, Amended 2000.

Roadway Lighting Handbook, Federal Highway Administration, Washington, DC, 1978.

Traffic Control Devices Handbook, Institute of Transportation Engineers, Washington, DC, 2001.

Appendix C - Safety Benefits of Roadway Lighting Report

Summary Report

HSIS

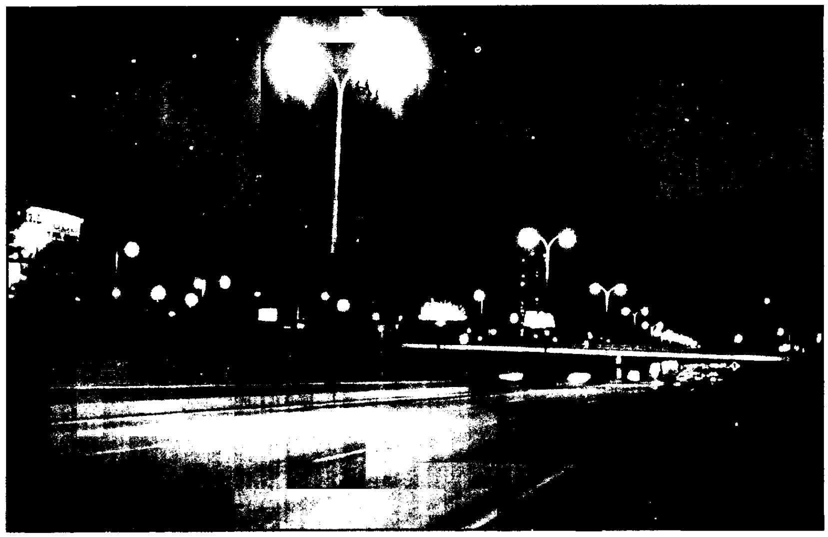
Highway Safety Information System

The Highway Safety Information System (HSIS) is a multi-State safety data base that contains crash, roadway inventory, and traffic volume data for a select group of States. The participating States—Illinois, Maine, Michigan, Minnesota, and Utah—were selected based on the quality of their data, the range of data available, and their ability to merge data from the various files. The HSIS is used by FHWA staff, contractors, university researchers ,and others to study current highway safety issues, direct research efforts, and evaluate the effectiveness of crash countermeasures.

U.S. Department of Transportation
Federal Highway Administration

Research and Development
Turner-Fairbank Highway
Research Center
6300 Georgetown Pike
McLean, Virginia 22101-2296

Comparison of the Safety of Lighting Options on Urban Freeways



Nationwide accident statistics show that more than 50 percent of fatal accidents occur during the hours of darkness. Because only 25 percent of travel occurs during the same period, the fatality rate is about three times higher at night than during the day. The installation of overhead lighting is a potential countermeasure to this nighttime accident problem. However, this is expensive, and much of the research to date offers inconclusive results about its effect on highway safety.

Many previous studies have evaluated the relationship of urban freeway lighting and highway safety. However, the majority of these studies were conducted in the 1960's and early 1970's, and the results from these studies may be outdated. On our Nation's highways, there have been many changes in traffic flow, vehicle fleet, and road-user demography in the past 20 to 30 years. Clearly, the volume of traffic on urban freeways is significantly higher today, and congestion is a greater problem.

This study compared the safety of continuously lighted urban freeways and urban freeways with interchange lighting only. A freeway section with continuous lighting has overhead lighting at the interchanges and between the interchanges, as opposed to overhead lighting at the interchanges only.

State Data Bases Used

Minnesota was the only HSIS State with a sufficient number of urban freeway sections with roadway lighting that had complete accident, roadway, and lighting information to permit a safety analysis of roadway lighting on urban freeways. In addition, at the time of the study, Minnesota was the only HSIS State with a videodisc photolog system. The Minnesota videodisc photolog system is a key tool in the HSIS laboratory, which allows users to have automatic computer access to all video images of the State-maintained roadway network. This system is used to collect supplementary data for studies and to verify existing data.

Currently, the HSIS laboratory has videodisc photolog systems for Minnesota and Michigan.

Analysis Methods

A cross-section approach was used in this research study to assess the safety effects of urban freeway lighting. The cross-section approach compares the safety of sites that are different. Two groups of sites were compared in this study: urban freeway sections with continuous lighting and urban freeway sections with interchange lighting only. The urban freeways evaluated in this study are located in the Minneapolis-St. Paul metropolitan area.

A review of the Minnesota HSIS data files revealed that most of the desired accident and roadway variables needed to conduct this study were present. However, the files did not have the lighting information or 24-h traffic distributions needed to develop day versus night accident rates. The Minnesota Department of Transportation (MnDOT) was able to provide needed supplementary information to support HSIS data. MnDOT provided lighting information (identification of urban freeway sections with roadway lighting, type of lighting, etc.) and automatic traffic recorder reports that provided summaries of 24-h traffic distributions. Sunrise and sunset information was acquired from the United States Naval Observatory to classify accident and traffic volume data by day and night.

A total of 87.9 km of urban freeway segments with continuous lighting and 57.1 km of urban freeway segments with interchange lighting only was used in the study. There is one major roadway difference between the urban freeway sections with continuous lighting and those with interchange lighting only. This difference pertains to the number of inter-changes per mile. The average spacing between interchanges is 1.3 km on the continuously lighted sections and 1.9 km on the sections with interchange lighting only. All of the interchanges are of the diamond type, except three that are cloverleafs.

Results

Day and night accident rates were calculated for the study sections. Accident data from 1985 through 1990 were used. Table 1 shows the total day accident rates, total night accident rates, and the total night/day accident-rate ratios. The total day accident rate is 3 times higher for the continuously lighted sections than the total day accident rate for the interchange lighting only sections. This contrast in the total day accident rate signifies differences exist between the subject sections. Comparisons between the subject sections can not be made without accounting for these differences. Night/day accident-rate ratios were calculated to adjust for roadway, traffic, driver, and/or other differences between the freeway sections with continuous lighting and those with interchange lighting only. The night/day accident rate ratio is computed by dividing the night accident rate by the day accident rate. This ratio gives an indication of the relative magnitude of the night accident problem to the day accident problem.

Table 1. Accident rates.

	Continuous Lighting	Interchange Lighting	Difference
Total Day Accident Rate	1.50	0.48	
Total Night Accident Rate	1.95	0.70	
Total Night/Day Accident-Rate Ratio	1.30	1.46	+12%*

* Indicates that the **ratios** are statistically different.

Accident rate is per 1 million vehicle-miles traveled.

The total night/day accident-rate ratio for the sections with interchange lighting only is 12 percent higher than the total night/day accident-rate ratio for sections with continuous lighting (a larger night/day accident-rate ratio indicates a relatively more hazardous night condition).

Figure 1 shows serious injury, injury, and property damage only (PDO) night/day accident-rate ratios. The only meaningful difference between the ratios is that the PDO night/day accident-rate ratio is 19 percent higher for the freeway sections with interchange lighting only than the PDO night/day accident-rate ratio for the continuously lighted sections.

Figure 2 shows the accident-rate ratios for interchange and non-interchange areas. For interchange areas, the night/day accident-rate ratios are statistically equal for continuously lighted sections and sections with interchange lighting only. One would expect these ratios to be similar since overhead lighting exists at the interchanges located on the sections with continuous lighting and the sections with interchange lighting only.

The night/day accident-rate ratio for non-interchange areas is 18 percent higher for sections with interchange lighting only than it is for continuously lighted sections. Statistically, the night/day accident-rate ratios for non-interchange areas are different. The primary focus of the study was to compare the non-interchange areas of the continuously lighted sections and interchange lighting only sections. The non-interchange areas of the continuously lighted sections are **lighted** and the non-interchange areas of the interchange lighting only sections are **unlighted**. A detailed analysis of the non-interchange areas was conducted.

Crash costs for lighted and unlighted sections for non-interchange areas were calculated. The costs were calculated for each accident severity by multiplying the accident frequency by the corresponding

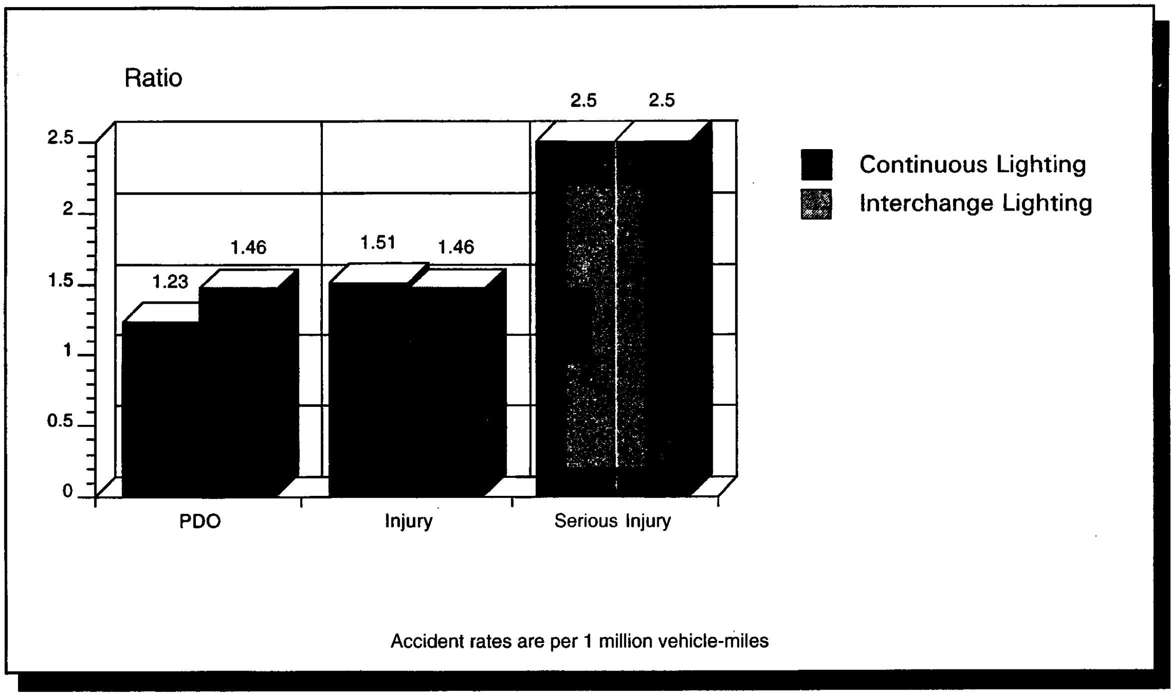


Figure 1. Night/day rate ratios

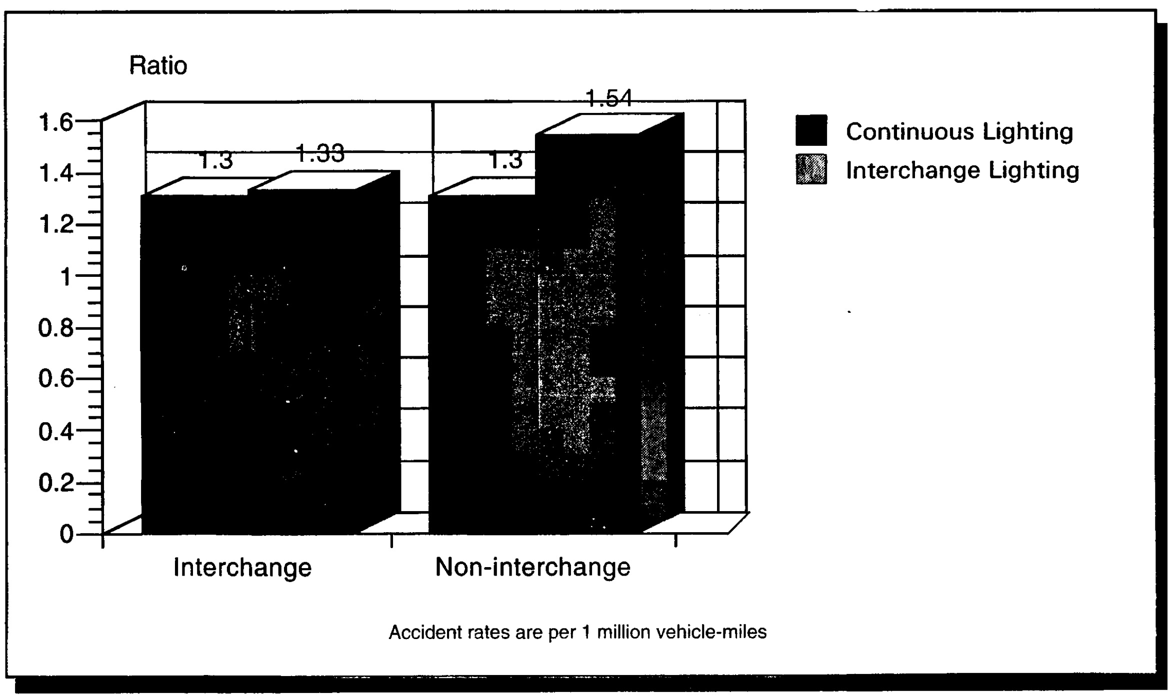


Figure 2. Total night/day rate ratios

cost per crash. The costs per crash used in 1988 dollars were: $2,722,548 (K-fatal), $228,568 (A-incapacitating), $48,333 (B-evident), $25,228 (C-possible), and $4,489 (O-property damage).[1] For the lighted sections between interchange areas, the total crash costs for night and day were $37,617,605 and $46,270,320, respectively. For the unlighted sections between interchange areas, the total crash costs for night and day were $17,727,099 and $17,228,489, respectively.

Night/day crash-cost ratios were computed using the crash costs. The night/day crash-cost ratios for freeway sections between interchange areas with lighting and without lighting were $37,617,605/ $46,270,320 = 0.81 and $17,727,099/ $17,228,489 = 1.03, respectively. The night/day crash-cost ratio for freeway sections between interchange areas without overhead lighting is 27 percent higher than the night/day crash-cost ratio for freeway sections between interchange areas with overhead lighting.

A benefit/cost analysis was conducted for the freeway sections between the interchange areas with lighting. The hardware, installation, and electric power costs for an urban freeway lighting system were obtained from a New York Department of Transportation (NYDOT) official. The use of lighting system costs from New York was not deemed to be ideal. However, these costs could not be obtained from Minnesota DOT. The costs of overhead lighting systems can vary across different regions of the country and, therefore, the benefit/cost results should not be considered definitive.

Based on the NYDOT cost information, it's estimated that the total costs (hardware, installation, and power) from 1985 through 1990 for the 35 km of continuously lighted freeways between the interchange areas were $2.7 million. The hardware and installation costs were established on a 20-year amortization period. These calculations are based on the assumption that the entire roadway lighting system was installed in 1984. The overhead lighting system was actually installed between 1960 and 1984 at the study locations.

For the benefit/cost analysis, the expected night crash costs (if roadway lighting did not exist at these locations) had to be calculated for the 35 km of continuously lighted freeways between the interchange areas. This was found by using the night/day crash-cost ratio for the unlighted sections between the interchange areas. One would expect that if roadway lighting was not installed on the 35 km of continuously lighted freeways between interchange areas that the night/day crash-cost ratio would equal 1.03 (night/day crash-cost ratio for the unlighted sections) and not 0.81. The expected night crash costs were equal to $47,658,429 ($46,270,320 x 1.03).

The actual night crash costs were $37,617,605; this was $10,040,824 less than the expected night costs. Therefore, the estimated economic benefit of roadway lighting is $7,340,824 ($10,040,824 - $2,700,000 [estimated hardware, installation, and power costs]) for the years 1985 through 1990. The benefit/cost ratio equals 3.7 ($10,040,824/$2,700,000).

Study Implications

Accurate estimates of the safety benefits of roadway lighting for urban freeways are needed. These estimates are required to better understand the potential impact roadway lighting can have on the nighttime accident problem for urban freeways. The majority of the previous research is 20 to 30 years old and it's inconclusive. This study provided new accurate information and found a positive relationship between roadway lighting and urban freeway safety.

Jurisdictions considering the installation of a roadway lighting system for an urban freeway facility need to assess its potential economic impact. Benefit/cost analyses should be conducted for the different types of freeway lighting systems that are being considered. The benefit/cost ratio of overhead lighting for the study's 35 km of urban freeway sections between interchange areas is 3.7. This ratio is primarily a function of the reduction of property damage only (PDO) accidents.

Additional research is needed to develop an even stronger knowledge base on the safety effects of roadway lighting for urban freeways. A before-and-after study would be desirable with data from several States that have urban freeway lighting systems in service with a wide range of maintained illumination levels.

The warranting conditions for continuous freeway lighting, complete interchange lighting, and partial interchange lighting can be found in publication The American Association of State Highway and Transportation Officials (AASHTO's) Informational Guide for Roadway Lighting.

For More Information

This research was conducted by Michael S. Griffith, a mathematical statistician with FHWA in the Office of Safety and Traffic Operations R&D. The final report was published in the Autumn 1994 issue of FHWA's *Public Roads*. To obtain more information about the study or HSIS, contact Jeffrey F. Paniati, HSIS Program Manager, at (703) 285-2568.

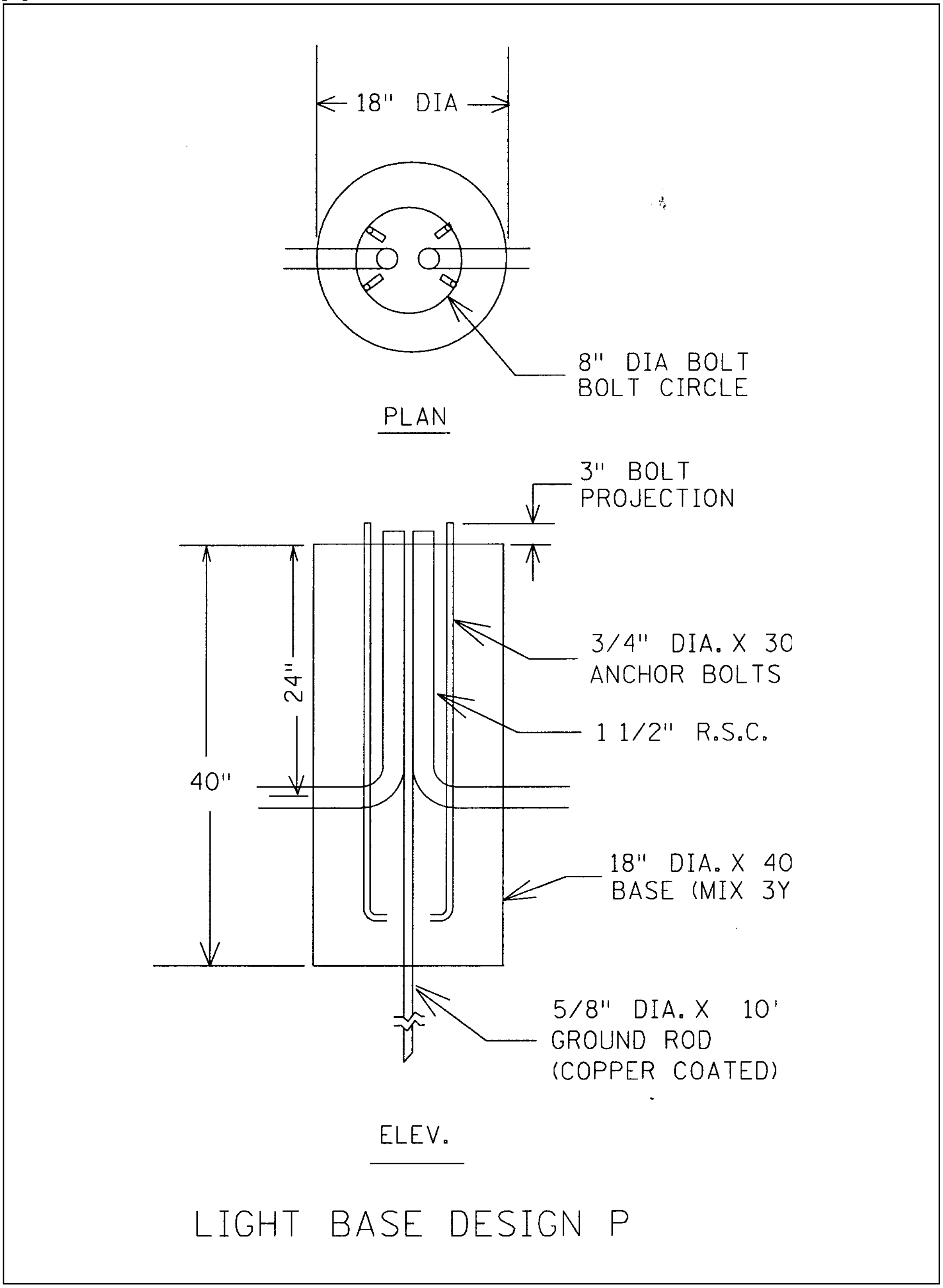
Reference

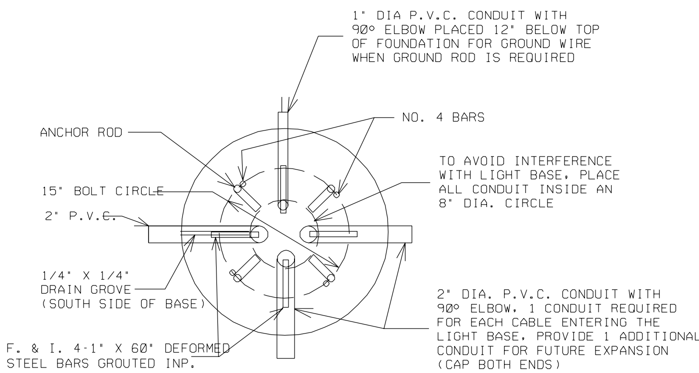
1. *The Costs of Highway Crashes*, Federal Highway Administration, October 1991, FHWA-RD-91-055.

Issued May 1995

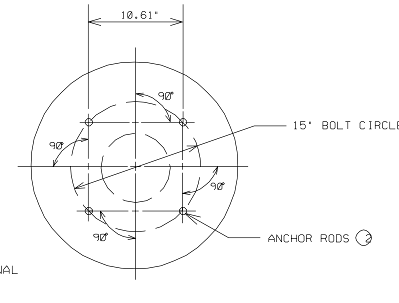
Publication No. FHWA-RD-94-188

Appendix D - Standard Plates and Details

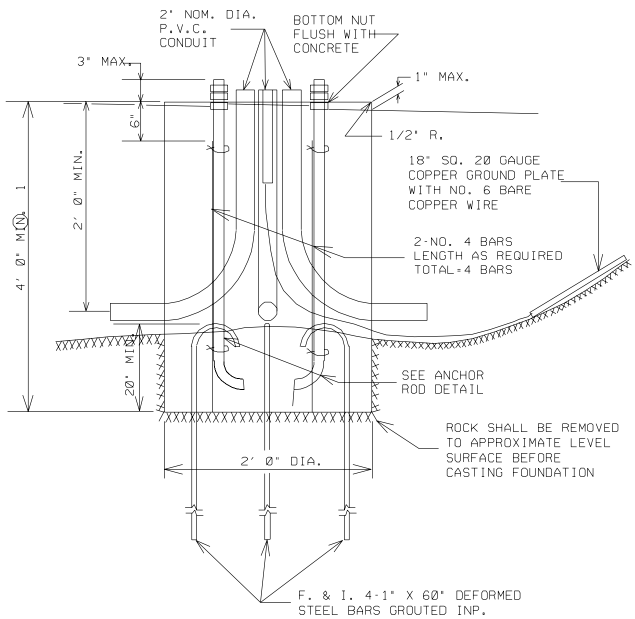




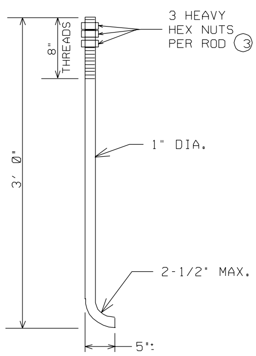
PLAN



ANCHOR ROD PLACEMENT



ELEVATION



ANCHOR ROD DETAIL

4 REQUIRED (2)

TYPICAL CONCRETE BASE
IN ROCK

LIGHT BASE DESIGN R-40

NOTES:

CONCRETE SHALL BE MIX NO. 3Y43.

FOUNDATIONS MAY BE CONSTRUCTED IN AUGURED HOLES UNLESS THE NATURAL SOILS WILL NOT STAND OPEN, IN WHICH CASE FORMING WILL BE REQUIRED.

P.V.C. CONDUIT PER SPEC. 3803 SHALL BE PROJECTED 1" ABOVE THE FOUNDATION BEFORE THE MORTAR IS PLACED AND SHALL BE THE SIZE AND NUMBER SHOWN IN THE PLAN.

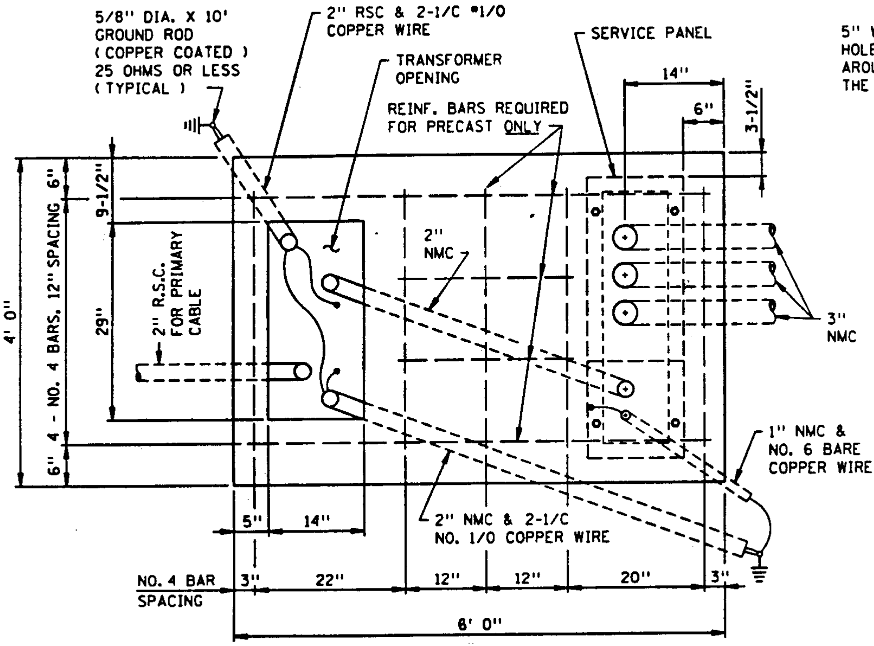
A TEMPLATE SHALL BE PROVIDED FOR ANCHOR ROD PLACEMENT AND SHALL BE LEFT IN PLACE UNTIL THE CONCRETE HAS SET.

(1) THE DEPTH OF THE FOUNDATION MAY BE CHANGED IN THE PLANS OR SPECIAL PROVISIONS.

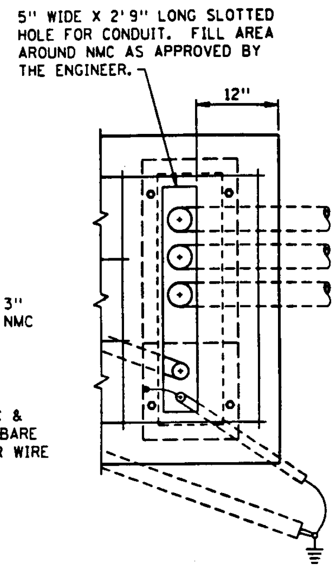
(2) ANCHOR RODS PER SPEC. 3385, TYPE B OR C SHALL BE PLACED AT RIGHT ANGLES TO THE DIRECTION OF THE MAST ARM. GALVANIZE THE TOP 1 FT. OF THE ANCHOR ROD AND NUTS PER SPEC. 3392.

(3) WRAP THREADS OF ANCHOR RODS BELOW BOTTOM NUT WITH 3 LAYERS OF PLASTIC ELECTRICAL TAPE.

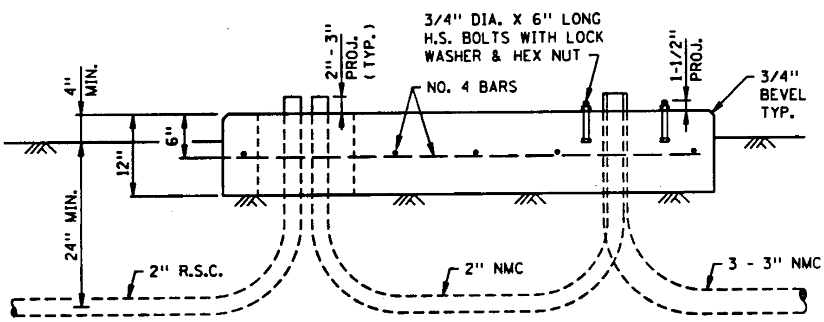
.../LOCALS~1/Temp/trainin2.lit 07/12/2002 11:06:53 AM



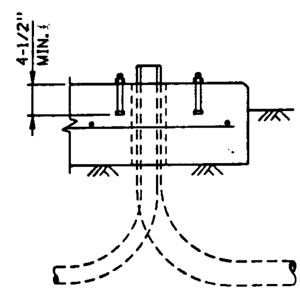
PLAN VIEW



PART PLAN VIEW
SHOWING SLOTTED HOLE
FOR PRECAST OPTION
SEE C-I-P FOR DETAILS



SIDE VIEW



PART SIDE VIEW
SHOWING SLOTTED HOLE
FOR PRECAST OPTION

NOTES:

PRECAST OR CAST-IN-PLACE EQUIPMENT PAD SHALL BE CONTRACTORS OPTION.

CONCRETE SHALL BE MIX 3A32.

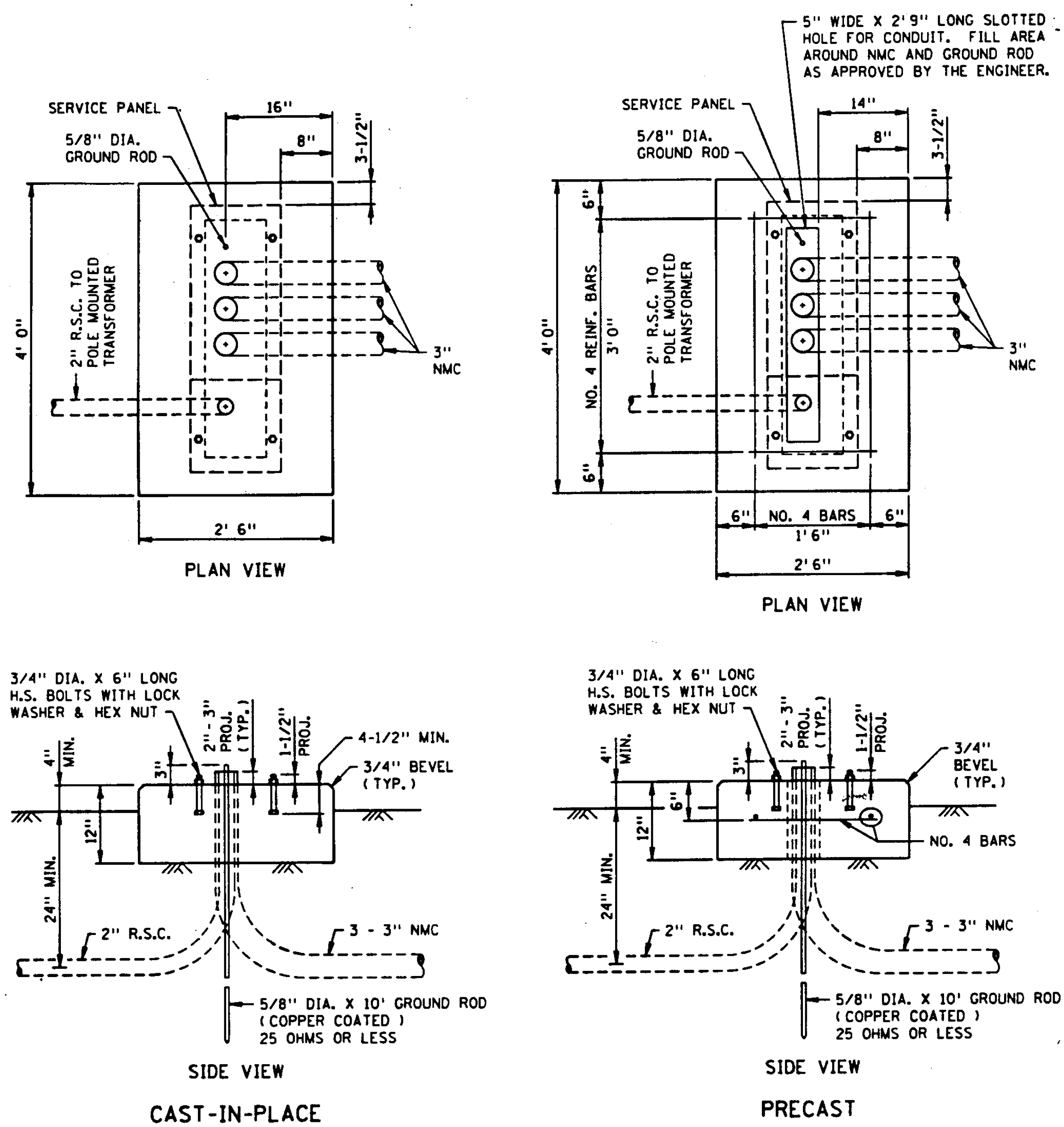
TOP OF PAD SHALL HAVE A WOOD FLOAT FINISH.

HIGH STRENGTH (H.S.) BOLTS, NUTS AND WASHERS PER SPEC. 3391 AND GALVANIZE HARDWARE PER SPEC. 3392. BOLTS CAN BE CAST-IN-PLACE OR PLACED AFTER PAD IS CAST IN A MANNER ACCEPTABLE TO THE ENGINEER.

INSTALL 3 - 3 IN. NMC CONDUIT ELBOWS FOR SERVICE PANELS.

NO. 4 REINFORCEMENT BARS REQUIRED FOR PRECAST OPTION ONLY.

APPROVED JULY 31, 1995 Gerald J. Rohrbach STATE DESIGN ENGINEER	STATE OF MINNESOTA DEPARTMENT OF TRANSPORTATION EQUIPMENT PAD A CAST-IN-PLACE OR PRECAST	SPECIFICATION REFERENCE 2461 2545 2550 2565	STANDARD PLATE NO. 8105A



NOTES:

PRECAST OR CAST-IN-PLACE EQUIPMENT PAD SHALL BE CONTRACTORS ALTERNATE.

CONCRETE SHALL BE MIX 3A32.

TOP OF PAD SHALL HAVE A WOOD FLOAT FINISH.

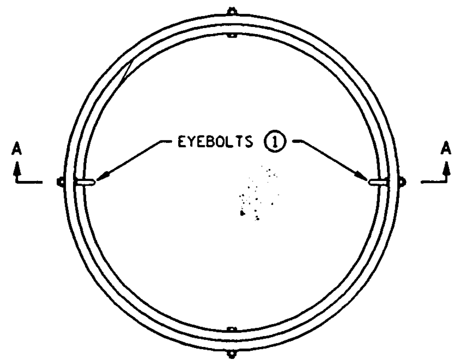
HIGH STRENGTH (H.S.) BOLTS, NUTS AND WASHERS PER SPEC. 3391 AND GALVANIZE HARDWARE PER SPEC. 3392. BOLTS CAN BE CAST-IN-PLACE OR PLACED AFTER PAD IS CAST, IN A MANNER ACCEPTABLE TO THE ENGINEER.

INSTALL 3 - 3 IN. NMC CONDUIT ELBOWS FOR SERVICE PANELS.

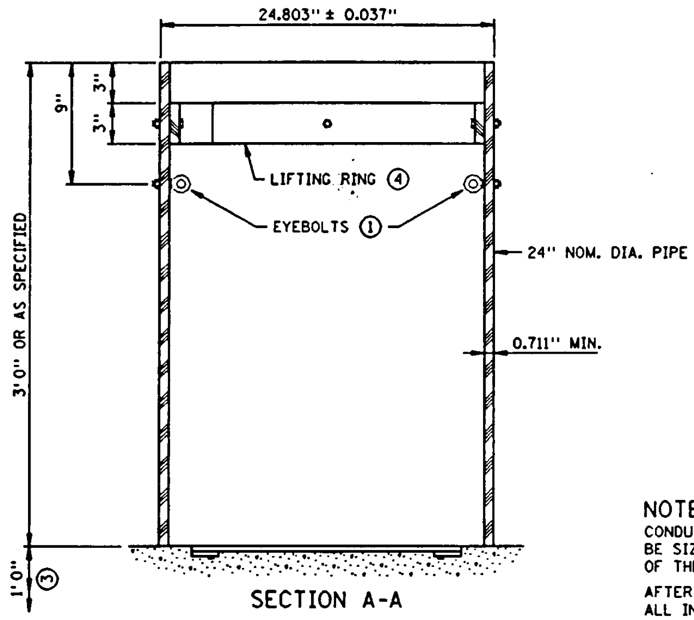
A 5/8 IN. DIA. X 10 FT. GROUND ROD SHALL BE INSTALLED IN THE EQUIPMENT PAD AND PROJECT 3 IN. ABOVE THE CONCRETE.

NO. 4 REINFORCEMENT BARS FOR PRECAST OPTION ONLY.

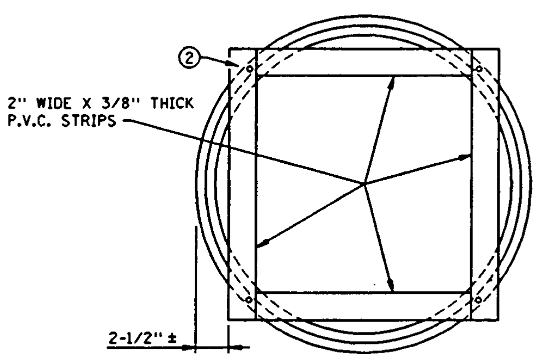
APPROVED JULY 31, 1995 [signature] STATE DESIGN ENGINEER	STATE OF MINNESOTA DEPARTMENT OF TRANSPORTATION EQUIPMENT PAD B CAST-IN-PLACE OR PRECAST	SPECIFICATION REFERENCE 2461 2545 2550 2565	STANDARD PLATE NO. 8106A



TOP VIEW



SECTION A-A



BOTTOM VIEW

NOTES:

CONDUIT HOLES LOCATED IN BARREL SECTION SHALL BE SIZED NO MORE THAN 1" LARGER THAN THE SIZE OF THE CONDUIT BEING USED.

AFTER THE HANDHOLE AND CONDUIT INSTALLATION, ALL INSIDE WALLS AND COVER SHALL BE MADE WATER TIGHT TO THE SATISFACTION OF THE ENGINEER.

P.V.C. PIPE SHALL MEET THE REQUIREMENTS OF ASTM F679T-1 OR EQUAL.

HEX HEAD BOLTS AND NUTS SHALL BE STAINLESS STEEL PER SPEC. 3391. OTHER FASTENERS SHALL BE GALVANIZED PER SPEC. 3392.

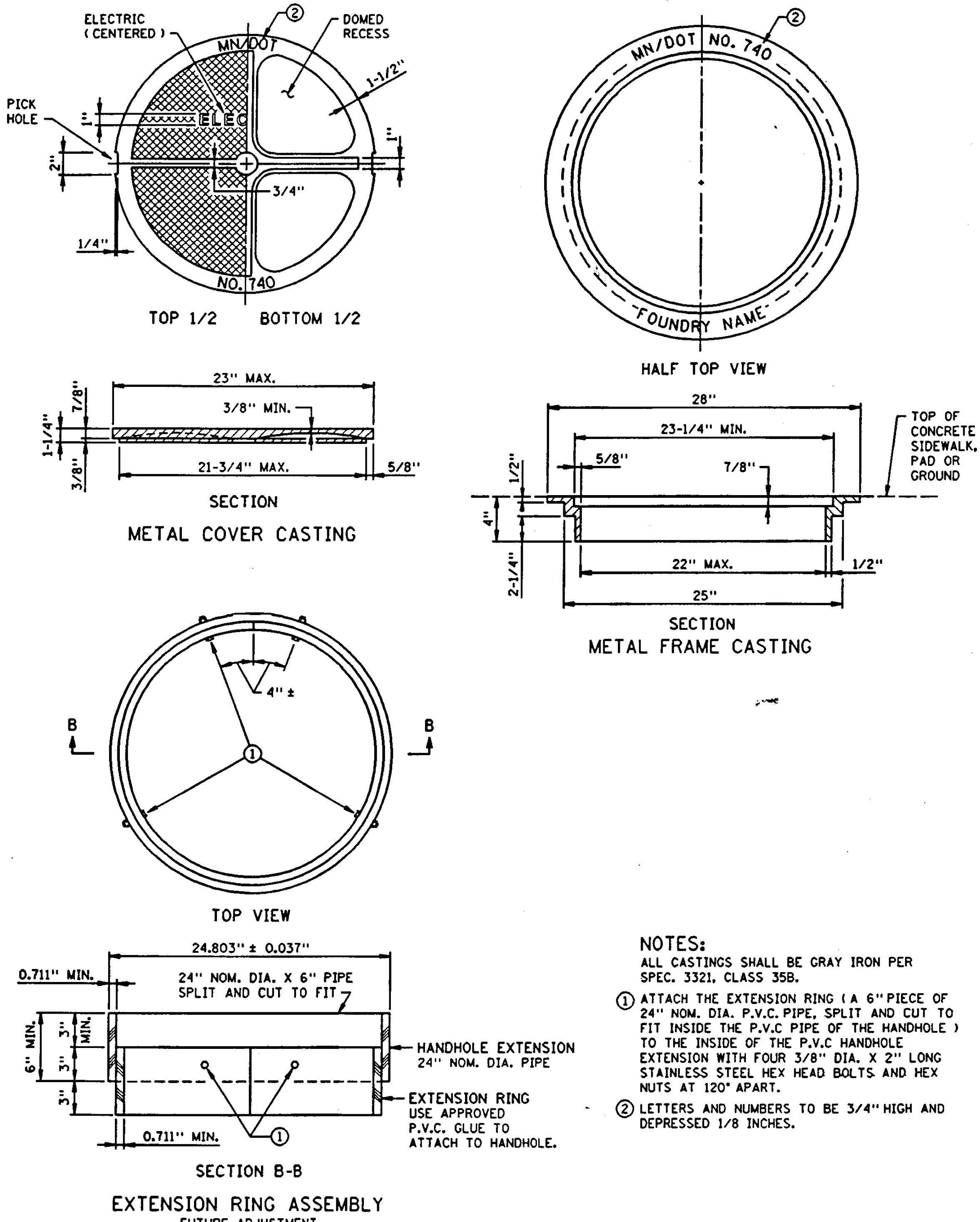
① TWO TYPE 2 SHOULDER EYEBOLTS, 3/8" DIA. X 1-1/4" SHANK LENGTH, AND HEX NUTS 180° APART (FOR SUPPORTING ELECTRIC CABLE)

② SCREW THE ASSEMBLY TOGETHER WITH FOUR 1/4" X 1-1/4" LONG GALVANIZED LAG SCREWS.

③ PLACE COMPACTED 1'0" THICK AGGREGATE DRAIN BED BELOW THE BOTTOM OF THE HANDHOLE TO THE SATISFACTION OF THE ENGINEER. USE SPEC. 3149.2H COARSE FILTER AGGREGATE.

④ ATTACH SPLIT 24" NOM. DIA. P.V.C. LIFTING RING WITH FOUR 3/8" DIA. X 2" LONG HEX HEAD STAINLESS STEEL BOLTS WITH HEX NUTS AT 90° APART. BOLT ASSEMBLY TOGETHER.

APPROVED JAN. 3, 1997 Gerald J. Rohrbach STATE DESIGN ENGINEER	STATE OF MINNESOTA DEPARTMENT OF TRANSPORTATION **P.V.C. HANDHOLE / PULLBOX** NO VEHICLE LOAD	SPECIFICATION REFERENCE 2545 2565	STANDARD PLATE NO. **8114A** 1 OF 2



NOTES:

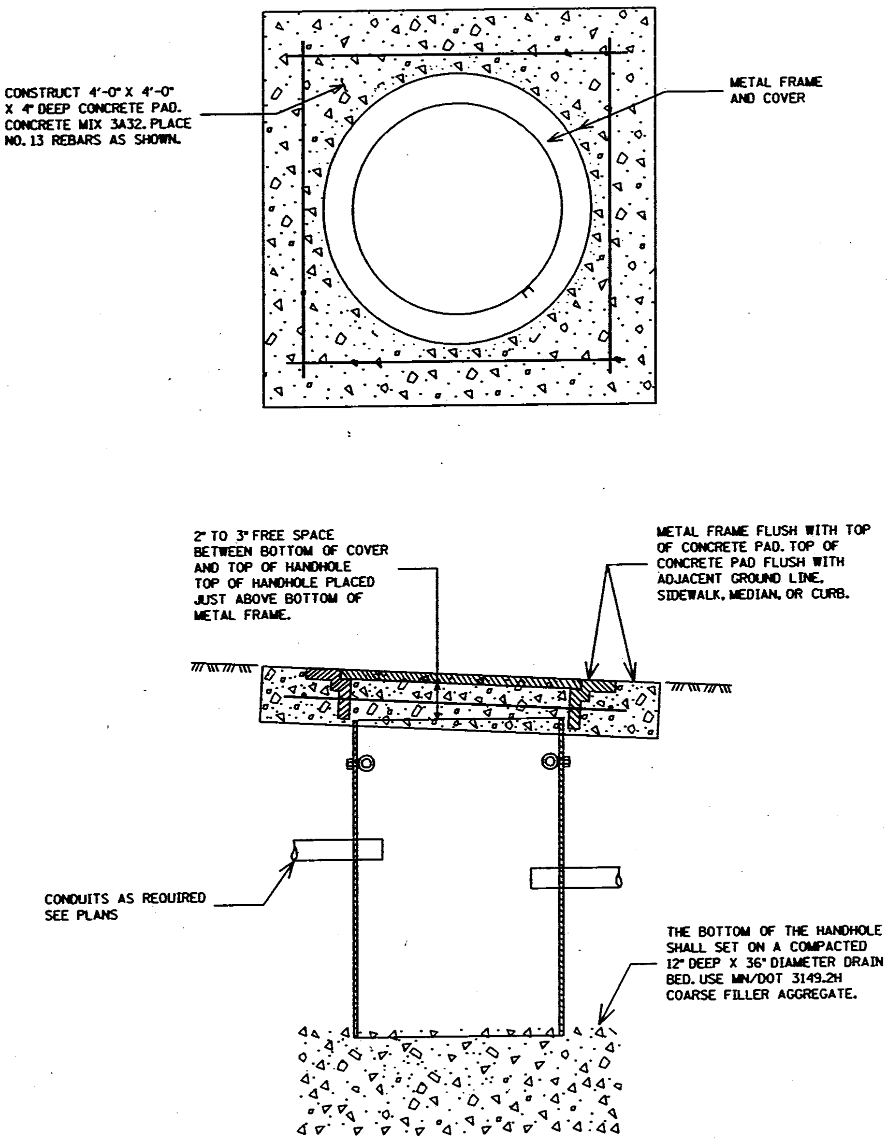
ALL CASTINGS SHALL BE GRAY IRON PER SPEC. 3321, CLASS 35B.

(1) ATTACH THE EXTENSION RING (A 6" PIECE OF 24" NOM. DIA. P.V.C. PIPE, SPLIT AND CUT TO FIT INSIDE THE P.V.C PIPE OF THE HANDHOLE) TO THE INSIDE OF THE P.V.C HANDHOLE EXTENSION WITH FOUR 3/8" DIA. X 2" LONG STAINLESS STEEL HEX HEAD BOLTS AND HEX NUTS AT 120° APART.

(2) LETTERS AND NUMBERS TO BE 3/4" HIGH AND DEPRESSED 1/8 INCHES.

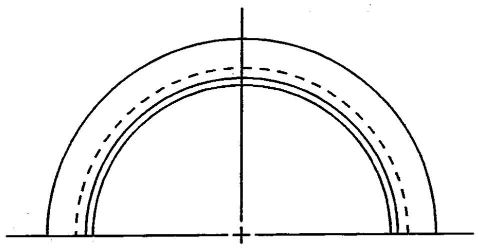
CASTING ASSEMBLY NO. 740

APPROVED JAN. 3, 1997 [signature] STATE DESIGN ENGINEER	STATE OF MINNESOTA DEPARTMENT OF TRANSPORTATION **P.V.C. HANDHOLE / PULLBOX** (EXTENTION RING AND METAL COVER) NO VEHICLE LOAD	SPECIFICATION REFERENCE 2545 2565 REVISED 3-27-98	STANDARD PLATE NO. **8114A** 2 OF 2

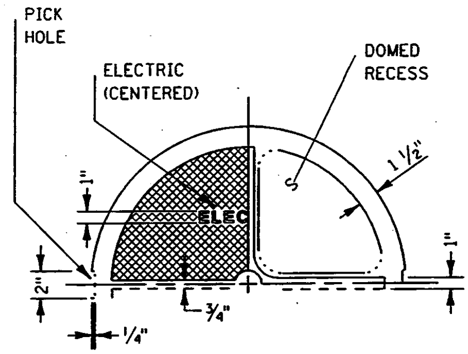


HANDHOLE WITH CONCRETE SURROUND

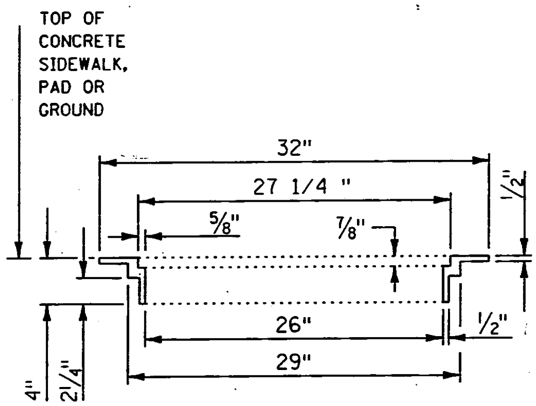
SEE STANDARD PLATE 8114 FOR HANDHOLE CONSTRUCTION DETAILS



HALF TOP VIEW

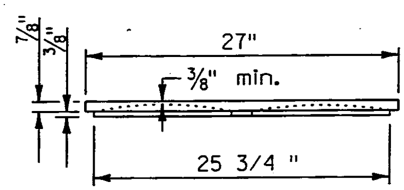


TOP 1/4 BOTTOM 1/4



SECTION

METAL FRAME CASTING



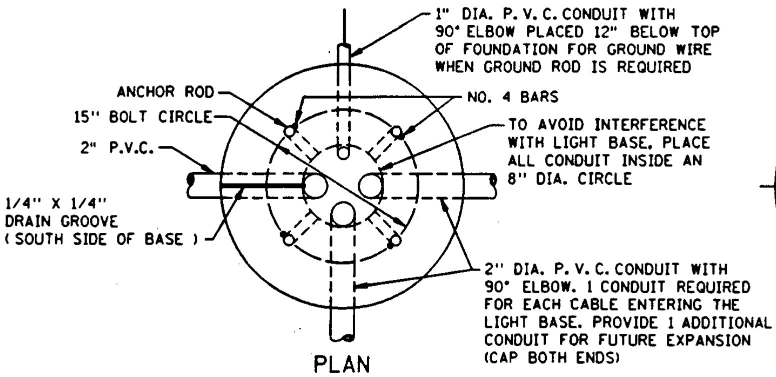
SECTION

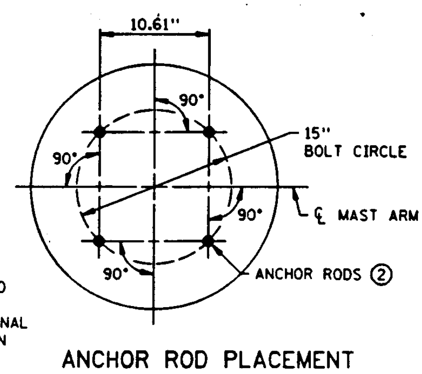
METAL COVER CASTING

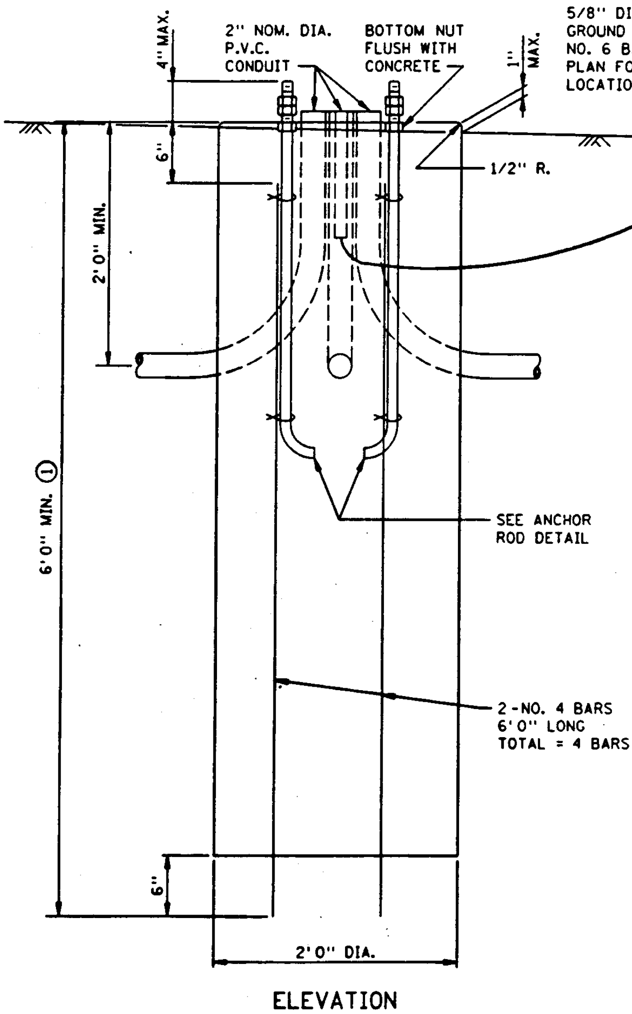
NOTE :

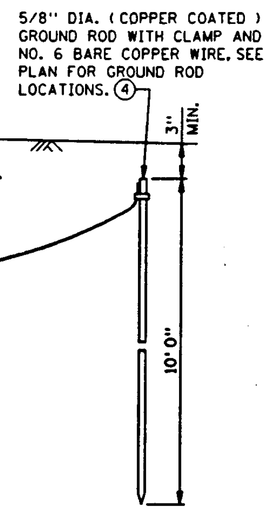
1. ALL CASTINGS SHALL BE GREY IRON AS PER SPEC. 3321, CLASS 35B.
2. SPECIFICATION REFERENCE: 2545 & 2565.
3. REFERENCE STANDARD PLATE NO. 8114 FOR DETAILS ON P.V.C. HANDHOLE/PULLBOX AND EXTENSION RING.

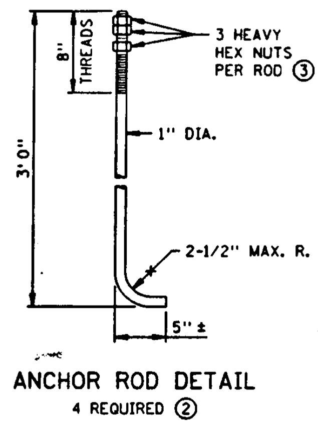
MODIFIED FRAME AND COVER CASTING DETAIL











NOTES:

CONCRETE SHALL BE MIX NO. 3Y43.

FOUNDATIONS MAY BE CONSTRUCTED IN AUGURED HOLES UNLESS THE NATURAL SOILS WILL NOT STAND OPEN, IN WHICH CASE FORMING WILL BE REQUIRED.

P.V.C. CONDUIT PER SPEC. 3803 SHALL BE PROJECTED 1" ± ABOVE THE FOUNDATION BEFORE THE MORTAR IS PLACED AND SHALL BE THE SIZE AND NUMBER SHOWN IN THE PLAN.

A TEMPLATE SHALL BE PROVIDED FOR ANCHOR ROD PLACEMENT AND SHALL BE LEFT IN PLACE UNTIL THE CONCRETE HAS SET.

WHEN ROCK IS ENCOUNTERED, SEE PLAN DETAILS.

AN ALTERNATE PRECAST BASE MAY BE USED WITH THE ENGINEERS APPROVAL.

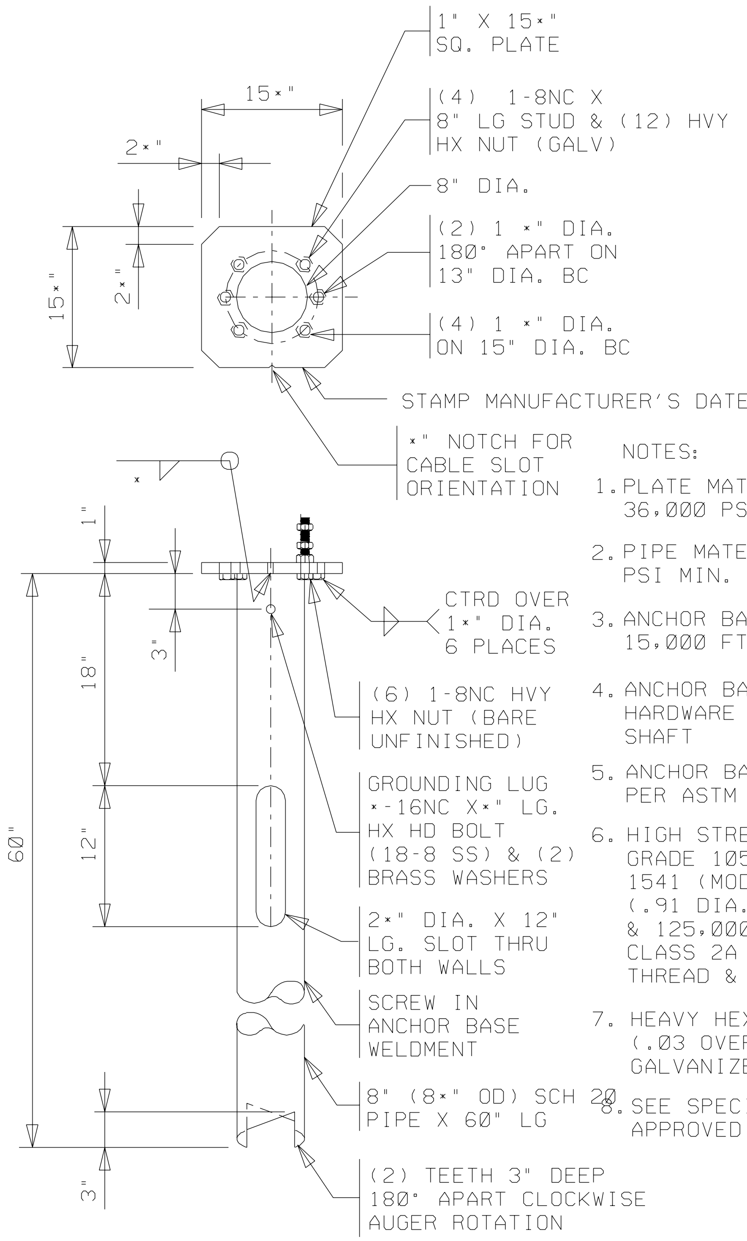
① THE DEPTH OF THE FOUNDATION MAY BE CHANGED IN THE PLANS OR SPECIAL PROVISIONS.

② ANCHOR RODS PER SPEC. 3385, TYPE A SHALL BE PLACED AT RIGHT ANGLES TO THE DIRECTION OF THE MAST ARM. GALVANIZE THE TOP 1 FT. OF THE ANCHOR ROD AND NUTS PER SPEC. 3392.

③ WRAP THREADS OF ANCHOR RODS BELOW BOTTOM NUT WITH 3 LAYERS OF PLASTIC ELECTRICAL TAPE.

④ PLACE GROUND ROD 3" TO 6" DEEP AND WITHIN 1' OF BASE.

APPROVED April 25, 1994 R.M. Hill STATE DESIGN ENGINEER	STATE OF MINNESOTA DEPARTMENT OF TRANSPORTATION LIGHT BASE - DESIGN E 40 FT. POLE OR LESS	SPECIFICATION REFERENCE 2545 REVISED 3-14-97	STANDARD PLATE NO. 8127B



NOTES:

1. PLATE MATERIAL- LOW CARBON STEEL 36,000 PSI MIN YIELD PER ASTM A36
2. PIPE MATERIAL- 8" SCH 20 PIPE 35,000 PSI MIN. YIELD PER ASTM 53 GRB
3. ANCHOR BASE IS DESIGNED TO WITHSTAND 15,000 FT LBS OF INSTALLATION TORQUE
4. ANCHOR BASE SHOULD BE SHIPPED WITH HARDWARE BAGGED AND SECURED TO PIPE SHAFT
5. ANCHOR BASE TO BE HOT DIP GALVANIZED PER ASTM A123
6. HIGH STRENGTH STUD PER ASTM F1554 GRADE 105, MATERIAL- ASTM A29 GRADE 1541 (MODIFIED) STRESS RELIEVED ROD (.91 DIA.) WITH 105,000 PSI MIN YIELD & 125,000-150,000 PSI TENSILE STRENGTH, CLASS 2A AMERICAN STD B1.1 ROLLED THREAD & GALVANIZED PER ASTM A153
7. HEAVY HEX NUTS PER ASTM A194 GR 2H (.03 OVER SIZED FOR GALVANIZED STUD) GALVANIZED NUTS PER ASTM A153
8. SEE SPECIAL PROVISIONS FOR APPROVED MANUFACTURERS.

LIGHT BASE DESIGN STEEL (E)

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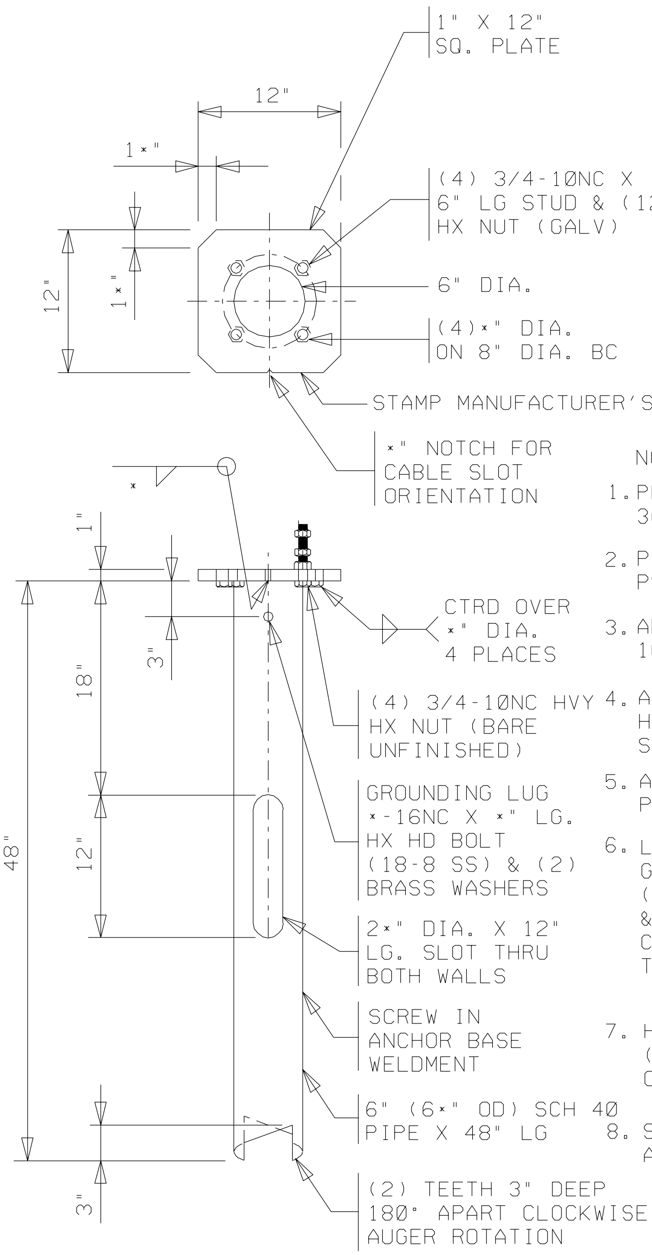

NOTES:

1. PLATE MATERIAL- LOW CARBON STEEL 36,000 PSI MIN YIELD PER ASTM A36
2. PIPE MATERIAL- 6" SCH 40 PIPE 35,000 PSI MIN. YIELD PER ASTM 53 GRB
3. ANCHOR BASE IS DESIGNED TO WITHSTAND 10,000 FT LBS OF INSTALLATION TORQUE
4. ANCHOR BASE SHOULD BE SHIPPED WITH HARDWARE BAGGED AND SECURED TO PIPE SHAFT
5. ANCHOR BASE TO BE HOT DIP GALVANIZED PER ASTM A123
6. LOW STRENGTH STUD PER ASTM F1554 GRADE 36, MATERIAL- ASTM A36 ROD (.68 DIA.) WITH 36,000 PSI MIN YIELD & 58,000-80,000 PSI TENSILE STRENGTH, CLASS 2A AMERICAN STD B1.1 ROLLED THREAD & GALVANIZED PER ASTM A153
7. HEAVY HEX NUTS PER ASTM A563 GR A (.03 OVER SIZED FOR GALVANIZED STUD) GALVANIZED NUTS PER ASTM A153
8. SEE SPECIAL PROVISIONS FOR APPROVED MANUFACTURERS.

LIGHT BASE DESIGN STEEL (P)

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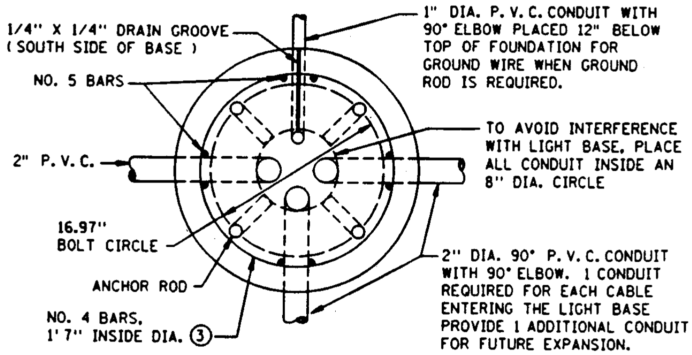
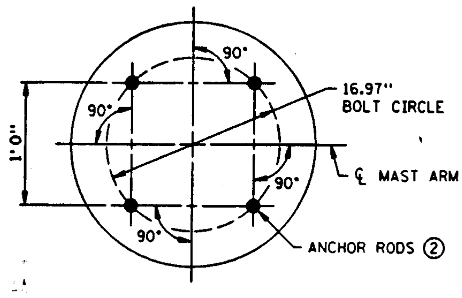
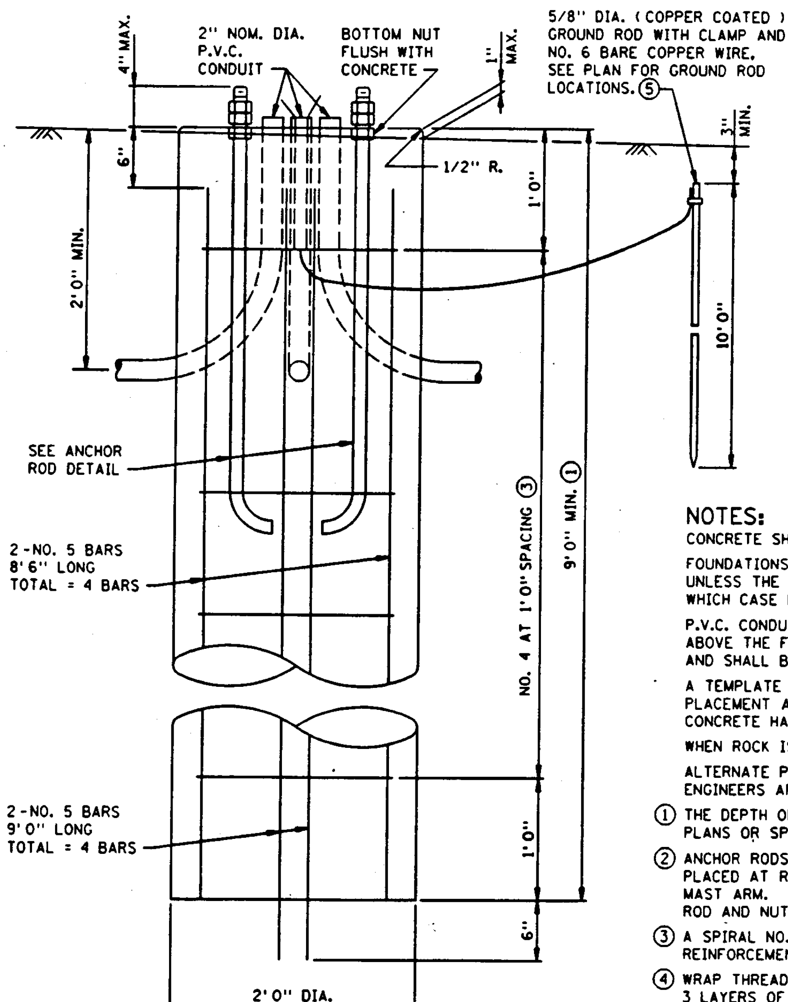


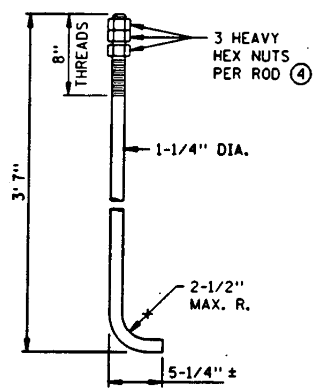
PLAN



ANCHOR ROD PLACEMENT



ELEVATION



ANCHOR ROD DETAIL

4 REQUIRED ②

NOTES:

CONCRETE SHALL BE MIX NO. 3Y43.

FOUNDATIONS MAY BE CONSTRUCTED IN AUGURED HOLES UNLESS THE NATURAL SOILS WILL NOT STAND OPEN, IN WHICH CASE FORMING WILL BE REQUIRED.

P.V.C. CONDUIT PER SPEC. 3803 SHALL BE PROJECTED 1" ± ABOVE THE FOUNDATION BEFORE THE MORTAR IS PLACED AND SHALL BE THE SIZE AND NUMBER SHOWN IN THE PLAN.

A TEMPLATE SHALL BE PROVIDED FOR ANCHOR ROD PLACEMENT AND SHALL BE LEFT IN PLACE UNTIL THE CONCRETE HAS SET.

WHEN ROCK IS ENCOUNTERED, SEE PLAN DETAILS.

ALTERNATE PRECAST BASE MAY BE USED WITH THE ENGINEERS APPROVAL.

① THE DEPTH OF THE FOUNDATION MAY BE CHANGED IN THE PLANS OR SPECIAL PROVISIONS.

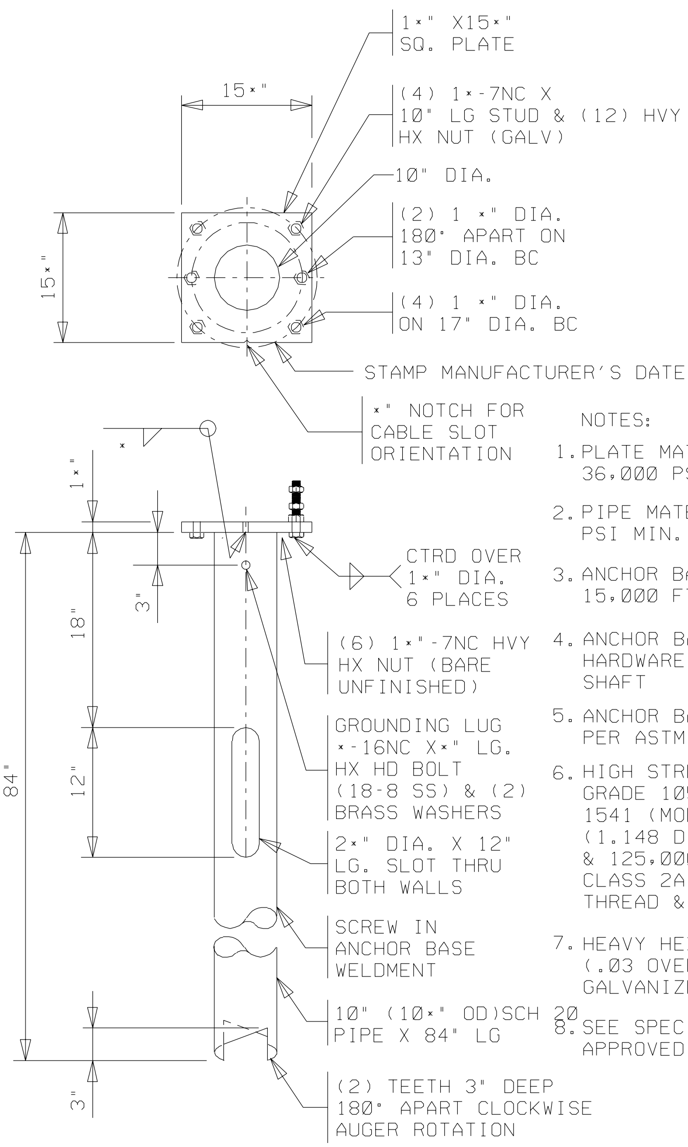
② ANCHOR RODS PER SPEC. 3385, TYPE A SHALL BE PLACED AT RIGHT ANGLES TO THE DIRECTION OF THE MAST ARM. GALVANIZE THE TOP 1 FT. OF THE ANCHOR ROD AND NUTS PER SPEC. 3392.

③ A SPIRAL NO. 4 BAR MAY BE USED AS AN ALTERNATE REINFORCEMENT.

④ WRAP THREADS OF ANCHOR RODS BELOW BOTTOM NUT WITH 3 LAYERS OF PLASTIC ELECTRICAL TAPE.

⑤ PLACE GROUND ROD 3" TO 6" DEEP AND WITHIN 1'OF BASE.

APPROVED April 25, 1994 R. M. Hill STATE DESIGN ENGINEER	STATE OF MINNESOTA DEPARTMENT OF TRANSPORTATION LIGHT BASE - DESIGN H 49 FT. POLE	SPECIFICATION REFERENCE 2545 REVISED 3-14-97	STANDARD PLATE NO. 8128B



NOTES:

1. PLATE MATERIAL- LOW CARBON STEEL 36,000 PSI MIN YIELD PER ASTM A36
2. PIPE MATERIAL- 10" SCH 20 PIPE 35,000 PSI MIN. YIELD PER ASTM 53 GRB
3. ANCHOR BASE IS DESIGNED TO WITHSTAND 15,000 FT LBS OF INSTALLATION TORQUE
4. ANCHOR BASE SHOULD BE SHIPPED WITH HARDWARE BAGGED AND SECURED TO PIPE SHAFT
5. ANCHOR BASE TO BE HOT DIP GALVANIZED PER ASTM A123
6. HIGH STRENGTH STUD PER ASTM F1554 GRADE 105, MATERIAL- ASTM A29 GRADE 1541 (MODIFIED) STRESS RELIEVED ROD (1.148 DIA.) WITH 105,000 PSI MIN YIELD & 125,000-150,000 PSI TENSILE STRENGTH, CLASS 2A AMERICAN STD B1.1 ROLLED THREAD & GALVANIZED PER ASTM A153
7. HEAVY HEX NUTS PER ASTM A194 GR 2H (.03 OVER SIZED FOR GALVANIZED STUD) GALVANIZED NUTS PER ASTM A153
8. SEE SPECIAL PROVISIONS FOR APPROVED MANUFACTURERS.

LIGHT BASE DESIGN STEEL (H)

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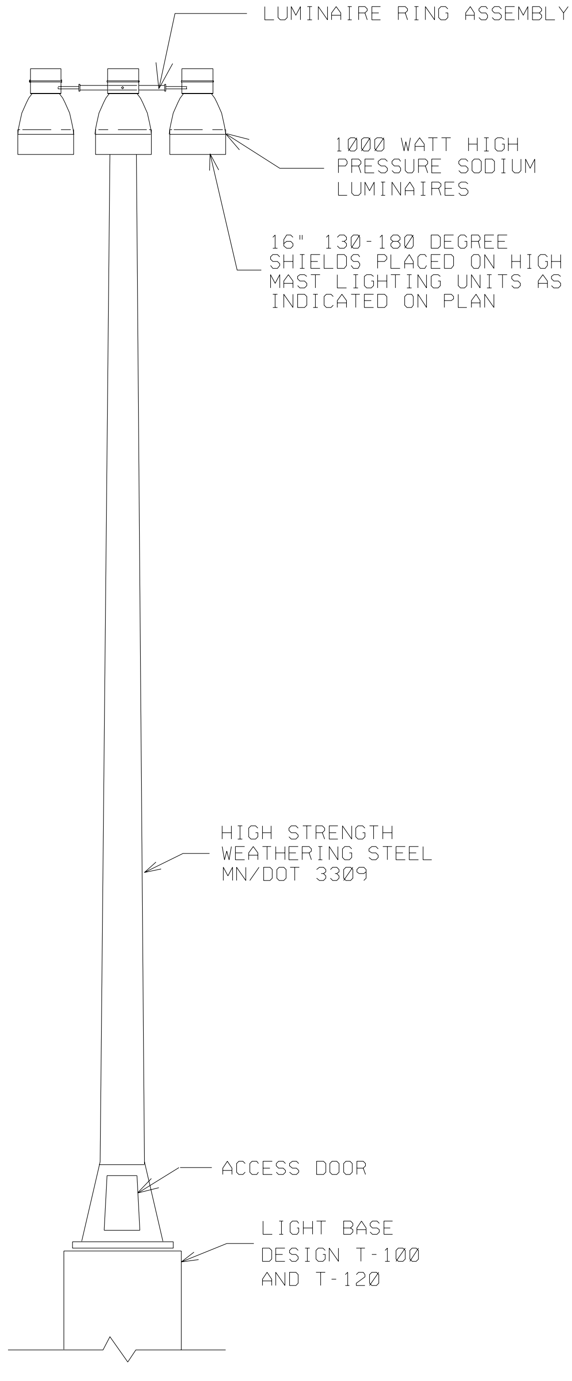

LIGHTING UNIT TYPE 3-100, AND 4-120

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Appendix E - Sample Special Provisions

Appendix F - Miscellaneous Information

Appendix G - Index